UNIVERSITI MALAYSIA PAHANG

BORANG PENGESAHAN STATUS TESIS

JUDUL: PREDICTION OF GRINDING MACHANABILITY WHEN GRIND HAYNES 242 USING WATER BASED COOLANT

SESI PENGAJIAN: 2011/2012

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SEMI SOLID METAL POURING TEMPERATURE EFFECTS ON MECHANICAL PROPERTIES OF AL-SI ALLOY

NURUL HIDAYATI BINTI SALLEH

Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
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JUNE 2012

UNIVERSITI MALAYSIA PAHANG
FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled “Semi Solid Metal Pouring Temperature Effects on Mechanical Properties of Al_Si Alloy” is written by Nurul Hidayati Binti Salleh. I have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering. I herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledged. The project has not been accepted for any degree and is not concurrently submitted for award of other degree.

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Special thanks to my parents on their support and cares,
En. Salleh Bin Ali
Pn. Wan Hayati Binti Wan Mokhtar
Also thanks to my siblings.

ACKNOWLEDGEMENTS

In the Name of Allah, The Most Gracious, and The Most Beneficial. Alhamdulillah, all praises to Allah for the strengths and His blessing in completing this thesis I would like to express my special gratitude to Faculty of Mechanical Engineering especially the Dean, staffs and coordinators of Final Year Project because of their understanding the requirement of students.

My utmost appreciation goes to my advisor, Dr. Syarifah Nur Aqida Binti Syed Ahmad for her guidance and precious time she spent in helping me. Most of her advises, moral supports, and knowledges are the things that invaluable to me in completing this project. Without her assistance me, the final year project will be tougher for completion. Also I would like to gratitude my thanks to Mr. Asnul Hadi Bin Ahmad for his encouragement and guidance offered.

I also would like to thanks Mr Sazali Salleh and Mr. Zahari Anuar for advising me about the casting process and the utilization of aluminium alloy as material on this project. Special thanks to Dr. Rizalman Mamat, Mr Fadhlur Rahman Mohd Romlay and Ms. Nurazima Ismail who gave me thoughtful and comments during my final year project presentation.

I express my sincere thankful to my parents for their love and prays when I got stacked and confused during finishing the project. Thanks for always supporting me and always believe in me. Not to forget, my family members that also make my days cheers and wonderfull.

Also, my appreciation goes to my friends, especially to casting team; Noor Hafizah Hanapi, Benjunior Bindamin and Mohd Azrul Amir that shared their thoughtful. Their ideas encourage me to carry on completing this project. Also thanks go to Nadhrah Azmi, Hardinnawirda Kahar, Zetty Akhtar Abd Malek, Jamilah Mustafha, and Noor Azuani Suliman for continuous support me and their concern in order to complete my thesis. Last but not least, thanks for those who helping me directly or indirectly, I am very appreciate it. Thank you so much!

ABSTRACT

In this study, mechanical properties and morphology study of semi-solid metal Al-Si alloy casting was investigated. The sand castings were conducted at three different pouring temperatures. The pouring temperatures for the investigation were 620°C, 640°C and 695°C. The three different samples were tested for their properties such as strength, hardness and the microstructure. Tensile test was conducted using Shimadzu Universal Testing Machine. Hardness was measured by Matsuzawa Rockwell Hardness Testing machine. Microstructure of cast samples were observed using LEICA DME working microscope. The different pouring temperatures caused different cooling rates on the cast samples. The results and observation indicates that a lower temperature produced good quality castings with the maximum values of strength and hardness of 124.34 N/mm^2 and 62.3 respectively. From metallographic study, primary phase of cast sample at the lower pouring temperature was globular structure while dendrite structure occurs due to a higher pouring temperature. The lower pouring temperature provides a finer microstructure and high hardness samples due to faster cooling rate produced at lower pouring temperature.

ABSTRAK

Dalam kajian ini, sifat-sifat mekanikal dan kajian morfologi logam separuh pepejal tuangan aloi Al Si telah disiasat. Penuang-penuang pasir telah dijalankan di tiga perbezaan suhu tuangan.. Suhu-suhu tuangan untuk siasatan merupakan 620°C, 640°C and 695°C. Tiga contoh lain diuji untuk hartanah mereka seperti kekuatan, kekerasan dan mikrostruktur. Ujian tegangan telah dijalankan menggunakan Shimadzu Universal Testing Machine. Kekerasan telah disukat oleh mesin Matsuzawa Rockwell Hardness Testing. Mikrostruktur sampel-sampel tersebut diperhatikan menggunakan LEICA DME mikroskop bekerja. Perbezaan suhu-suhu tuangan menyebabkan kadar penyejukan berbeza pada sampel-sampel tuangan. Keputusan-keputusan dan pemerhatian menunjukkan bahawa satu suhu lebih rendah menghasilkan acuan-acuan berkualiti baik dengan nilai-nilai maksimum kekuatan dan kekerasan 124.34 N/mm^2 dan 62.3 masing-masing. Dari kajian metalografik, fasa primer sampel tuangan lebih rendah suhu tuangannya, ada struktur bulat terlihat manakala struktur ranting berlaku disebabkan oleh suhu tuangan yang lebih tinggi. Suhu tuangan yang lebih rendah menyediakan satu mikrostruktur lebih baik dan kekerasan tinggi disebabkan kadar penyejukan lebih cepat pada suhu tuangan yang lebih rendah.

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LIST IF SYMBOLS

%	Percent
°	Degree
σ	Yield stress
α	Alpha

LIST OF ABBREVIATIONS

Al-Si	Aluminium Silicon
SSM	Semi solid metal
Al	Aluminium
Si	Silicon
Sn	Synthium
Pb	Plumbum
Mg	Magnesium
Fe	Ferum
Ti	Titanium
Mn	Manganese
Zn	Zinc
Ni	Nickel
Cr	Chromium
Cu	Copper
V	Vanadium
Co	Cobalt
wt	Weight percentage
HPDC	High pressure die casting
CACs	Charge air coolers
ASME	American Society for Testing and Materials
DTA	Differential Thermal Analysis
O.B.B	Olivin Oil Base
CNC	Computer Numerical
UTS	Ultimate Tensile Strength

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Semi solid metal (SSM) processing was discovered by Spencer *et al.* in early 1970s when he investigating hot tearing with a rheometer and this process was put into commercial production by 1981 (Lashkari *et.al*., 2006). Semi-solid metal process is a recent casting that combines the advantage of liquid metal casting with the advantage of solid metal forging. This process is mainly used to cast complex products with near-net-shapes and excellent dimensional accuracy.

In semi-solid metal casting, metal is melted at temperature where slurry remains at a temperature between the solid and liquid state. The ideal temperature is up to 10°C to 660°C which the metal is in a slurry state which is 30% to 60% solid. When it enters the die, the metal which is consist of liquid and solid components is stirred so that the all the dendrites are crushed into fine solids, and when cooled in the die, it developed into fine-grained structure. In this state the metal is further process into the desired castings. To maintain uniform structure and quality of the castings, care must be taken to homogeneously distribute the solid metal without liquid is segregated.

Nearly 30 years of work and effort have been invested in the field of semisolid processing and the increase in interest in this field has been marked by eight international conferences. Semisolid processing is rivalling other manufacturing routes for military, aerospace and most notably automotive components. Europe was produces the part for automotive such as suspension parts, engine brackets and fuel rails. Examples in the USA include mechanical parts for mountain bikes and snowmobiles, while in Asia there is concentration on the production of electronic components such as computer notebook cases and electrical housing components.

1.2 IMPORTANCE OF STUDY

This study was significant because of several causes:

(i) Focusing on the mechanical properties of casting part with different processing temperature.
(ii) Determination of mechanical properties such as tensile strength, yield strength and hardness

1.3 PROBLEM STATEMENTS

Semi-solid metal (SSM) process is a recent casting which combines the advantage of liquid metal casting with the advantage of solid metal forging. This process is mainly used to cast complex products with near-net-shapes and excellent dimensional accuracy. For an engineer, the knowledge and understanding of casting parameters in casting different metals and alloys is as significant as the cast products (Ndaliman *et.al*, 2007).

To produce good quality in castings, semi-solid Al-Si alloy at lower temperature had been choose due to their strength and hardness. When pouring temperature is lower, the mould cavity will not fill the gate or riser will solidify rapidly (Lancer, 1981). At contrast, at higher pouring temperatures causes shrinkage of the casting and mold warping (Grill, 1982). In the current study, the effect of different pouring temperature on mechanical properties of semi-solid Al-Si alloy has been studied.

1.4 OBJECTIVE OF STUDY

The objective of this project is to investigate the effect of different pouring temperatures on the mechanical properties of the material.

1.5 SCOPE OF THE STUDY

The work scopes included in this project were:

(i) To conduct sand casting at different pouring temperatures of semi-solid metal A356 alloy.
(ii) To conduct metallographic study of cast Al-Si Alloy sample using LEICA DME working microscope.
(iii) To conduct tensile test at room temperature for cast Al-Si alloy samples using Shimadzu Universal Testing Machine.
(iv) To measure hardness properties on casting Al-Si Alloy examples using Matsuzawa Rockwell Hardness Testing Machine. .

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

In this literature review, metal casting process and properties of Aluminium Silicon alloy were reviewed. By reviewing on the others author review, the effect of pouring temperature on semi solid microstructure and mechanical properties of Al-Si alloy was determined.

2.2 SEMI SOLID METAL

Semi-solid metal (SSM) process is a recent casting which combines the advantage of liquid metal casting with the advantage of solid metal forging. This process is mainly used to cast complex products with near-net-shapes and excellent dimensional accuracy. Semi solid occurs between the liquidus and solidus of the alloy, a temperature range in which the fluidity of the molten metal can change greatly. This SSM processed was first discovered by Spencer et al. during his continuously hot tearing test of solidifying Sn-15% Pb (Lashkari *et.al.*, 2006)..

Semi-solid metal processing is a unique manufacturing method to produce near-net shape products for various industrial applications (Fleming, 2006). The aim is to obtain a semi-solid structure free of dendrites which are formed by conventional liquid casting, with the solid present as nearly a spherical form as possible. This semi-solid mixture like a gel or toothpaste flows homogeneously, behaving as a thixotropic fluid with viscosity depending on shear rate and fraction solid (Lashkari *et al.*, 2007). There are two different SSM processes which are thixocasting and rheocasting. With thixocasting, a specially prepared billet of solid material with a globular microstructure is reheated into the semi-solid range and formed. Rheocasting involves preparation of a SSM slurry directly from the liquid, followed by a forming process such as high pressure die casting (HPDC).

An overall, all types of materials, whose solidification extends over a temperature range which is mushy zone, are suitable to be SSM processed. This is true for metallic alloys to have a wide solidification range with dendritic growth (Fleming ,1991; Kirkwood,1994; Fan,2001). The mushy zone contains the solid and liquid phase which also known as “the mush”. However, the alloys with narrow solidification range or single point transformation such as eutectic alloys cannot be SSM process.

2.3 ALUMINIUM SILICON ALLOY

Al–Si alloys are widely used in different fields of industry. Various additives are usually used to modify industrial alloys. Nowadays, much attention has been given to unmodified cast alloys, especially to hypereutectic Al–Si alloys. In the same time, the structure and mechanical properties of hypereutectic unmodified cast alloys has been studied for Si content up to 19%. It is only known that increasing the Si content results in an increase of the strength of hypoeutectic alloys and a decrease of the strength of hypereutectic alloys (Stroganov *et al*., 1977; Gupta *et al*., 1999).

In addition to chemical composition, the structural and mechanical properties of alloys depend on many factors act during solidification. The important factors are the structure of the melt, the crystallization rate, and the temperature gradient at the liquid–solid interface.

As a rule these factors are varied simultaneously, giving rise to contradictory information on the structure and mechanical properties of Al–Si alloys. Thus, for example, the yield stress, σ 0.2 was published to increase (Mondolfo, 1976; Gupta *et al.,* 1999) or decrease (Stroganov *et al*., 1977) with increasing content of Si. In order to investigate the influence of the Si content on structure and mechanical properties, it is necessary to prevent contamination by impurities from the crucible and the environment, to maintain constant the superheating of the melt, to have a constant and rather high cooling rate, and effective mixing of the molten alloy.

2.3.1 Phase Diagram Al-Si Alloy

Based on the phase diagram for Al-Si system as show in Figure 2.2 below, it contains a eutectic point at 12.6 wt% Si. The eutectic temperature is 577°C is very low and the Al dissolves a maximum 1.65 wt% Si while the solubility if aluminium in silicon is very low and can be neglected. The slow cooling of Al-Si alloys, starting from the liquid phase, leads to different microstructure being formed depending on whether the silicon content is lower than the eutectic composition (hypoeutectic alloys) or higher than the eutectic composition (hypereutectic) as show in Figure 2.1**.**

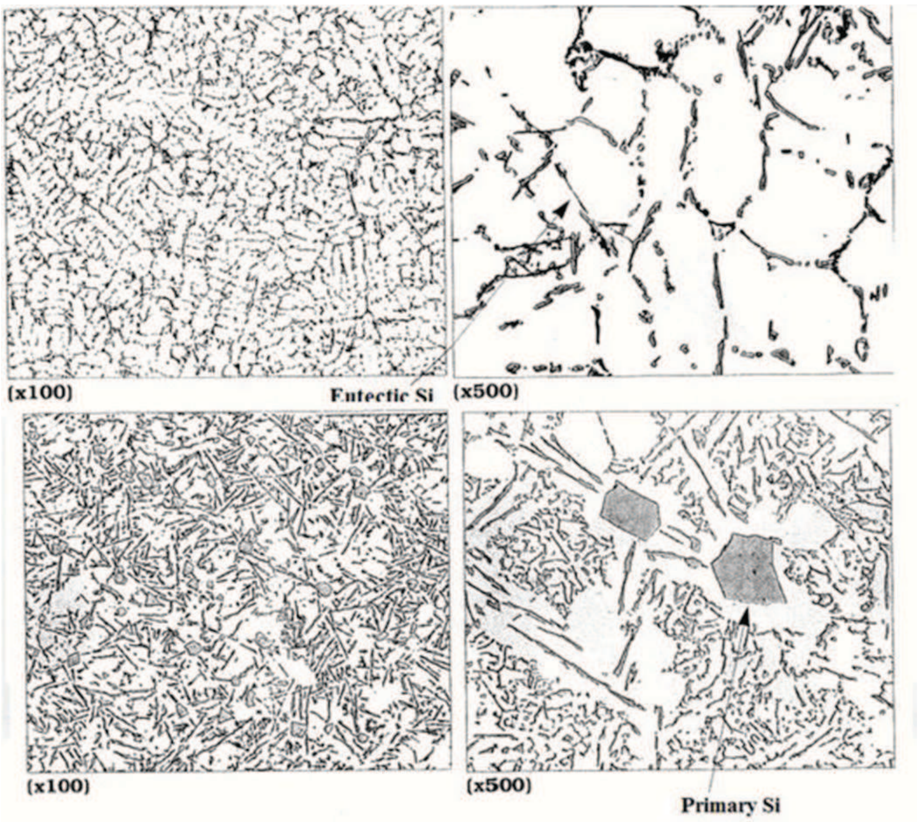

Figure 2.1: Hypeeutetic of Al-Si

(Source: NCMTT, SIRIM BERHAD)

2.3.2 Primary and Eutectic Phase

Al-Si binary alloy is a eutectic system with the eutectic composition at 12.6 wt% Si (Massalski *et al*., 1990) (Fig.2.2). When the Al-Si alloy solidifies, the primary aluminum forms and grows in dendrites or silicon phase forms and grows in angular primary particles (Haizhi, 2002). The eutectic Al-Si phases nucleate and grow until the end of solidification when it reached at the eutectic point. At room temperature, hypoeutectic alloys consist of a soft and ductile primary aluminum phase. It also has a hard and brittle eutectic silicon phase. In hypereutectic alloys, it usually contains coarse, angular primary silicon particles as well as a eutectic silicon phase.

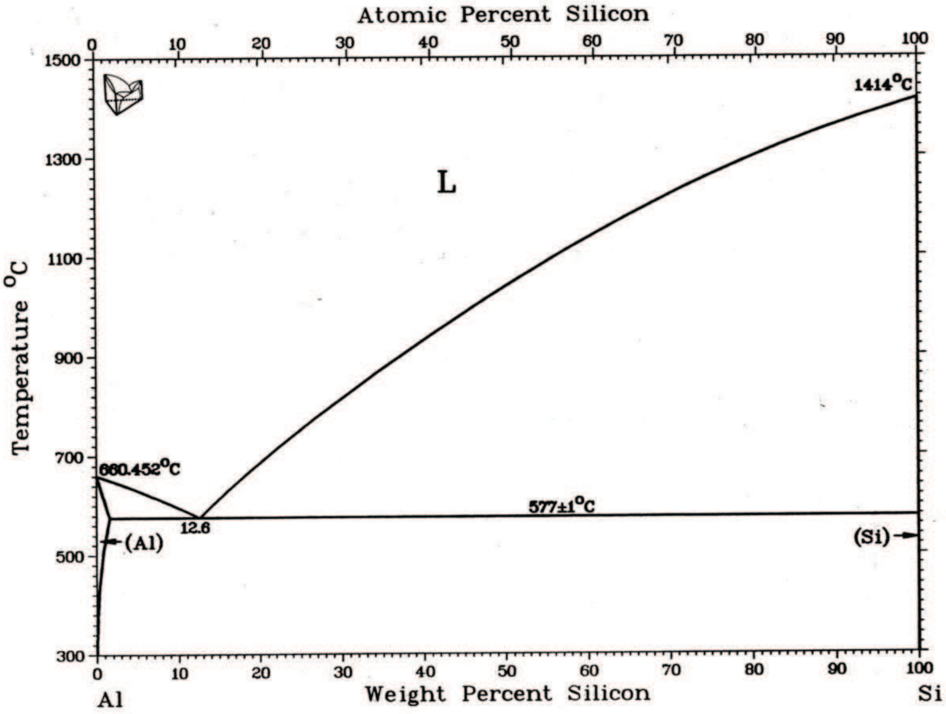

Figure 2.2: The Al-Si binary phase diagrams

(Source: Massalski *et al*., 1990)

The hypoeutectic and hypereutectic Al-Si alloys have both been used as tribological material in engine applications. However, hypereutectic Al-Si alloy can be used to produce engine block without cylinder liner as it has a higher wear resistance resulting from a larger fraction of silicon phase. Usually, the hypereutectic AL-Si alloy engine block surface is electrochemically treated to etch away some of the matrix aluminium alloy so that the eutectic and primary silicon particle can protrude to sustain wear (Haizhi, 2002).

2.3.3 Al-Si Alloy Applications

The applications of Aluminium nowadays are in vehicles cover, chassis, power trains, air conditioning and also in body structure. For a long period, the aluminum casting have been applied to various automobile parts such as engine block, which is the one of the heavier parts in vehicle, is being changed from cast iron to Aluminium casting that give the best result in weight reduction. In power train, aluminum castings have been used for almost 100% of pistons, about 75% of cylinder heads, 85% of intake manifolds and transmission and also other parts like rear axle, differential housings and drive shafts and so on. Aluminium casting in chassis applications are used about 40% of wheels, for bracket, brake components, suspension which are control arms and supports, for steering component such as air bag supports, steering shafts, knuckles, housings, wheels and also for instrument panels (Nayak *et al*., 2011).

Forged wheels have been used where the loading conditions are more extreme and where higher mechanical properties are required. Aluminium alloys have also found extensive application in heat exchangers. In this modern years, high performance automobiles have many individual heat exchangers, e.g. engine and transmission cooling, charge air coolers (CACs), climate control, made up of Aluminium alloys (Miller *et al*.).

Due to its unique properties, Al-Si becomes an important alloy for many commercial automotive applications such as piston, cylinder liners and so on. Al-Si alloy is the most versatile in the production of pistons for automotive engines. Commercial uses for hypereutectic alloys are limited because due to the high Si contents, it difficult Al alloys to cast and machine. When the high Si content is alloyed in Al, it causes a large amount of heat capacity that must be removed from the alloy to solidify it during the casting operation. Between different areas of cast structure, the major variation sizes of the primary Si particle can be seen. It causes the significant deviation in the mechanical properties for the specimen. To accomplish the better hardness and wear resistance, the primary of the Si crystals must be refined (Nayak *et al.*, 2011).

From these reason, hypereutectic alloys are not very cost-effective to fabricate because they have a broad range of solidification resulting in poor castability and requires extra foundry processes to control the microstructure and high heat of fusion. In the other hand, the hypoeutectic and eutectic alloys are very widespread in industries. This is because:

(i) More efficient to produce by casting
(ii) Simpler to control the cast parameters
(iii)Easier to machine than hypereutectic.

But, most of them are not appropriate for high temperature applications, such as in the automotive field, for the reason that their mechanical properties, such as tensile strength, are not as high as anticipated in the temperature range of 250°C - 400°C (Lee *et al.*).

2.4 ALUMINIUM CASTING PROCESS

Casting is a manufacturing process where a solid is melted, heated to proper temperature which sometimes treated to modify its chemical composition, and is then poured into a cavity or mold, which contains it in the proper shape during solidification. Thus, in a single step, simple or complex shapes can be made from any metal that can be melted. The resulting product can have virtually any configuration the designer desires.

Nowadays, there are a large number of industrial casting processes. These can be classified based on the mould material, method of producing the mould and the pressure on molten metal during filling which are gravity, centrifugal force, vacuum, low pressure and high pressure. There are three main processes of casting which are permanent metal mould, sand casting and die casting.

Permanent metal moulds was used in gravity and pressure die casting processes, suitable for producing a large number of parts. In expendable mould processes which are sand, shell and investment, a new mould is required for every casting or a bunch produced in the same mould. Expendable mould can be made using either permanent pattern or expandable pattern. Permanent pattern can be made from wood, metal, or plastic (Ravi, 2006).

Sand casting is process which sand mixed with binders and water is compacted around wood or metal pattern halves to produce a mould. The mould is removed from the pattern, assembled with cores, if necessary, and metal is poured into the resultant cavities. After cooling, mould is broken to remove the casting. This process is suitable for a wide range of metals which both ferrous and non-ferrous, size and shape complexity.

The sand casting process usually chosen for the production of (1) small quantities of identical castings, (2) complex castings with intricate cores, (3) large castings, and (4) structural castings (Smith *et al*., 2006). The advantages of the sand casting is almost any metal can be cast which is no limit to part size, shape, weight and it is low tooling cost to do this laboratory (Kalpakjian *et al*., 2006). Basically, the common method of proceed in sand casting process must include pattern making, mould making, melting and pouring of metal, cooling and solidification and lastly is the cleaning process and the inspection.

In die casting, identical parts are cast at maximum production rates by forcing molten metal under consideration pressure into metal molds. Two metal die halves are securely locked together to withstand high pressure. The molten aluminum is forced into the cavities in the dies. The dies are unlocked when the metal has solidified to eject the hot casting. The casting cycle is repeated after the die halves are locked together again. The advantages of die casting are (1) parts die cast are almost completely finished and can produce at high rates, (2) dimensional tolerance of each cast part can be more closely held than with any other major casting process, (3) smooth surfaces on he casting are obtainable, (4) rapid cooling of the casting produce a fine-grain structure, and (5) the process can be automated easily (Smith *et al*., 2006).

2.5 POURING TEMPERATURE ON SEMI-SOLID MICROSTRUCTURE

In studying the effect of pouring temperature on the morphology of primary Al particles and the rheological behavior of microstructures for semi-solid Al–Si A356 alloy, Lashkari (2006) reported that dendrite primary Al structures formed at the highest pouring temperatures of 675°C –695°C have the greatest viscosity numbers. They are almost two orders of magnitude greater than those for rosette structure formed at moderate pouring temperatures of 630°C –645°C. The viscosity of the dendrite primary Al structures is three orders of magnitude greater than those for globular morphology formed at the lowest pouring temperature of 615°C (Lashkari *et al*, 2006).

Figure 2.3 shows the semi-solid microstructures of A356 alloy obtained at the different pouring prepared by low superheat pouring and slightly electromagnetic stirring researched by Liu *et al*;(2006). The microstructure of A356 of semi-solid A356 alloy poured at 650°C is shown in Fig. (a). It is seen that the morphology of primary phase is mainly rossete-like, and a few globular-like and particle-like coarse grains are observed. The microstructure of semi-solid A356 alloy poured at 630°C is shown in Fig. (b) which contains of globular-like and particle-like primary phase and a few rosette-like fine grains. The microstructure of semi-solid A356 alloy poured at 615°C in shown in Fig. (c), and basically consists of globular-like and particle-like primary phase with small grain size (Liu *et al*., 2006).

It seem that, under the electromagnetic stirring, the morphology of primary phase obtained from semi-solid A356 alloy is changed from rosette-like to particle like. Besides, the grain size is decreased as pouring temperature of liquid alloy decrease (Liu *et al*., 2009). It is feasible to refine grain size and improve grain morphology by controlling pouring temperature or make use of low superheat pouring (Flemings, 1991 and Liu *et al.,* 2006).

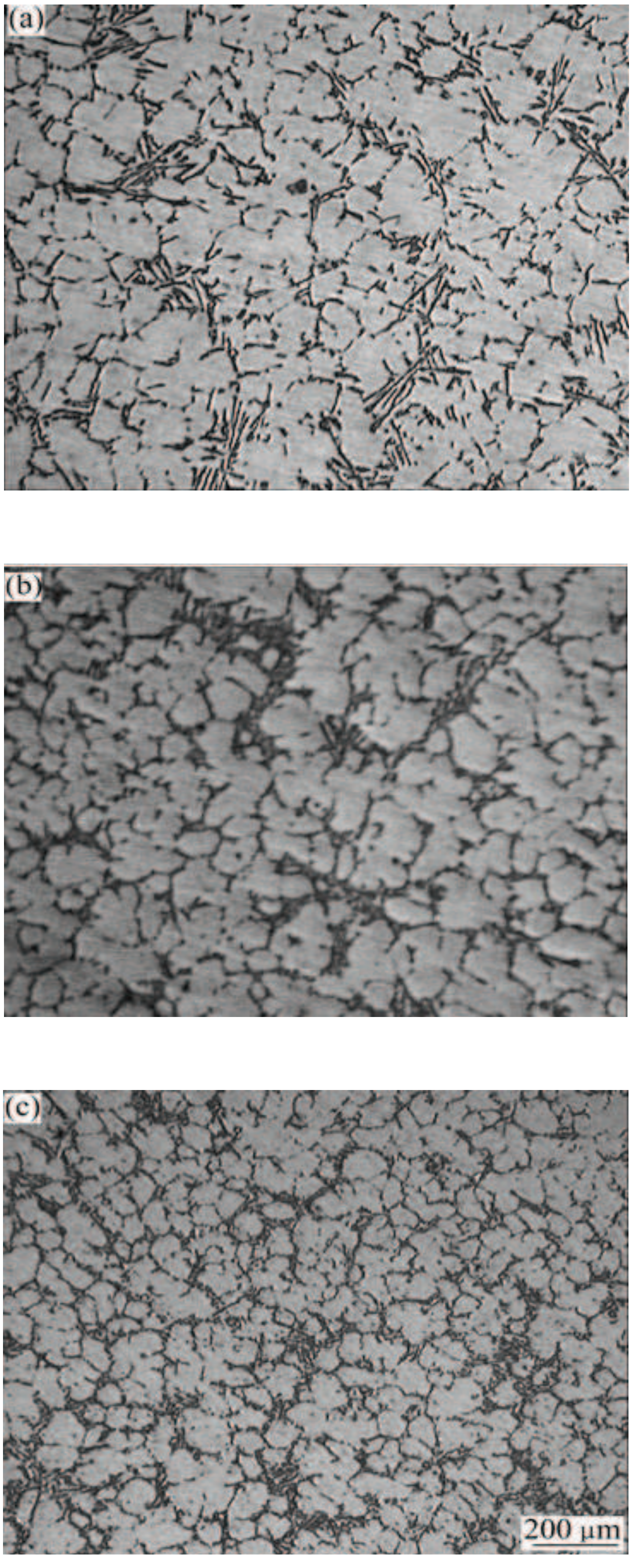

Figure 2.3: Morphologies of primary phase in A356 alloy obtained at different pouring temperatures: (a) 650°C; (b) 630°C; and (c) 615°C

(Source: Liu *et al*., 2006)

2.6 POURING TEMPERATURE ON SEMI-SOLID MECHANICAL PROPERTIES

Figure 2.4 shows the effect of temperature for SSM mush in term of viscosity, investigated by Lashkari *et. al.,* (2006). It said that, the billet with higher temperature, 602°C showed greater deformation than 594°C. This behavior maybe attribute to liquid matrix and primary α–Al particles. It is because, the both have flow and deform easier at high temperature.

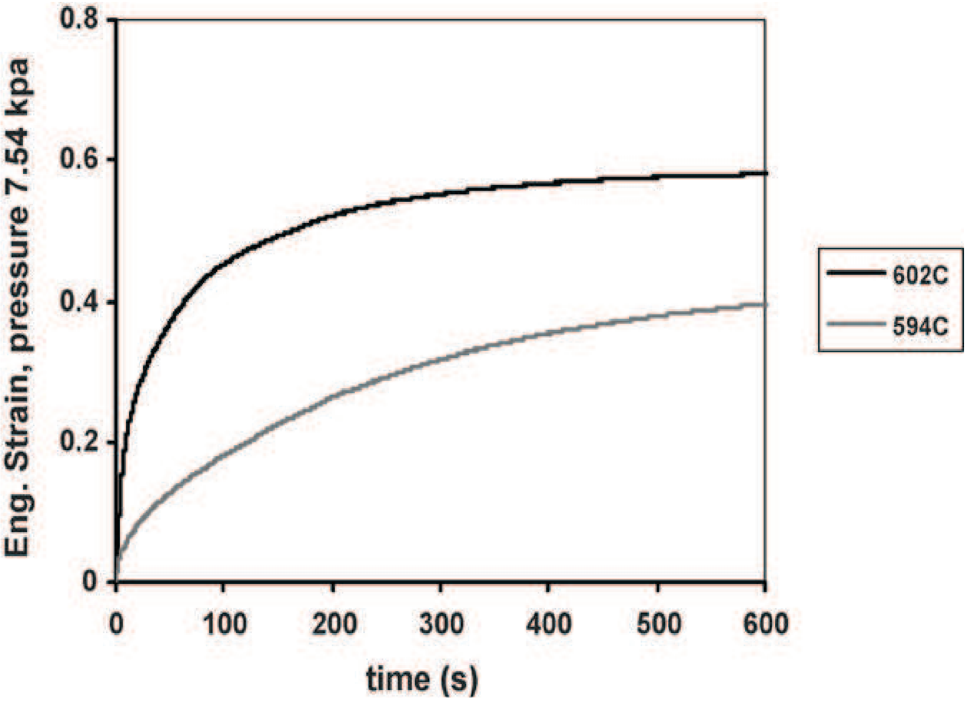

Figure 2.4: Strain-time graph for the same α–Al morphology at different temperature.

(Source: Lashkari *et. al.,* 2006)

In Figure 2.5, the percentage elongation of Al is seen to increase with pouring temperature from 2.8% to a maximum value of 3.1%. Ndaliman has stated that when pouring temperature is increase, it will reduce the percentage elongation. On the other hand, the percentage reduction in diameter increases initially with pouring temperature from 2.0% to 2.5% at the temperature of 700°C. After that it decreases to 2.2% after which it increases to a maximum value of 2.5%. Thereafter it falls to 1.0%. Since these properties compared favorably well with the castings of similar alloy compositions, the products can be used in areas such as food and chemical industries as well as marine and architectural works.

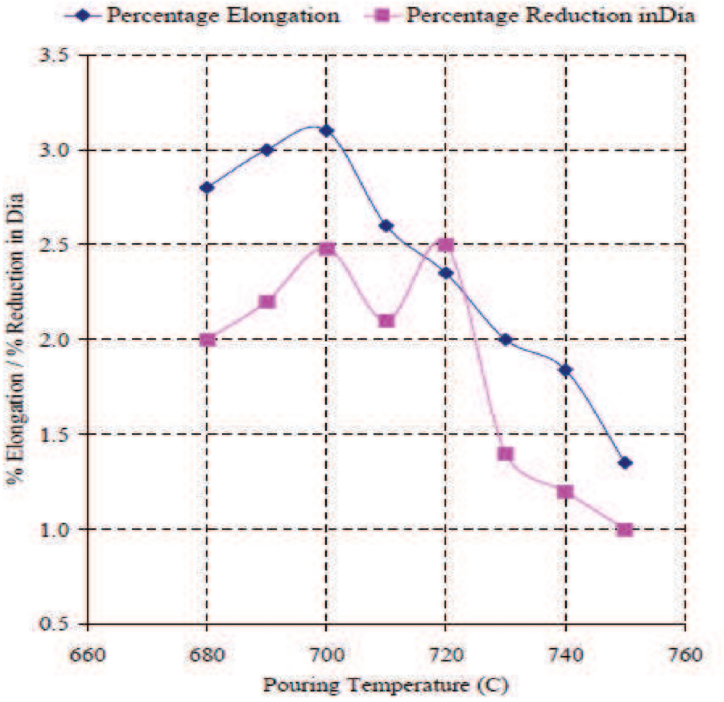

Figure 2.5: % Elongation / % Reduction in diameter with pouring temperature

(Source: Ndaliman *et.al*, 2007)

Ndaliman *et.al* has figured out the ultimate tensile strength (UTS) value for this Al. Figure 2.6 show the graph of the versus with pouring temperature. It shows that, the UTS value decreases with increasing the pouring temperature. The minimum value attained is 79.5N/mm^2 at the pouring temperature of 740°C (Ndaliman *et.al*., 2007).

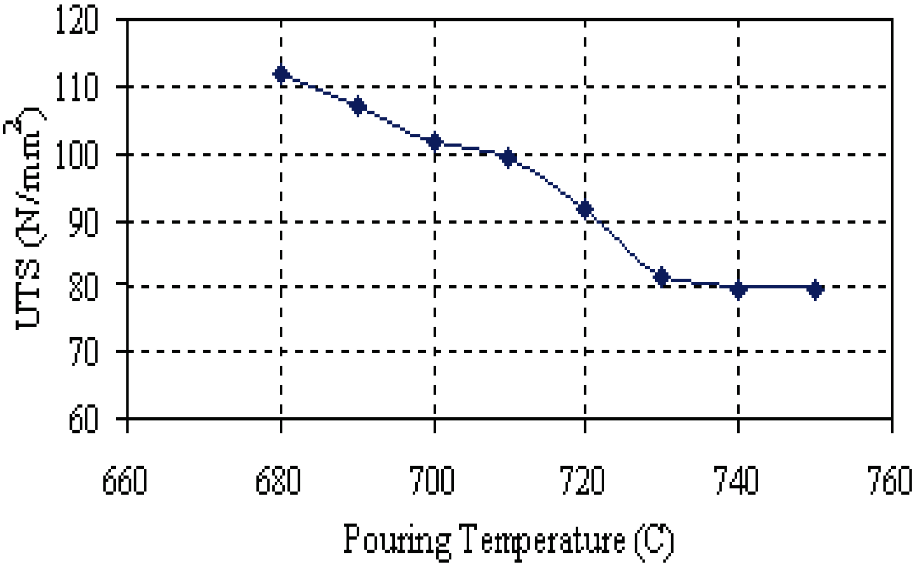

Figure 2.6: Variation of UTS with temperature

(Source: Ndaliman *et.al.*, 2007)

Figure 2.7 shows the variation of Rockwell hardness with pouring temperature studied by Ndaliman *et.al.* (2007). the hardness across the axis is shown to be always higher than that along axis. The hardness across the axis increases initially with pouring temperature to a maximum of 65.5 at temperature of 688°C. The maximum hardness attained along the axis at the pouring temperature of 688°C is 62.8. The behavior of the two hardness types follows waveforms, but generally decreases at higher pouring temperatures. At the pouring temperature of 760°C, the Rockwell hardness across the axis is 51.0, while that along the axis is 40.0.

ASME has been observed that pinholes in aluminum castings are caused by the absorbed hydrogen (ASME, 1996). To minimize it, pouring the alloy at temperatures just necessary for casting. Therefore, once this optimum pouring temperature is identified, it should be properly applied.

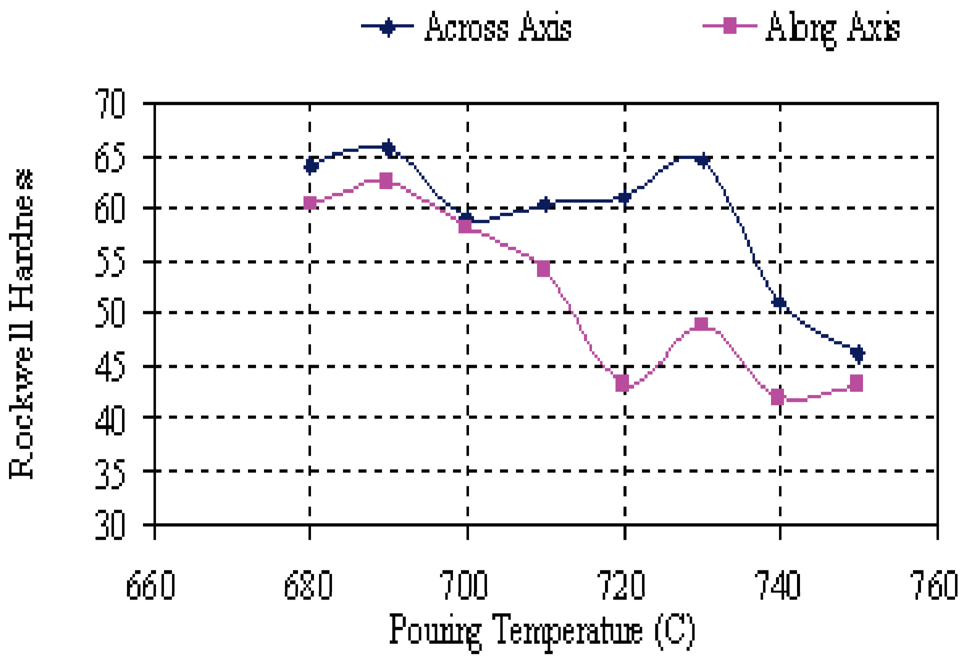

Figure 2.7: Variation of hardness with pouring temperature

(Source: Ndaliman *et.al.*, 2007)

CHAPTER 3

METHODOLOGY

3.1 MATERIALS

In this study, A356 alloy was used with chemical composition given in Table 3.1. A356 alloy is a kind of hypoeutectic Al-Si alloy. It was extensively used in semi-solid processing because of its wider solid-liquid range and good fluidity.

The liquidus temperature of A356 alloy was determined at 615.3°C by DTA. A356 was melted in an electric resistance furnace. The melting point was 700°C (Liu *et.al.*2009), The pouring temperature was determined to be 695°C, 640°C and 620°C.
The mechanical properties of Al-Si alloy is given in Table 3.2.

Table 3.1: Composition analysis (wt %) of A356 alloy

Constituent	Al	Si	Fe	Mg	Ti	Mn	Zn
Weight (%)	92.5	6.515	0.371	0.278	0.128	0.082	0.030

Constituent	Ni	Cr	Cu	V	Co	Pb
Weight (%)	0.020	0.014	0.013	0.006	0.004	0.0004

(Source: Sunnel, 2010)

Table 3.2: Mechanical properties of A356 alloy

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Composition (wt%)	Ultimate tensile strength (N/mm^2)	0.2% tensile proof stress (N/mm^2)	Elongation (%)	Hardness (VHN)	Density (kg/m^3 x 10^3)
Al-6%Si	Al-6%Si	64.8	9.6	55.6	2.65

(Source: Torabian, 1994)

3.2 CASTING PROCESS

3.2.1 Type of casting

For this work, sand casting was used. This type of metal casting involves making a mold in a sand mixture and then pouring liquid metal into the sand cavity. This is a simple six-part process which are; a pre-existing pattern is use to create a sand mold, or craft one by hand. Next, the gating system is added in order to control the liquid metal. After that, the pattern is removing if the pattern is used. Then, pour in the metal. The metal after that leave cool. Lastly, remove the casting and get the product. This is the best form of casting for a small operation that will be making casting in small batches. But, the sand casting for this project was improved from using green sand to the O.B.B Sand from Germany. This type of sand no need to mixture the sand into the sand mixture. It is easy and ready to use.

3.2.2 O.B.B – Sand “E”

OBB-sand "E" is an oil-bonded Formfeinstsand who delivered ready to use and is due to this binding cannot dry out. Its high green strength enables accurate contours and custom castings. OBB-sand "E" is used mainly in heavy metal as well as in gray iron and ductile- range used for parts with thin to medium thickness. The O.B.B-sand can be used as a landing sand and recirculating sand. O.B.B sand is as lean- used sand, so it goes into the normal form of sand and circulation. It is current-sand (sand unit), so it can be regenerated with O.B.B-oil and paste is.

Figure 3.1: O.B.B sand

3.2.3 Molding

Molding involves packing the molding sand uniformly around a pattern placed in a molding box or flask. Molding box was shown in Figure 3.2(a). While for the pattern, it shows in Figure 3.2(b). Next step, the pattern was placed based on the parting line between cope and drag as shown in Figure 3.3(a). White flour was used to separate the cope and the drag as shown in Figure 3.3(b), besides it also help to lift the cope up for to remove the pattern inside. For Figure 3.3(c), it shown the mold after the pattern was taken out while Figure 3.3(d) showed the mold that ready for pouring.

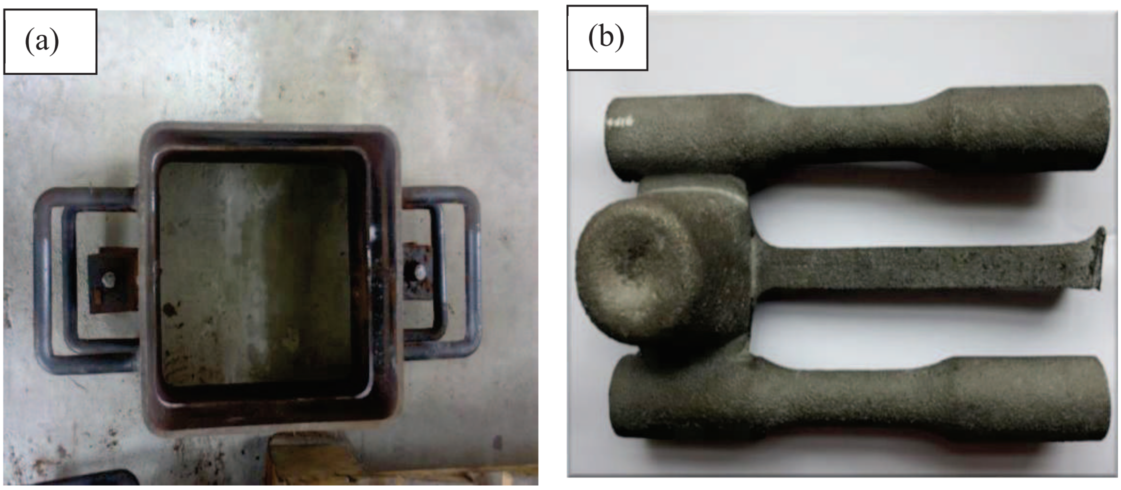

Figure 3.2: (a) Molding box and (b) the pattern

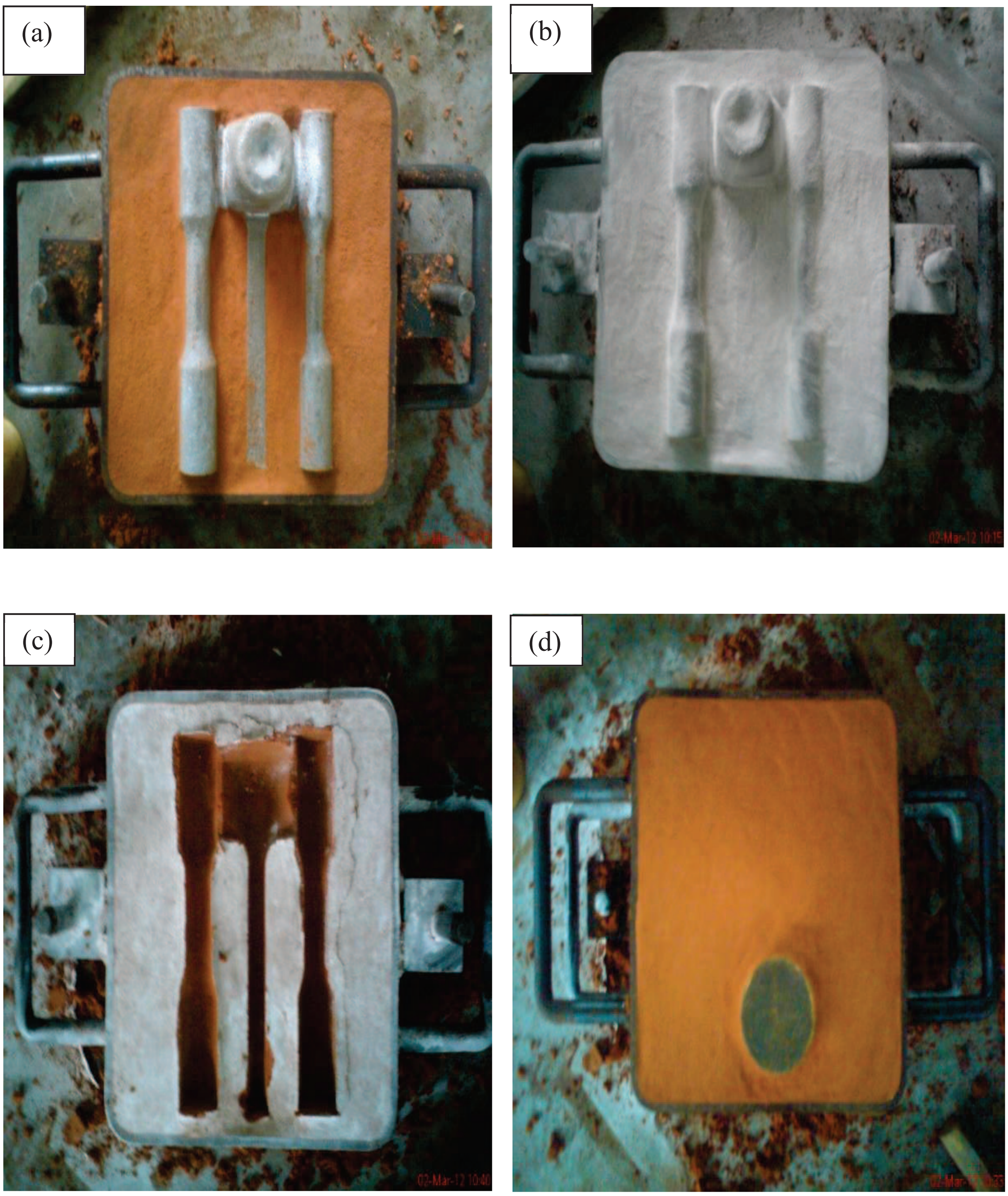

Figure 3.3: The pattern was placed on the mold (b) the white flour was tabor on the pattern and the mold (c) the pattern was taken out from mold and (d) mold ready for pouring

3.2.4 Melting Process

Melting process is important aspect of casting operations because it has a direct bearing on the quality of castings. Melting procedures involves a furnace, heat source and iron tools to remove or pour the melted metal. First, the Al-Si alloy was put into the crucible furnace. Then, the furnace was on and waited the metal to melt.

In this project, oil fired crucible furnace was used to melt A356 alloy as shown in the Figure 3.4. This furnace provides low fuel costs, superior fuel efficiency and precise temperature control for melting temperature of Al, Zinc and other non-ferrous metals. The oil fired crucible furnace is ideal for Al melting so as to avoid hydrogen picks up and achieve casting without blow hole. For direct melting of high grade Al casting, the electric resistance heated crucible furnace are used. Central axis tilting or lip axis hydraulic tilting type crucible furnaces are excellent for melting and pouring directly into the molds or transfer ladles.

Figure 3.4: Oil fired crucible furnace

3.2.5 Pouring

Molten alloy pouring was conducted slowly to provide a constant flow into the mold. A ladle was used to transfer the molten metal from furnace to the mold. Before pouring the molten metal, the molten metals need to check the temperature was determined using a thermocouple as shown in the Figure 3.5 and Figure 3.6. The temperature was measured by thermocouple and the alloy was always heated 5°C above the specified pouring temperature. It is important to allow the temperature drops during the time required for pouring of the castings.From Figure 3.7 two people who are wearing the appropriate safety cloth poured the molten aluminium into the sprue hole. The process need to be done carefully and slowly so that molten metal not overflow. In order to get the uniformity measurement, the size and the shapes cast were same.

Figure 3.5: Checking the temperature before pouring to the mold

Figure 3.6: Thermocouple for checking the molten metal temperature

Figure 3.7: Molten metal was pouring to the mold

3.2.6 Fettling

Fettling is cleaning of casting, removal of the riser and getting system which are sprue, runner and separating out the casting product and cleaning the casting surface. Hammer was used to knockout the casting from sand mold while abrasive cut used to remove the gating system and riser. CNC milling was used to get dog bone shape for tensile test. As shown in Figure 3.8, this was sample from pouring temperature of 620°C before finishing and Figure 3.9 showed the dog bone samples for tensile test.

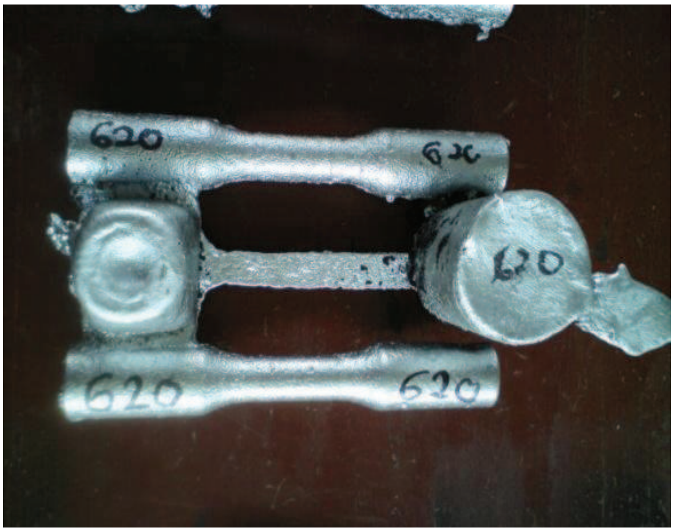

Figure 3.8: Before fettling

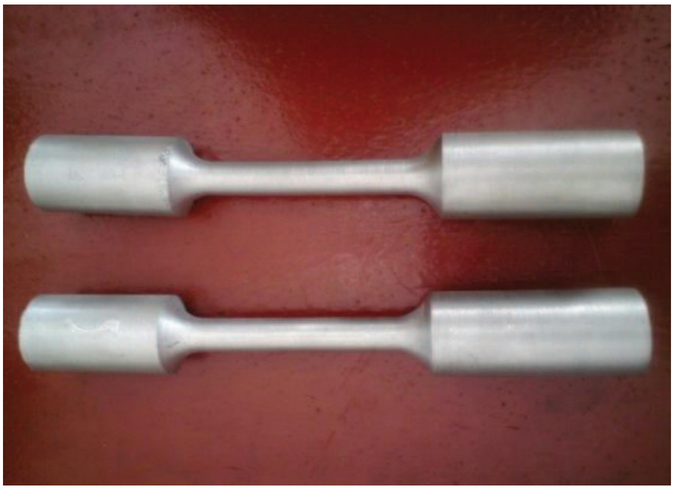

Figure 3.9: Dog bone for tensile test samples

3.3 CHARACTERIZATION

3.3.1 Samples Preparation

After casting process, samples went through finishing process. The gating was removed and the cast samples were cut using a die cutter machine. Figure 3.10 shows MSX200M Sectioning cut – off machine used to cut the samples into the small piece. These samples were used in Rockwell Hardness test and also for the metallographic study.

Figure 3.10: MSX200M Sectioning cut-off machine

After that, the small sample was mounted using hot mounting machine which is BuhlerSimpliMet 1000, Automatic Mounting Press as shown in the Figure 3.11. After turning on the stabilizer, the small sample was horizontally placed on the given space. Buehler green powder then was added before the small sample clamped. Then, the sample with green mount was proceeding to the next step.

Figure 3.11: Buhler SimpliMet 1000, Automatic Mounting Press

3.3.2 Microstructure Test

In order to get a smooth surface, grinding and polishing process were conducted using Buehler HandiMet 2, Roll Grinder as shown in Figure 3.12. The samples were manually grinded in the alternating longitudinal and latitudinal direction with four different grit papers. The HandiMet 2 provides a self-contained four-stage grinding station with controlled water flow for lubricant and flushing. The four-stage grinding station was used four rolls of CarbiMet Paper Rolls: Grit 240, 320, 400 and 600 (P280, P400, P600, P1200) while the continuous water flush removes grinding residue from the abrasive grit. This process is to ensure the accuracy of the results generated and avoided the damage of the instrument.

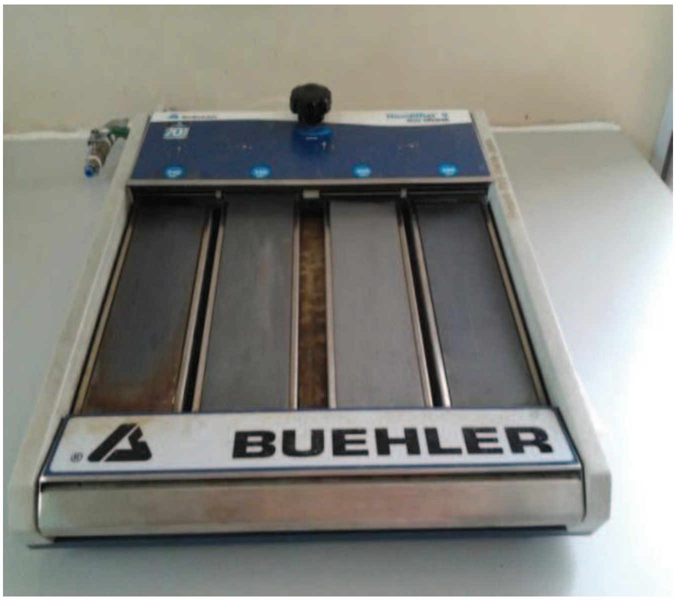

Figure 3.12: Buehler HandiMet 2, Roll Grinder

For polishing process, Metkom FORCIPOL 2V Grinder-polishing as shown in the Figure 3.13 was used. The purpose of process was to get a mirror like surface finish on the specimen. The specimen that had been grinded smoothly was now going through the polishing. The purpose of polishing is to remove fine scratches that formed during the grinding stage. This is to make sure that, the microstructure can clearly capture by microscope. Forcipol 2V have two discs and variable speed range between 50 and 600 rpm. Under this speed, the polishing process was conducted three stages using three different discs. First, disc that mark 6µm, after that, 1µm and last 0.05µm using their own lubricant for each stages.

After the samples were polished, the microstructure of the sample was observed on an optical microscope to determine the shape factor of this alloy. Figure 3.14 shows the LEICA DME working microscope. For each sample, we have taken 4 fields for each different magnificent lens which are 05X, 10X, 20X, and 50X.

Figure 3.13: Metkon FORCIPOL 2V Grinder-Polisher

Figure 3.14: LEICA DME Working Microscope

3.3.3 Tensile Test

To analyze mechanical properties of the specimen, tensile test machine was used. The main objectives for tensile test are to determine the yield stress, tensile stress and behavior of samples when subjected to an axial tensile load. In a broad sense, tensile test is a measurement of the ability of a material to withstand forces that tend to pull it apart and to what extent the material stretches before breaking. The stiffness of a material which represented by tensile modulus was determined from stress strain diagram. For this test, as shown in Figure 3.15(a), Shimadzu Universal Testing Machine with capacity 100 kN was used in this tensile test. For Figure 3.15(b), it shows the tebsile test stage. The speed for this test was 1mm/min and the dog bone specimen that clamp at the machine was 100cm length. 100All data of the material was added in software call Trapezium, which generated the chart and results for tensile test.

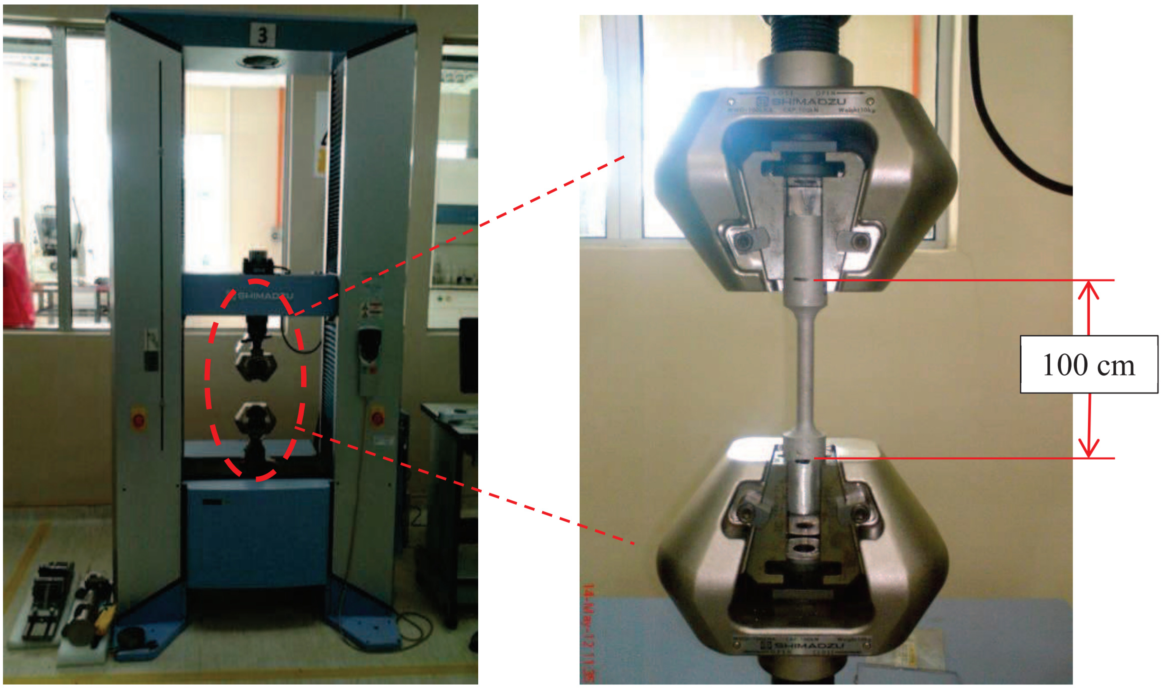

Figure 3.15: (a) Shimadzu Universal Testing Machine (b) Tensile test stage

3.3.4 Rockwell Hardness Test

For hardness of the material, Matsukawa Rockwell Hardness Tester (refer Figure 3.16(a)) was used. Figure 3.16(b) shows the indenter stage of the Rockwell machine which can be lifted manually. This hardness test uses a direct reading instrument based on the principle of differential depth measurement. Rockwell testing differs from Brinell testing in that the Rockwell hardness number is based on an inverse relationship to the measurement of the additional depth to which an indenter is forced by a heavy (major) load beyond the depth resulting from a previously applied (minor) load. Initially a minor load is applied, and a zero datum position is established. The major load is then applied for a specified period and removed, leaving the minor load applied. The resulting Rockwell number represents the difference in depth from zero datum position as a result of the application of major load. 5 readings have been taken and the average for each sample was plotted as a graph.

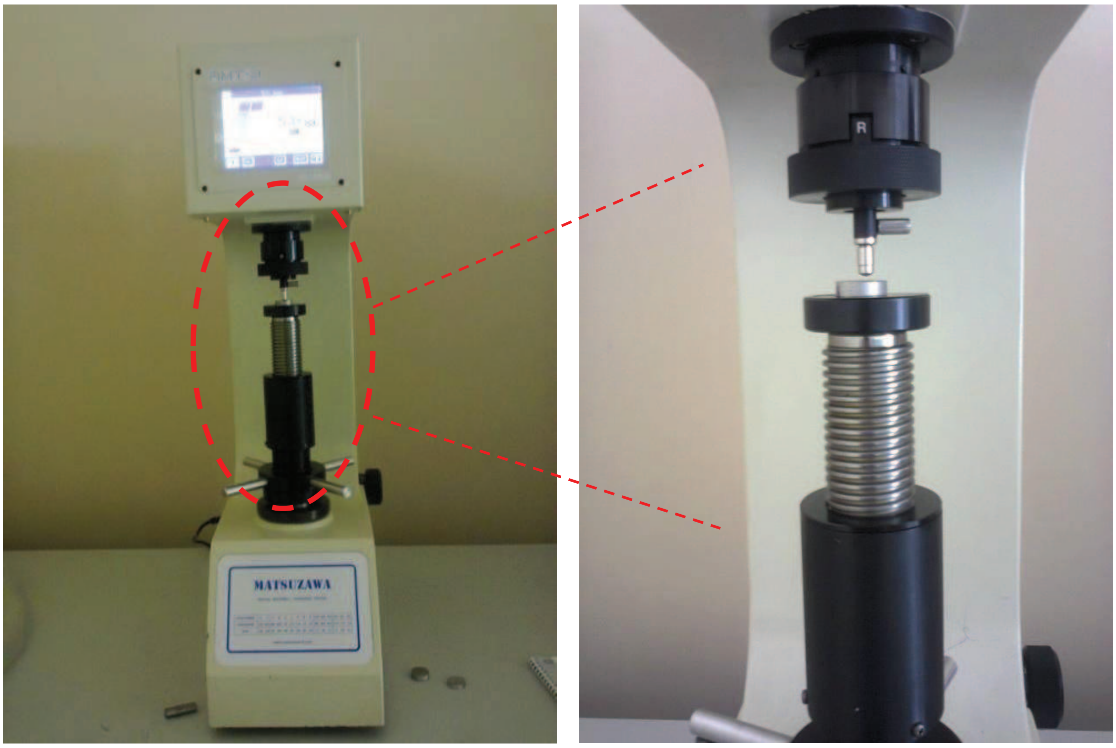

Figure 3.16: (a) Matsuzawa Rockwell Hardness Testing Machine (b) The indenter stage

CHAPTER 4

RESULT AND DISCUSSION

4.1 MICROSTRUCTURAL ANALYSIS

The microstructures of cast A356 samples captured are shown in Figure 4.1. Figure 4.1 shows the semi-solid microstructures of A356 alloy obtained poured at the three different temperatures which are 620°C, 640°C, and 695°C respectively. As expected, it can be observed that for a lower poured temperature the microstructure becomes finer.

From the observation, it seen that for a lower pouring temperature resulting in a finer microstructure. This is because, under the lower temperature, the rapidly cooling caused a fine equiaxed α-Al structure and uniformly globular grain shape. For the higher pouring temperature, the slower cooling rates require dendrite structure and coarse grain shape. That is mean; grain shape controlled by cooling and solidification rates.

From Figure 4.1(a), the α-Al particles of semi-solid A356 alloy poured at 620°C is less dendrite structure, more equiaxed α-Al structure. The globular particles are at same size and spread uniformly on the microstructure. The eutectic Si particles on this microstructure are also in form of fine needles and it particles did not spread uniformly. When the temperature is low, the solidification rate is too high. When the solidification rate is high, it can cause the molten phase of slurry to solidify faster and the α-AL globes and broken eutectic silicon particles. It is because the fast solidification of molten metal did not have enough time to reconfiguration and spread.

For semi solid A356 that poured at 640°C as shown in Figure 4.1(b), the microstructure have both dendritic and equiaxed α-Al structure which also called as co-exist. This microstructure has a few rosette-like fine grains.

As shown in the Figure 4.1(c), the microstructure of semi-solid A356 that poured at 695°C consist mainly dendrite and a few equiaxed α-Al structure. A particle-like coarse grain was observed in this microstructure. When the temperature is high, the solidification rate is too low. When the solidification rate is low, it can cause the molten phase of slurry to solidify slower and the primary α-Al becomes dendrite. It is because the slower solidification of molten metal has enough time to absorb more molten alloy and become non globular.

In general, from Figure 4.1, the effect of pouring temperature in SSM A356 alloy is changed from dendrite grain structure to the equiaxed or globular grain structure as the pouring temperature of liquid alloy increased from 620°C to 695°C. In addition, pouring temperature has a great influence on the morphology and the grain structure of the primary phase in SSM. The reduction of pouring temperature can obviously reduce the grain structure of microstructure and improve the shape factor at primary phase in SSM A356 alloy. This is also obvious as casting at lower temperature results in faster cooling rates and hence finer microstructure.

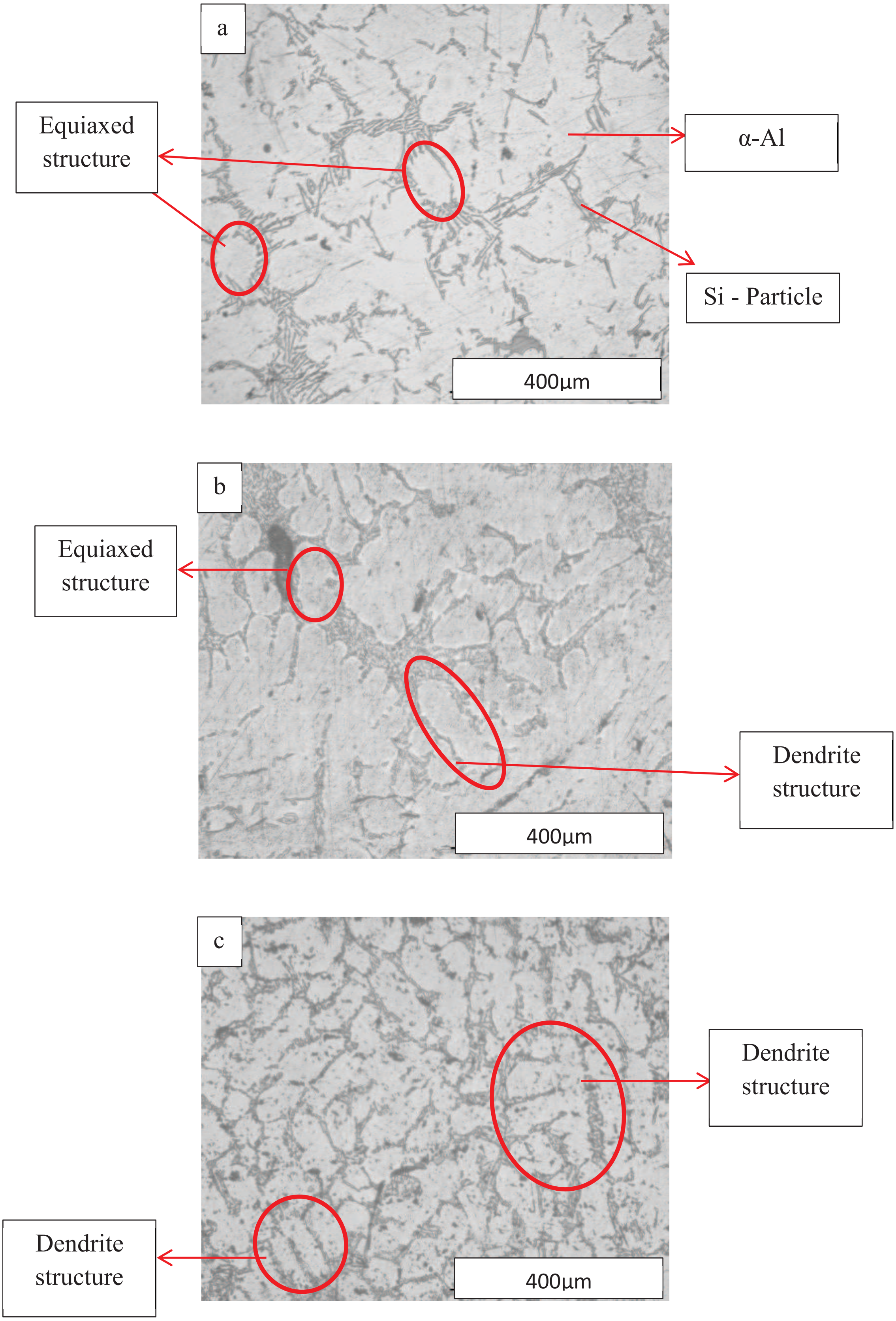

Figure 4.1: The morphology of primary phase in A356 alloy obtained at pouring temperature (a) 620°C, (b) 640°C, and (c) 695°C

4.2 TENSILE TEST TESTING

4.2.1 Yield Strength

Yield strength is the strength at which a metal or alloy shows significant plastic deformation. The 0.2 percent yield strength, also known as 0.2 percent offset yield strength, was determined from the engineering stress-strain graph by Trapezium Software. From Figure 4.2, the maximum value for yield strength is 85.33 N/mm^2 at lower pouring temperature which is 620°C. For the higher pouring temperature which is 695°C, the value of yield strength is 62.52 N/mm2.

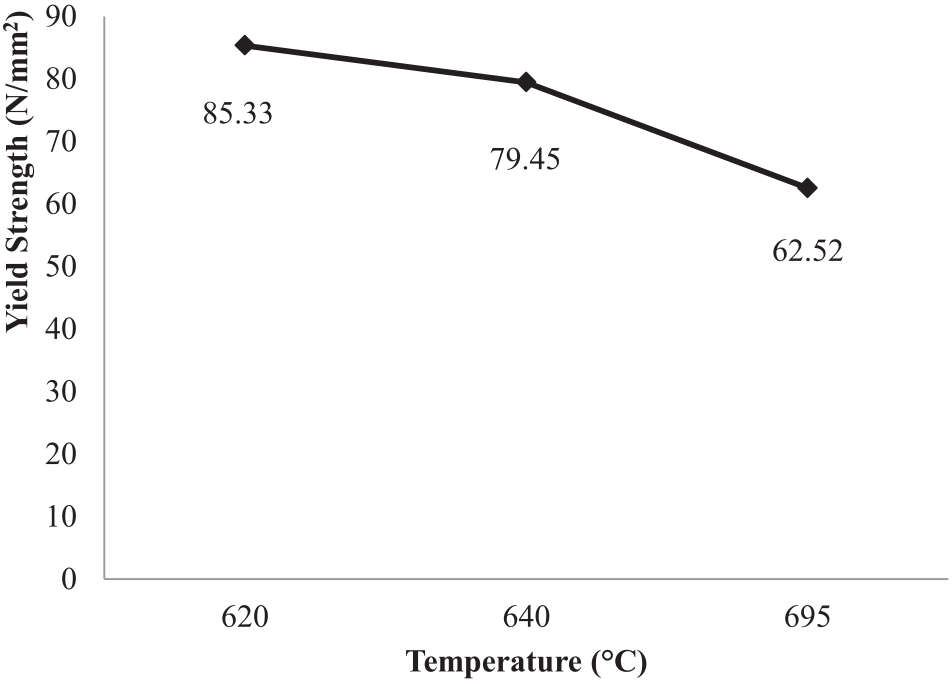

Figure 4.2: Graph yield strength versus pouring temperature

4.2.2 The Ultimate Tensile Strength (UTS)

The ultimate tensile strength is the maximum strength reached in the engineering stress-strain graph. As shown in Figure 4.3, UTS decreases with increasing pouring temperature. For the lower pouring temperature, the value for UTS is 112.30 N/mm^2. The minimum value is 82.32 N/mm^2 obtained at the higher pouring temperature which is 695°C.

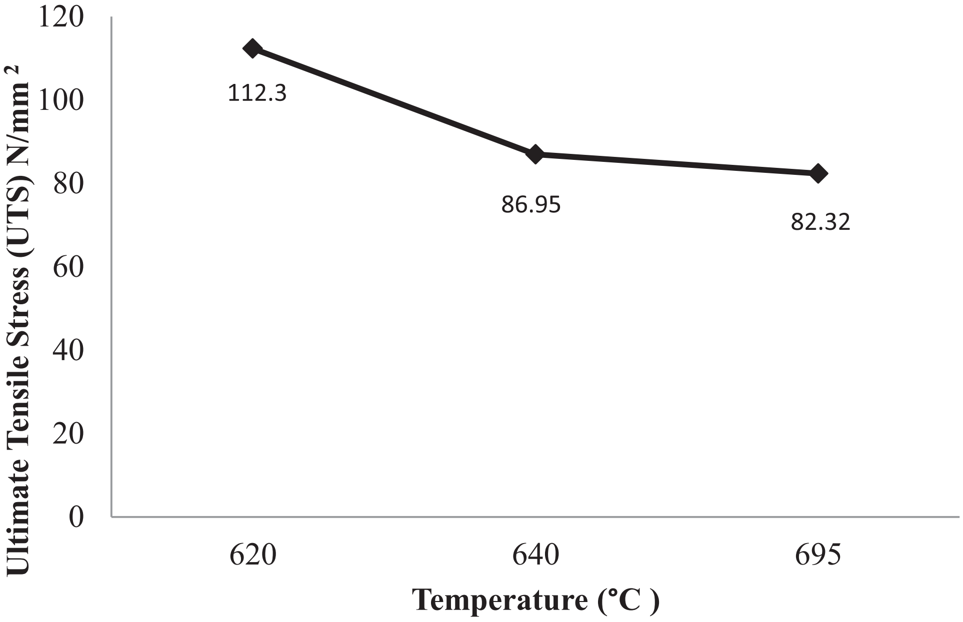

Figure 4.3: Graph UTS versus pouring temperature

4.2.3 Percent Elongation

Percent elongation is the amount of elongation that a tensile specimen undergoes during testing. That elongation provides a value for the ductility of the metal. In general, the higher the percent elongation of the specimen, the higher the ductility or the more the deformable the metal is. From Figure 4.4, the higher percent elongation was obtained by lower pouring temperature, 620°C which is 2.16%. At higher pouring temperature which is 695°C, the value of percent elongation is lower, 1.09%.

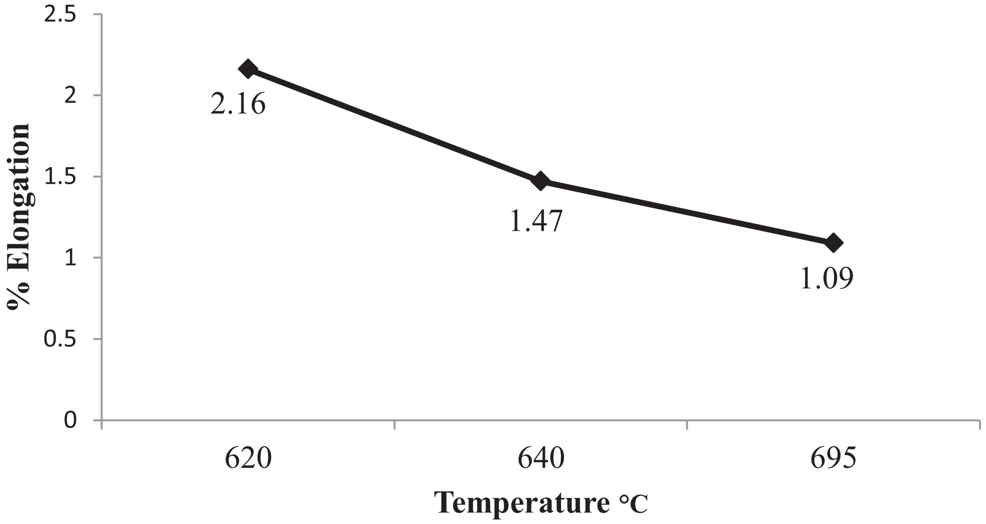

Figure 4.4: Graph percent elongation versus pouring temperature

From the Figure 4.2, Figure 4.3, Figure 4.4, we can said that, when the pouring temperature is increase, the yield strength, UTS and % elongation is decrease. The behavior of this specimen highly depends on the shape of grain. Dendrite grain shape increases the tendency of crack formation. The elongation to fracture depends on the ability of Si particles in the Al-Si eutectic to stop the motion of dislocations. The Si particles become more homogeneously in a fine microstructure on the higher temperature of casting.

The dislocations pass the Si particles and pile up at grain boundaries where the fracture takes place, resulting in a high elongation to fracture. The coarse Si particles form a more continuous boundaries for the dislocations which pile up at the Al–Si eutectic, where the fracture takes place and resulting in lower elongation to fracture. That is mean, the Si particle grain shape of microstructure play important role either in strength or hardness.

Grain size has a direct impact on the mechanical properties of metals. Metals with fine grain size are stronger and it has more uniform properties. The strength of Al-Si alloy is related to its grain size through the empirical relationship. For nanocrystal metals, reducing the grain size, a harder, stronger, and tougher metal may be produced.

To get the smaller and finer grain size, for semi solid metal, lower the pouring temperature is important (Smith, 2006).

4.3 HARDNESS TEST

Figure 4.5 shows the results of Rockwell Hardness test with pouring temperature. The result obtained that at lower pouring temperature which is 620°C, the value of hardness is maximum, 61.32. It also evidence that, as the temperature increase, the hardness decreases. This is because the relatively fine microstructure produced by lower temperature is more easily to be dispersed in the alloy compare to the less fine microstructure produced by higher temperature.

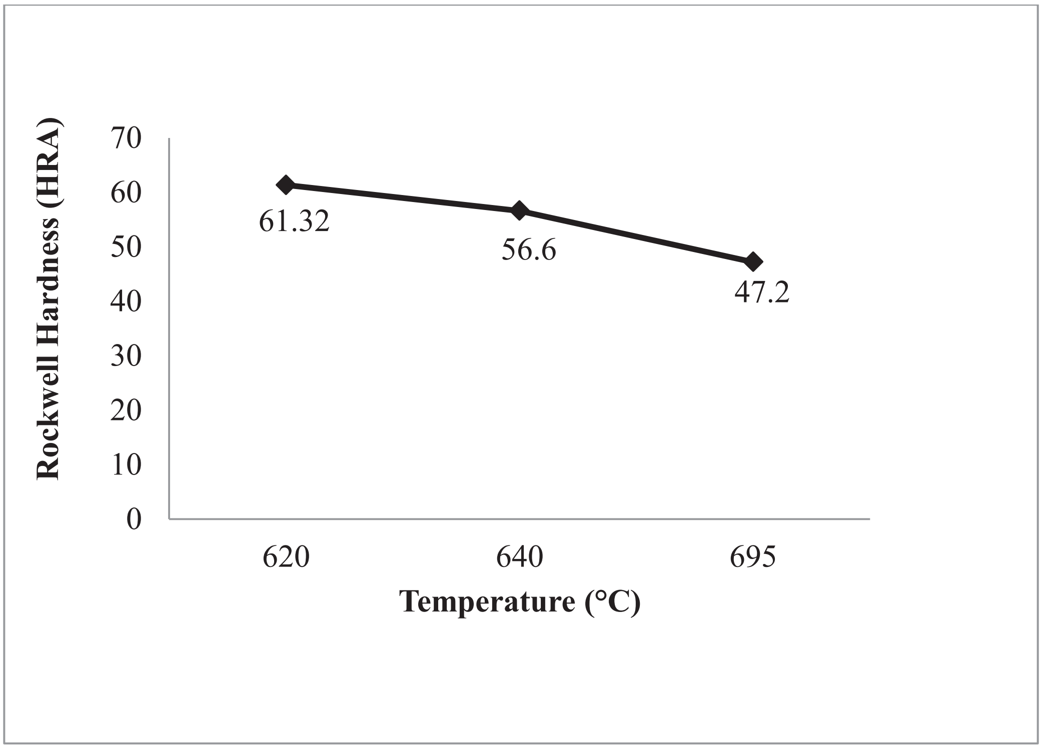

Figure 4.5: Graph of Rockwell hardness versus pouring temperature

CHAPTER 5

CONCLUSION AND RECOMMENDATION

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5.1 CONCLUSION

The effect of different pouring temperature on the mechanical properties of the SSM was investigated. In order to determine the different pouring temperature of semi-solid metal Al-Si alloy (A356), several experiments was conducted such as casting process, microstructure observed, tensile test for strength and also the hardness test. Based on this research, the conclusions are:

(i) The grain structures change from dendrite to globular primary α-Al structure as pouring temperature of liquid alloy decrease.
(ii) Rapid cooling produced by lower temperature causes a fine grain structure.
(iii) The hardness and strength of Al-Si alloy A356 increase with a decrease grain structure of α-Al from dendrite to equiaxed structure.
(iv) The lower pouring (620°C) temperature produces the higher tensile strength and hardness.
(v) From the microstructure and mechanical property assessments, the lower pouring temperature is a region where good quality cast are produced for SSM.

5.2 RECOMMENDATION

The recommendations to improve this study are:

(i) This study may use another types of casting such as die casting and permanent mold casting to observe the result.

(ii) When pouring the molten metal, the flow of molten metal maybe not laminar flowing, so that, we can find alternative to make the molten metal flow laminar by creating a molten metal flowing machine so that the flow can flow smoothly and laminar to avoid porosity and others defect that may occur during casting.

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APPENDIX A

A1: PSM 1 GANTT CHART

NO	PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15
1.	Receive project title	🟥														
		🟨														
2.	Discussion and set appointment with supervisor		🟥													
			🟨													
3.	Working on experiment		🟥	🟥	🟥											
			🟨	🟨	🟨											
4.	Working on introduction			🟥	🟥	🟥										
					🟨	🟨	🟨									
5.	Working on literature review						🟥	🟥	🟥	🟥						
							🟨	🟨	🟨	🟨						
6.	Working on methodology								🟥	🟥	🟥	🟥				
										🟨	🟨	🟨	🟨			
7.	Report documentation										🟥	🟥	🟥	🟥	🟥	
												🟨	🟨	🟨	🟨	
8.	Completing draft report											🟥	🟥	🟥	🟥	
													🟨	🟨	🟨	
9.	Preparation for presentation											🟥	🟥	🟥	🟥	
														🟨	🟨	
10.	Submit draft report, slide presentation and log book														🟥	
															🟨	🟨
11.	Presentation															🟥
																🟨

🟥 Plan 🟨 Actual

APPENDIX A

A2: PSM 2 GANTT CHART

NO	PROJECT ACTIVITIES	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17	W18
3.	Working on experiments		🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥								
	a) Moulding			🟨															
	b) Pouring				🟨														
	c) Fettling					🟨													
	d) Microstucture						🟨	🟨	🟨	🟨	🟨								
	e) Tensile test									🟨	🟨								
	f) Hardness										🟨								
4.	Preparation for presentation											🟥	🟥	🟥					
												🟨	🟨	🟨	🟨				
5.	Presentation														🟥	🟥			
															🟨				
6.	Report writing										🟥	🟥	🟥	🟥	🟥	🟥			
											🟨	🟨	🟨	🟨	🟨	🟨			
7.	Submit report 1														🟥	🟥			
																🟨			
8.	Submit report 2																🟥	🟥	
																	🟨		
9.	Submit report																		🟥
																			🟨

Plan 🟥

Actual 🟨