EFFECT OF SOLUTION TREATMENT TEMPERATURE ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A356 ALLOY

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Thesis submitted in fulfillment of the requirements
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JUDUL: **EFFECT OF SOLUTION TREATMENT TEMPERATURE ON MICROSTRUCTURE AND MECHANICAL PROPERTIES OF A356 ALLOY**

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A small gift for my beloved parents for their love, patience, support and all the hard work poured throughout my entire life

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ABSTRACT

Aluminum content in a vehicle is keep increasing around the globe due to the needs to reduce vehicle weight and increase fuel efficiency. The majority of the components are cast product which mostly casted from A356 alloy because of its excellent characteristics such as cast ability, high weight-to-strength ratio, good corrosion resistance and good weld ability compared to other types of alloy. Heat treatment is done to harness the full potential of cast A356 alloy and T6 is the commonly used heat treatment for this alloy. Most of the solution treatments (ST) study is done on sample having α-Al with dendritic structure. The specimen was cast using low pouring temperature (LPT) method which produces equiaxed α-Al structure. The objective of this research is to study the effect of ST temperature on microstructure and mechanical properties of A356 (Al7Si0.3Mg) aluminum alloy. The specimen undergone ST for two (2) hours at three different temperatures (530 °C, 540 °C, and 550 °C), quenched in water at room temperature, and artificial aged for six (6) hours at 170 °C. Mechanical properties of A356 aluminum alloy were investigated by utilizing tensile test and hardness test, the later is the main interest of this study. The relation between size, shape, and distribution of Si particle and the alloy's mechanical properties were investigated. It was found that Si particle size, shape, and dispersion affect the mechanical properties of cast A356 alloy. Higher ST temperature produce smaller and more globular Si particle before completing T6 heat treatment. Elongation decreases while ultimate tensile strength (UTS) increased as ST temperature increased from 530 °C to 550 °C. A356 aluminum alloy specimen solution treated at 530 °C have comparable hardness compared with specimen ST at 540 °C before and after artificial ageing (AA) - complete T6 heat treatment - with higher elongation and lower energy usage as added benefit.

ABSTRAK

Kandungan aluminium di dalam kenderaan terus meningkat di seluruh dunia berikutan keperluan untuk mengurangkan berat kenderaan dan meningkatkan kecekapan bahan api. Kebanyakan komponen adalah produk tuangan yang kebanyakannya dituang daripada aloi A356 kerana ciri-cirinya yang cemerlang seperti keupayaan tuangan, nisbah berat kepada kekuatan yang tinggi, ketahanan terhadap kakisan yang baik dan keupayaan kimpal yang baik berbanding dengan lain-lain jenis aloi. Rawatan haba dilakukan untuk mendapatkan potensi penuh aloi A356 tuang dan T6 ialah rawatan haba yang biasa digunakan untuk aloi ini. Kebanyakan kajian rawatan larutan (ST) dilakukan ke atas sampel yang mempunyai α-Al dengan struktur dendritik. Spesimen yang dituang menggunakan kaedah tuangan suhu rendah (LPT) menghasilkan α-Al dengan struktur yang mempunyai dimensi yang hampir sama dalam semua arah. Objektif kajian ini adalah untuk mengkaji kesan suhu ST ke atas mikrostruktur dan sifat mekanik aloi aluminium A356 (Al7Si0.3Mg). Spesimen melalui rawatan larutan selama dua (2) jam pada tiga suhu yang berbeza (530 °C, 540 °C, dan 550 °C), padam dalam air bersuhu bilik, dan penuaan tiruan selama enam (6) jam pada suhu 170 °C. Sifat mekanikal aluminium aloi A356 telah disiasat menggunakan ujian ketegangan dan ujian kekerasan, dimana ujian kekerasan dijadikan sebagai tumpuan utama dalam kajian ini. Hubungan diantara saiz, bentuk, dan serakan zarah Si dengan sifat mekanikal aloi ini telah disiasat. Kajian mendapati bahawa saiz zarah, bentuk, dan serakan zarah Si memberi kesan kepada sifat-sifat mekanik aloi A356 tuang. ST pada suhu tinggi menghasilkan zarah Si yang lebih kecil dan lebih globular sebelum melengkapkan rawatan haba T6. Pemanjangan berkurangan manakala kekuatan tegangan mutlak (UTS) bertambah apabila suhu ST bertambah daripada 530 °C ke 550 °C. Spesimen aluminium aloi A356 yang melalui rawatan larutan pada suhu 530 °C mempunyai kekerasan yang setanding berbanding dengan spesimen yang dirawat pada suhu 540 °C sebelum dan selepas penuaan tiruan (menamatkan proses rawatan haba T6) dengan pemanjangan yang lebih tinggi dan penggunaan tenaga yang lebih rendah sebagai manfaat tambahan.

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LIST OF ABBREVIATION

530 ST	Solution treated at 530 °C, room temperature water quench
530 T6	Solution treated at 530 °C, room temperature water quench, artificial ageing
540 ST	Solution treated at 540 °C, room temperature water quench
540 T6	Solution treated at 540 °C, room temperature water quench, artificial ageing
550 ST	Solution treated at 550 °C, room temperature water quench
550 T6	Solution treated at 550 °C, room temperature water quench, artificial ageing
AA	Artificial ageing
AAA	American Aluminum Association
AC	As-cast
Al - Si	Aluminum - Silicon
ASTM	American Society for Testing and Material
DAS	Dendrite arm spacing
GP	Guinier-Preston
HV	Vickers' hardness number
LPT	Low pouring temperature
NP	Normal pouring
SDAS	Secondary dendrite arm spacing
ST	Solution treatment
UTM	Universal Testing Machine
UTS	Ultimate tensile strength
YS	Yield strength

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Over the years, aluminum content in a vehicle is keep increasing around the globe due to the needs to reduce vehicle weight and increase fuel efficiency. The majority of the components are cast product which, mostly casted from A356 alloy. A356 alloy become the favorite type of alloy to be cast because of its excellent characteristics over other type of alloy such as cast ability, high weight-to-strength ratio, good corrosion resistance and good weld-ability. Most of the cast component in a vehicle such as cylinder head for example, favors hardness over tensile strength.

Dendritic α-Al structure is produced by casting A356 alloy using normal pouring (NP) method, which is pouring melted alloy at high temperature. In the other hand, the low pouring temperature (LPT) method, which is pouring melted alloy at low temperature near its liquidus temperature produce α-Al with equiaxed or globular structure. Equiaxed structure reduce forming resistance, thus, more complicated component can be cast. In case of permanent mold and die casting, LPT method prolonged the mold service life.

Heat treatment is done to harness the full potential of cast A356 alloy. Study by Möller et al. (2008) shows long solution treatment time provide low hardness and short solution treatment provide high hardness. The distribution, morphology, volume fraction, degree of Si particle modification, composition of phases of the as-cast microstructure, along with the ST parameters (temperature, time) chosen determine the successfulness of ST.

1.2 IMPORTANT OF RESEARCH

Unsuitable ST regime will waste the effort of producing equiaxed/globular α-Al structure of sand cast A356 alloy. If ST temperature is too low, the alloying elements will not have complete dissolution and become unavailable for precipitation hardening and too high ST increase the cost due to high energy usage than is necessary.

1.3 PROBLEM STATEMENT

Most of ST studied was based on dendritic α-Al structure like what was done by a number of researchers such as Sjölander et al. (2008) for example. The objective of ST is to homogenize the alloying element (Si) and spheroidize the eutectic Si particle. The LPT method produced equiaxed α-Al structure, in which the alloying element is spread throughout the aluminum in a much higher degree compared to NP which produces dendritic α-Al structure. This means that LPT helps in homogenizing the alloying element to some extent. ST will further homogenize the alloying element – with less work to do thanks to the LPT method; therefore its priority now is to spheroidize the eutectic Si particle. Therefore, the ST regime needs to be reviewed for α-Al having equiaxed or globular structure.

1.4 PROJECT OBJECTIVE

To investigate the effect of solution treatment temperature on microstructure and mechanical properties of A356 alloy

1.5 PROJECT SCOPE

i. Casting of A356 alloy by sand casting method
ii. Heat Treatment of A356 alloy
iii. Microstructure study
iv. Mechanical properties analysis namely hardness, tensile strength,% elongation

1.6 RESEARCH FLOW CHART

Figure 1.1 shows the process flow chart along the study. This provides clear image of the research flow of this study.

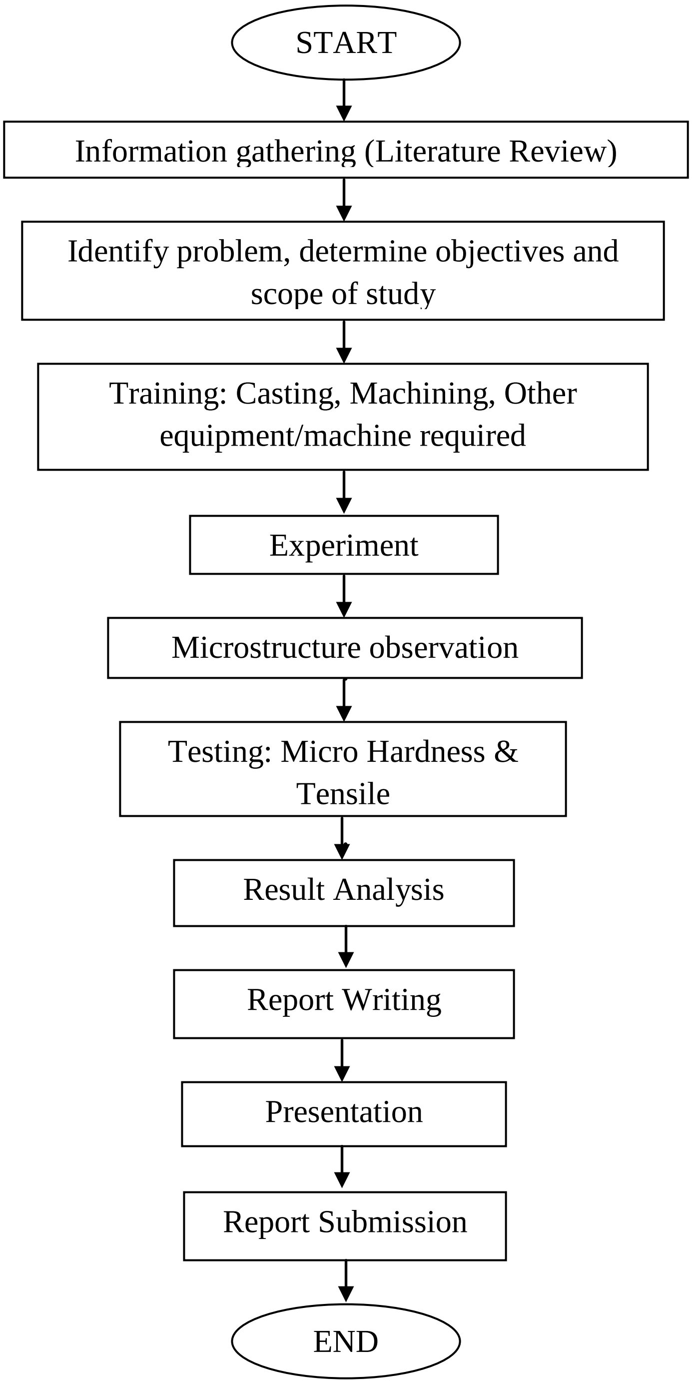


Figure 1.1: Research flow diagram

CHAPTER 2

LITERATURE REVIEW

2.1 ALUMINUM AND A356 ALLOY

2.1.1 Aluminum

Aluminum made up about 8% of the earth crust and can be found in most rocks, clay, soil, and vegetation. It occurs in nature only as compounds with oxygen and other elements, never in the metallic form. The availability of products based on aluminum depends on two chemical processes developed in the late nineteenth century. In the Bayer process, alumina (Al_2O_3) is extracted from bauxite – rock in which aluminum hydroxides have been highly concentrated by weathering. In the hall/herald process, molten cryolite (Na_3AlF_6) is used to dissolve alumina, and the solution is then electrolyzed to obtain aluminum metal. Aluminum is distinguished from other metals by its low density, high surface reflectivity, and high electrical and thermal conductivity (Shuey et al., 1993).

Aluminum-silicon (Al-Si) alloys are gaining popularity compared to other type of aluminum alloys used in automotive and aerospace applications, due to to their higher strength-to-weight ratios, better cast ability, better wear resistance, and better surface finish. An increase in cast Al-Si alloy component in vehicle is seen due to the need to produce component with higher strength-to-weight ratios. A near-net-shape process is once more gaining interest due to the need to conserved energy, manufacturing costs, material, and section thickness which is difficult to achieve via sand-casting processes. The aluminum alloy is the second most popular casting materials after ferrous castings in term of tonnage usage. The American Aluminum

Association (AAA) has divided the aluminum alloys into groups based on their alloying element.

Al-Si is identified as the 3XX.X series of aluminum alloys by the AAA, which makes up 80 to 90% of the total cast aluminum, produced worldwide (Gruslezki et al., 1990, Campbell, 2003, ASM, 1990). The characteristics of 3XX.X series are heat treatable, excellent fluidity, high-strength, approximate ultimate tensile strength range: 130 to 275 MPa (20–40ksi) and readily welded.

The 3XX.X series is one of the most widely used aluminum alloy in casting because the high silicon content contribute to its fluidity and flexibility. Variety of high strength option could be achieved via heat treatment due to their good response to heat treatment. In addition, variety of techniques can be used to cast the 3XX.X series, from the simple sand or die casting to the complicated permanent mold, investment castings, and the newer thixocasting and squeeze casting technologies.

Among the widely used aluminum alloys are 319.0 and 356.0/A356.0 for sand casting; 360.0, 380.0/A380.0 for permanent mold casting; 390.0 for die casting; and 357.0/A357.0 for many types of casting, including, especially, the relatively newly commercialized squeeze cast technologies.

2.1.2 A356 Alloy

In recent years, the use of Al–Si–Mg casting alloys, especially the A356 (Al7Si0.3Mg) has increased in the automotive industry due to its excellent cast ability, corrosion resistance and good mechanical properties in the heat-treated condition, hot tearing resistance, good weld ability and high strength to weight ratio (Wang et al., 2001). A356 is a hypoeutectic Al-Si alloy with a wide range of applications in the automotive and avionics industries. A356 is one of the most common aluminum alloys used in near-net-shape process because of its advantages of high fluidity and good cast ability due to the high content of Al-Si eutectic (Zhang et al., 2008). Example of application of sand cast A356.0 alloy are automotive transmission cases, water-cooled cylinder blocks, flywheel housings, oil pans, various fittings and pump bodies. This alloy, after being heat treated under T6 heat treatment, is also applied in various marine applications where pressure tightness or corrosion resistance is major requirements.

2.2 SAND CASTING

Sand casting is one of the earliest metal forming processes used for manufacturing metal parts. It is a process of pouring molten metal into a sand mould with a cavity of the shape to be made and allowing it to solidify. The process of casting involves the basic operations of pattern making, sand preparation, molding, melting of metal, pouring in moulds, cooling, shake-out, fettling, heat-treatment finishing and inspection (Rao, 1996). Almost any shape, size, and metal can be cast using sand casting method by suitable molding and core-making technique. Sand casting provides a wide range of property selection for the finished cast-parts by suitable choice of alloy and heat-treatment.

2.2.1 Pattern

A pattern is a model used to make dimensionally accurate mould cavity in which liquid metal is later poured, to make a casting (Rao, 1996). Pattern could be made of wood, metal, plastic and rubber, wax and polystyrene, etc. The material needs to have characteristics such as lightweight for ease of handling and working, strong, hard and durable, easy to work, shape and join, easily available at low cost, easy to repair and having the ability to give good surface finish. A good pattern has the following characteristics (Rao, 1996):

- **a.** Dimensional accuracy to get high quality casting
- **b.** Strength to withstand ramming and abrasion of molding sand
- **c.** Rigidity to prevent distortion and warping through seasonal change over a long period of use.
- **d.** Good surface for easy removal from mould
- **e.** Proper color-code to indicate to the molder, information regarding final casting and precaution during molding.

f. Should help to increase molding productivity through suitable design and construction and achieve overall economy in molding.

2.2.2 Molding Sand

There are seven requirements of good molding sand as stated by Rao (1996):

a. Refractoriness

Ability of the molding sand to withstand high pouring temperature of molten metal without itself being partially melted and fuses with the liquid metal, which could results in a very rough sand-fused casting surface.

b. Chemical Resistivity

The sand used for molding should be inert and not react chemically with the molten metal/alloy being poured into it.

c. Strength With Proper Binder

When combined with proper binder, the sand should develop adequate cohesion among its grains to be able to form and stay as a mould, withstand movement and handling of mould before pouring. It also should be able to withstand the compressive and erosive force by the liquid metal while filling in the mould cavity

d. Permeability

The ability to let gases and vapors produced from the pouring of molten metal to escape by having sufficient porosity.

e. Surface Finish

The smoothness of the casting depends on the fines of the sand grain. Good surface finish is necessary to avoid costly finishing operations.

f. Flow Ability

The capacity of molding sand to flow to different corners and intricate details in mould without much special effort to ram is a useful requirement of molding sand.

g. Collapse Ability

The sand should be able to peel off and disintegrate easily so that the cooled casting can be taken out and finished. In addition, sand having good collapse ability reduces the fettling and finishing cost.

h. Availability and Economy

2.2.3 Pouring Temperature

The grain size, secondary dendrite arm spacing (SDAS), interdendritic porosities, and structure of eutectic silicon affect the mechanical properties of Al–Si alloys (Kumai et al., 1996, Zhang et al., 1999, Atxaga et al., 2001). To improve the mechanical properties of Al-Si alloys, interest is now directed to make the as-cast microstructure to be finer. Common practice is to add grain refiner and modifier during melting to improve the mechanical properties of Al–Si casting alloys (Mohanty et al., 1996, Murty et al., 2002, Hegde et al., 2008).

Wang et al. (2011) found that low pouring temperature produced equiaxed α-Al structure, maximum microstructure refining effect could be obtained especially by the over melt thermal treatment. The refinement is caused by the nuclei multiplication in the melt. In addition, the higher cooling rate does little change on the morphology of eutectic silicon. Due to the refinement of the grain size, the silicon particle size also becomes finer. The tensile properties of the alloys improved, the alloy's UTS and elongation increased because of the refinement of the grain size and eutectic silicon. Apart from the increase in nucleation rate, the LPT also contribute to the growth of grains in globular form, resulting in microstructure to be fine, equiaxed and non-dendrite which are benefit for the tensile properties of AlSi7Mg alloy (Wang et al., 2002, Easton et al., 2006).

Both Mao et al. (2001) and Srinivasan et al. (2006) were in good agreement that LPT produce finer grain. It is clear that DAS increases with increase in pouring temperature and this (increase of DAS) will reduces the mechanical properties of the alloy (Srinivasan et al., 2006).

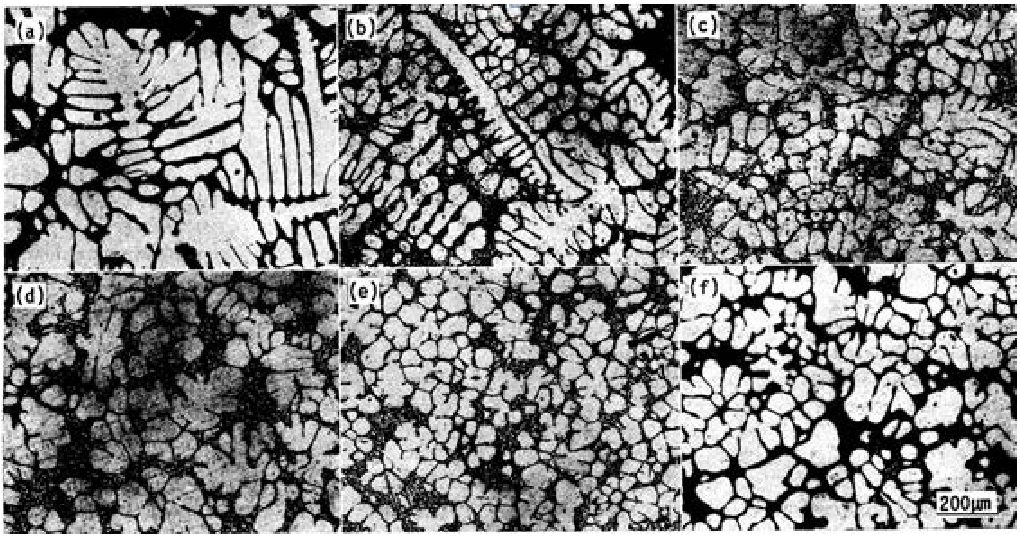


Figure 2.1: Microstructure of Al7Si0.3Mg alloy samples poured at different temperature (a) 750, (b) 650, (c) 630, (d) 620, (e)615, (f)610 °C

Source: Mao et al. (2001)

2.3 T6 HEAT TREATMENT

According to Smith et al. (2009), heat treatment refers to any of the heating and cooling operations which purpose is to change the mechanical properties, morphology or the residual stress state of a metal product. The T6 heat treatment is the typical and the most common heat treatment applied to sand cast A356 aluminum alloy, the treatment consist of the following stages (Sjölander et al, 2010):

1. Solution treatment at a relatively high temperature.
2. Quenching
3. Age hardening, either at room temperature (natural ageing) or at an elevated temperature (artificial ageing)

ASTM Standard B917-01 designates 6-12 hours at 540 °C, hot water quench, and then 2-5 hours at 155 °C for sand-cast A356. However, variations of a standard T6 heat treatment were investigated by researchers for Sr-modified and unmodified cast aluminum alloy A356 in terms of the effects on the mechanical properties.

2.3.1 Solution Treatment (ST)

ST is done at a high temperature, close to the eutectic temperature of the alloy; its purpose is to (Sjölander et al., 2010):

- Dissolve soluble phases containing Cu and Mg formed during solidification;
- Homogenize the alloying elements;
- Spheroidize the eutectic Si particles.

The time required for ST depends on a few factors such as the composition, structure, size and distribution of the phases present after solidification, and ST temperature (Sjölander et al., 2010, Smith et al., 2009). Most ST is carried out between 4 to 6 hours at 540 ^{o}C and is said to be the most optimum condition (Tensi et al., 1996, Shabestari et al., 2004, Cavaliere et al., 2004). ST of cast Al-Si-Mg alloys in the 400-560 ^{o}C range dissolves the hardening agents (Mg_2Si particles) into the α-Al matrix, reduces the micro-segregation of magnesium, copper, manganese, and other addition elements in aluminum dendrites, and spheroidize the eutectic silicon particles to improve the ductility (Davidson et al., 2002). The desired solution time and temperature, to a great extent, depend on the casting method, the extent of modification, and desired level of spheroidization and coarsening of silicon particles (Ma, 2006). According to Sjölander et al. (2010), homogeneous solid solution is formed when atoms leave the coarse particles formed during solidification and propagate into the Al-Si matrix and reduces the concentration gradient. The time required to homogenize the casting depends on the morphology of the diffusing atoms and the ST temperature (diffusion rate) as well as by coarseness of the microstructure (Sjölander et al., 2010). The time needed for spheroidize the eutectic Si particle is strongly depends on the ST temperature, shape and structure, and size of the eutectic Si particles in the as-cast (AC) condition. A Sr-modified sand-cast A356 alloy requires of 3-6 hours at 540 °C for optimal ST temperature (Shivkumar et al., 1990, Sjölander et al., 2010). The ST time can be reduced if the AC microstructure is finer (Sjölander et al., 2010).

The maximum temperature for ST of a metal must not exceed, when possible, its solidus temperature (Smith et al., 2009). Möller et al. (2008) investigated the effects of variations from T6 standard treatment on the hardness, ductility, and UTS of A356 alloy cast in a permanent mould with and without strontium modification. The main variables considered in the experiments were ST time and temperature. The as-cast samples were solution treated for various times (t=2, 4, 8, 16 and 32 hours) at 520 ^{o}C/540 ^{o}C and aged at 160 ^{o}C for 6.5. The highest hardness was obtained at a short ST time (2 hours) for both unmodified and modified A356, while the highest ductility wasn't achieved until the samples undergone 8 hours of ST at the same temperature.

2.3.2 Quenching

Quenching is done to suppress precipitate upon cooling the casting to room temperature from the high ST temperature (Sjölander et al., 2010). If the quench rate is high enough, the solute is retained in solid solution and high number of vacancies would also be retained (Sjölander et al., 2010). Conversely, too slow cooling rate cause the particle to precipitate heterogeneously at grain boundaries or at the dislocations; resulting in a decrease in the super saturation of solute and in the same time, resulting in lower maximum yield strength after completing the heat treatment. Weakness with rapid cooling is that the thermal stresses are induced in the casting. Water is the commonly used quenching media. Oil, salt baths and organic solutions can be used when a slower quench rate is required (Sjölander et al., 2010).

The most favorable characteristic of water as a quenching media is the exceptionally high quenching power due to its high specific heat of vaporization and high specific heat capacity. Other advantages of water, relative to production practices are (Luty, 1993):

- Non-flammability
- Low cost

- No hazards to health
- Easy scale removal
- No damages to the natural environment when drained to the wastes

In most practical cases, the water quenchants are used between 15 to 25 °C, although slightly lower or higher temperatures may occasionally appear to be favorable (Luty, 1993).

2.3.3 Artificial Ageing (AA)

Natural ageing occurs at room temperature while AA is at high temperatures. Ageing is done to obtain a uniform distribution of small precipitates, which contribute to high strength (Sjölander et al., 2010). According to ASM (1995) aging must be accomplished below the metastable solubility gap called Guinier-Preston (GP) zone solvus line. Li et al. (2004) reported the age hardening behavior of cast aluminum alloy A356. At higher aging temperature peak hardness was obtained at shorter aging times since the diffusion was faster at higher temperature (Li et al., 2004).

AA is typically done in the 150–210 °C range for Al-Si alloy. At these temperatures atoms can travel over larger distances and the precipitates formed during AA are normally much larger in size than Guinier-Preston (GP) zones (Sjölander et al., 2010). Al–Si–Mg alloys artificial aged at temperatures in the 170–210 °C range produce alloy with comparable level of strength (Rometsch et al., 2000). AA regimes at high temperatures for short periods are suggested to produce comparable mechanical properties obtained by AA regime at low temperature for long periods (Ber, 2000). Rometsch et al. (2000) also agreed that higher temperature can shorten the time required for AA

Sjölander et al. (2011) works with three different microstructure of Al-Si-Mg and he found that ageing at 170 °C produce comparable yield strength for the three coarsenesses of the microstructure as can be seen in Figure 2.3.

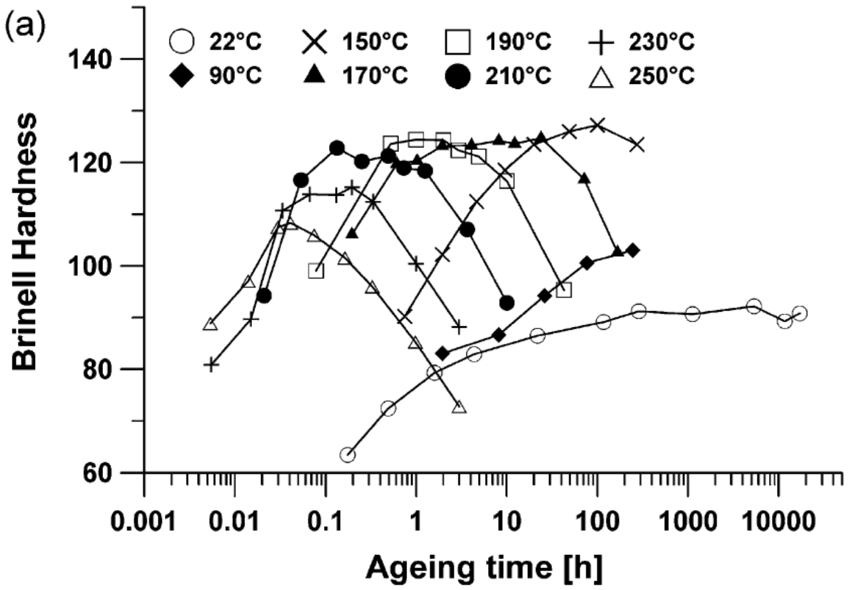


Figure 2.2: Hardness versus ageing time for different ageing temperature

Source: (Rometsch et al., 2000)

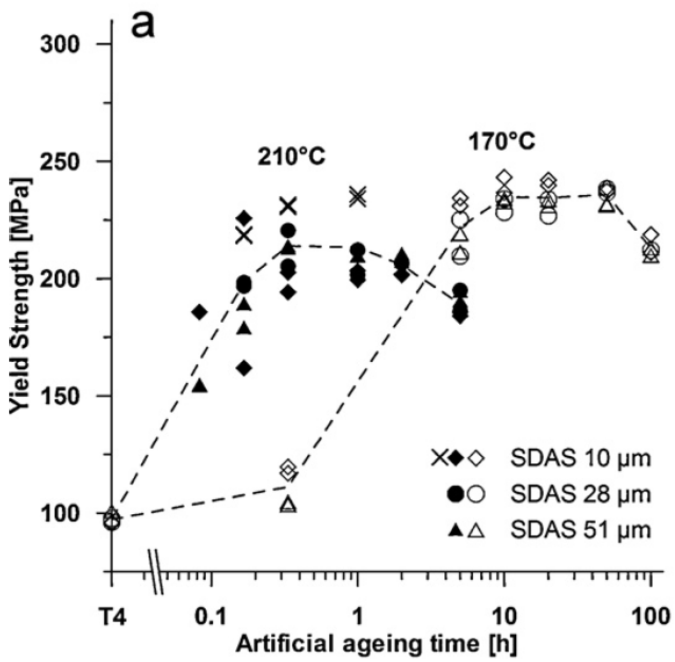


Figure 2.3: Artificial ageing time versus yield strength for different ageing time for different SDAS

Source: (Sjölander et al., 2011)

CHAPTER 3

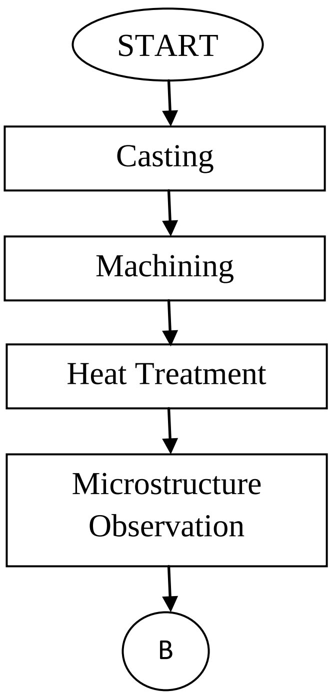
EXPERIMENTAL PROCEDURE

3.1 INTRODUCTION

In this chapter, the appropriate sequences of the works planned by the researcher in order to achieve the project objective and keeping it in the scope are presented. The experimental procedures, starting from the sample preparation until obtaining the data are described in details here on this chapter.

3.2 FLOW CHART

Figure 3.1 shows the experiment flow chart throughout this research paper starting from casting the A356 alloy until analyzed the data.



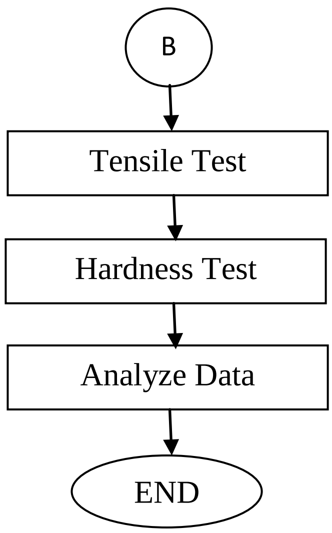


Figure 3.1: Experimental flow chart

3.3 MATERIALS

A356 alloy was used for this experiment. It is widely used in semi-solid processing because of its wider solidus - liquidus temperature range and good fluidity compared to other type of aluminum alloy. Table 3.1 shows the chemical composition of A356 alloy. The solidus and liquidus temperature of A356 alloy was determined from Al-Si phase diagram to be 615 °C and 574 °C respectively.

Table 3.1: Chemical composition of A356 alloy (%Wt)

Al	**Si**	**Mg**	**Cu**	**Fe**	**Mn**	**Ti**	**Zn**	**Other, each**	**Other, total**
Remain.	6.50 - 7.50	0.30 - 0.45	≤20	≤0.15	≤0.10	≤0.20	≤0.10	≤0.050	≤0.15

3.4 CASTING AND MACHINING PROCESS

A pre-existing pattern was used to create the cavity for the sand mold (Figure 3.2). OBB sand E was used for the mold. OBB sand E is oil-bonded sand which is ready to be used as received, and is specially engineered to be used for aluminum castings. Its high green strength enables accurate contours and custom castings.

Figure 3.3 shows the process of making the mold. Parting powder (white powder in Figure 3.3b) was used to ease the process of separating the cope and drag before removing the pattern, leaving a cavity with the shape of the pattern. Four (4) sets of mold were made for this experiment, which produces eight (8) cylindrical dog bone tensile test specimen in which two (2) of the specimen is made as spare should any unwanted event that requires the actual specimen to be replaced occur.

A356 ingots were melted in a diesel furnace (Figure 3.4) and the molten metal was poured (Figure 3.5) at a temperature of 620 °C. The cast was left to solidify for about 30 minutes before the mold was broken. A few millimeter of the casting sand around the cast product was burned and turned to dark black color (Figure 3.6).

Figure 3.2: Pattern

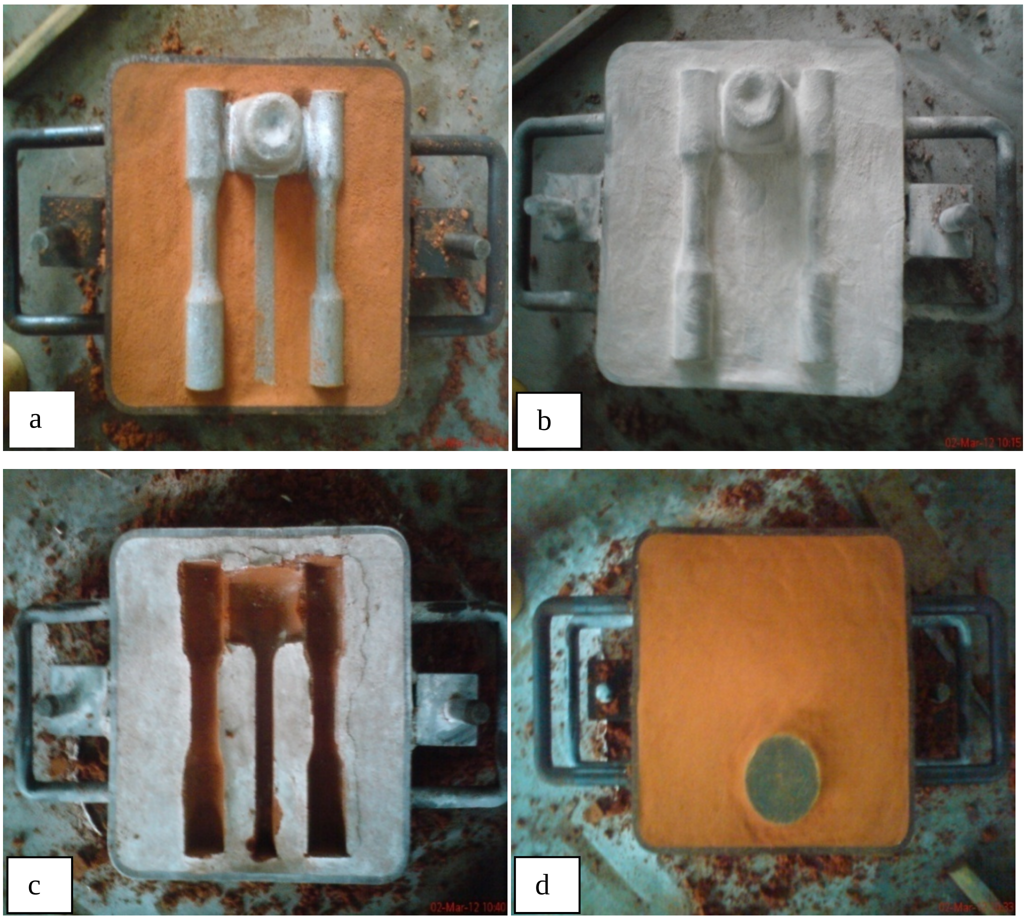


Figure 3.3: (a) drag, (b) drag with parting powder, (c) cope cavity, (d) completed mold

Figure 3.4: Melting of A356 ingots in a diesel fueled furnace

Figure 3.5: Pouring

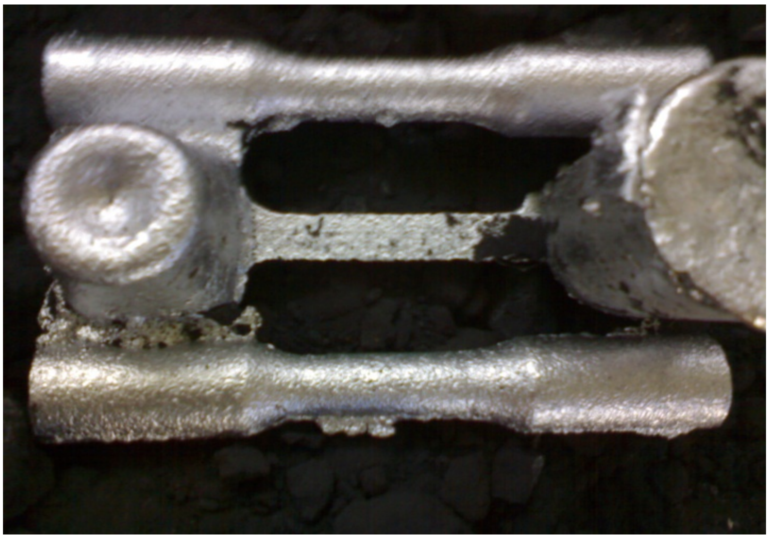


Figure 3.6: Cast product and the burned sand in the back ground

Figure 3.7 shows the cast product after all the gating system was removed. The final dimension of the tensile test specimen is shown in Figure 3.8. NEF 400 GILDERMEISTER CNC turning machine was used to machine the cast cylindrical dog bone for tensile test specimen to its final dimension (Figure 3.9). Figure 3.10 shows machined tensile specimen with the profile circled in red was manually removed.

Figure 3.7: Before machining with gating system removed

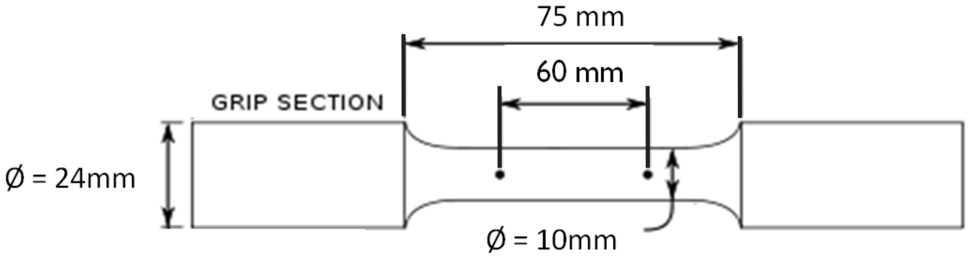


Figure 3.8: Dimension for tensile test specimen

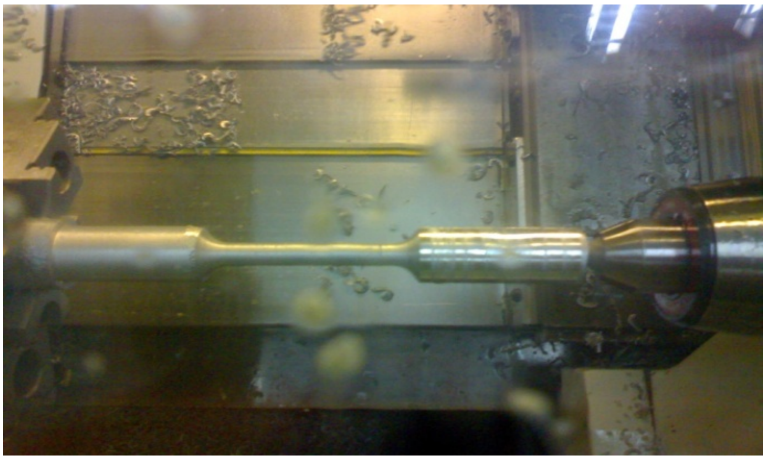


Figure 3.9: Machining

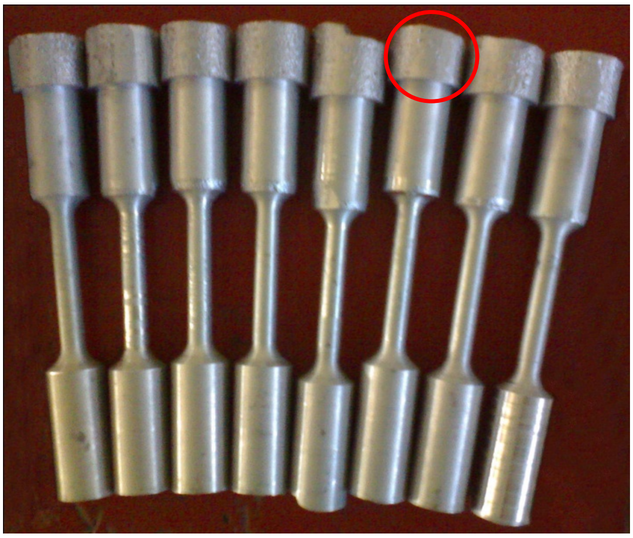


Figure 3.10: Machined tensile test specimen.

3.5 T6 HEAT TREATMENT

Table 3.2: T6 heat treatment parameter.

T6 heat treatment parameter			
ST Temperature	530 °C	540 °C	550 °C
ST Time	2	2	2
Quench	Water at room temperature		
AA Time	6 hours	6 hours	6 hours
AA Temperature	170 °C	170 °C	170 °C
No. of specimen	2	2	2

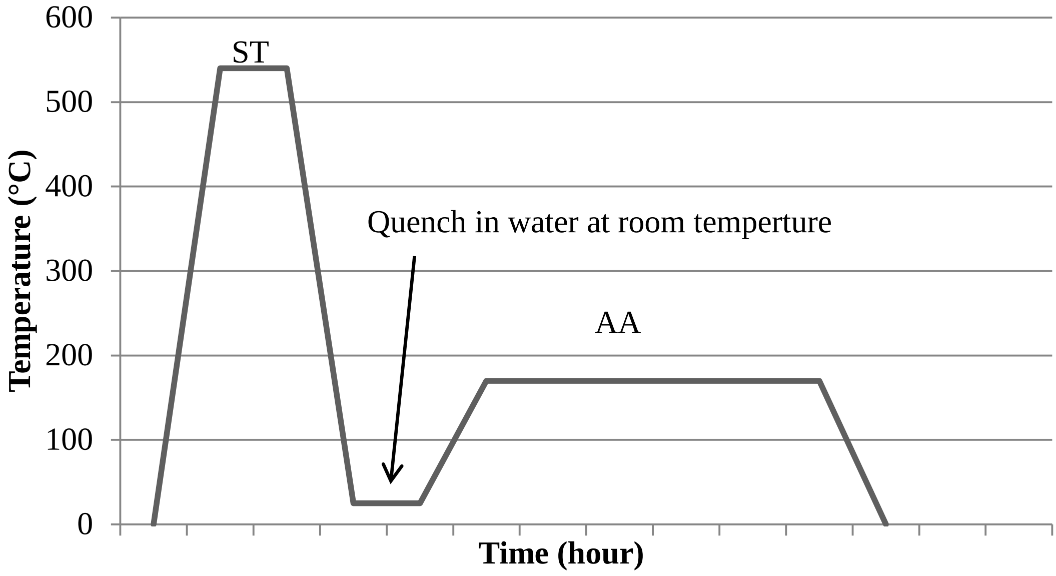


Figure 3.11: Solution treatment time line used in this study

The ST was done for two (2) hours at three (3) different temperatures as listed on the above Table 3.2 and shown in Figure 3.11. Notice that the only manipulated parameter made by the researcher in this study was the ST temperature while the other parameters were kept constant. Two (2) tensile specimens for each temperature variation was solution treated in an induction furnace (Figure 3.12). All the specimens were rapidly quenched in water at room temperature after completing the ST. After quenching, a sample for microstructure observation and hardness test was taken from tensile test specimen of each temperature variation before proceeds with AA. The specimens, after undergo ST and quenching, was left to age naturally for one night before proceed with AA on the following day. Again, a sample for microstructure observation and hardness test was taken from tensile test specimen of each temperature variation after completing T6 heat treatment.

Figure 3.12: Induction Furnace

3.6 MICROSTRUCTURE OBSERVATION

Seven (7) specimens for microstructure observation were made which consist of AC (1 sample), ST condition (3 samples), complete T6 heat treatment condition (3 samples).

3.6.1 Specimen Preparation

The samples acquired from each temperature variation and condition was further cut into smaller pieces using sectioning cut-off machine (Figure 3.13) so that the samples would fit into a cold mounting mold to be mount. Cold-curing resin mixture was made by mixing the ingredients with ratio of 2:1, two (2) parts of powder transparent to one (1) part of liquid (Figure 3.14).

Figure 3.13: Sectioning Cut-Off Machine

Figure 3.14: Ingredient for cold-curing resin. (a) Powder transparent, (b) Liquid

The mounted samples were then gone through a series of grinding and polishing to get a smooth and mirror like surface. Buehler HandiMet 2, Roll grinder (Figure 3.15) was used to grind the sample surface. The four-stage grinding station used are four rolls of CarbiMet Paper Rolls with grit size of 240, 320, 400 and 600 (P280, P400, P600, P1200) The samples were grinded throughout the station starting from small grit size number to large grit size number by alternating the grinding direction either forward or side way. Only one direction is used for particular grit number, and changed when moving to larger grit number.

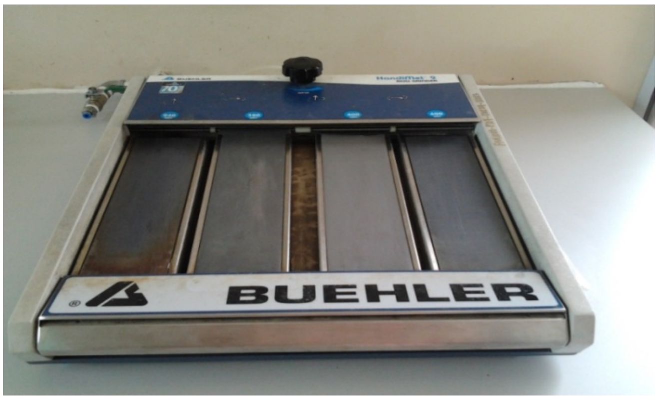


Figure 3.15: Buehler HandiMet 2, Roll Grinder

In order to get the smooth, mirror-like with almost scratch free surface, so that a clear microstructure can be observed, polishing process were conducted after finishing the grinding process. Metkon FORCIPOL 2V Grinder-polishing (Figgure 3.16) was used for polishing process. Forcipol 2V have two discs and variable speed range between 50 and 600 rpm. Under this speed, the three stages of polishing process were conducted using three different discs. Starting with disc marked 6µm, followed by, 1µm and finished by disc marked 0.05 µm. The number, 6 µm, 1 µm, and 0.05 µm indicate the suspended-diamond solution type that is used for the particular disc.

Figure 3.16: Metkon FORCIPOL 2V Grinder-Polisher

The polished samples were then etched using nital solution to bring out their grain boundary. The composition of the nital solution is listed on Table 3.3.

Table 3.3: Etchant for aluminum

Chemical Reagent	**Amount (ml)**
Distilled water	95
Hydrochloric acid	1.5
Hydrofluoric acid	1.5
Nitric acid	2.5

3.6.2 Microstructure Analysis

The specimen was then observed for its microstructure using optical microscope under magnification of 5× and 50×. Three (3) different field-of-views was observed and captured under the 5× magnifications. For magnification of 50×, five field-of-views from the third 5× field-of-view was observed and captured.

A free image analyzing software called ImageJ version 1.46 was used to analyze the size of Si particle and distribution statistic for every field-of-view with magnification of 50×. The setting used for measurement is shown in Figure 3.17.

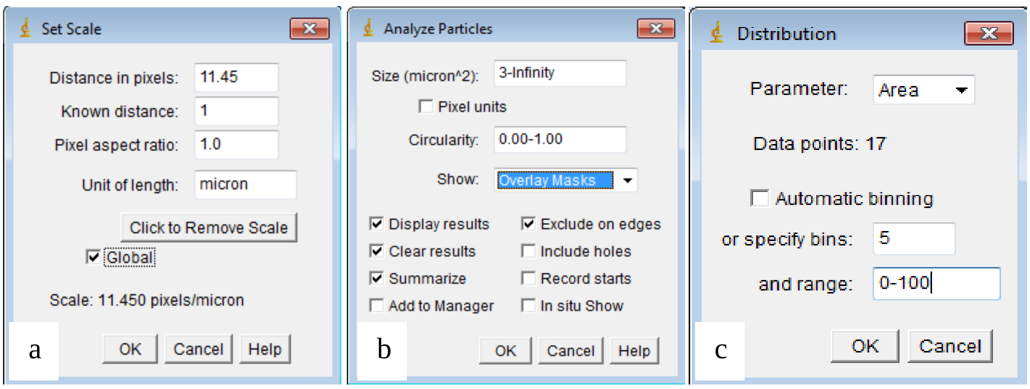


Figure 3.17: Settings used in ImageJ. (a) Scale, (b) Analyze particle, (c) Area distribution statistic.

3.7 MICRO HARDNESS TEST

Vickers hardness test was used for hardness testing in this study. ASTM E384 was used as the standard for this test (see Table 3.4). The same specimen used for microstructure observation was also used for this test.

Table 3.4: ASTM E384 standards for Vickers Hardness testing

Standard	**Distance between indentation**	**Distance from the center of the indentation to the edge of specimen**
ASTM E384	2.5d	2.5 d

** d is the diagonal distance of the indenter.

3.8 TENSILE TEST

For this test, only specimen which completed the T6 heat treatment is tested. Shimadzu Universal Testing Machine (UTM) with capacity 100 kN was used to test the tensile properties of the specimen. The main objectives for tensile test are to determine the ultimate tensile strength (UTS), yield strength (0.2%YS), and % elongation of the specimens when subjected to axial tensile load. The stiffness of a material which represented by tensile modulus was determined from stress strain diagram. All data from the material was recorded by a software call Trapezium, which run the machine and generated the chart and results for tensile test.

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

Throughout this chapter, clear presentation of full analysis of experimental data acquired are provided and discussed in details. Analysis focused on the relation between the size, shape, and distribution of Si particle produced by the different ST temperature on the mechanical properties of A356 alloy.

4.2 MICROSTRUCTURE OBSERVATION

The α-Al shape does not differ much between the three ST temperatures even after completing the T6 heat treatment, which all exhibiting equiaxed shape (Figure 4.2 and Figure 4.3). The major different observed is with the number of eutectic Si particle and its size produced by the different ST temperature which became the interest of the present study (Figure 4.4 and Figure 4.5).

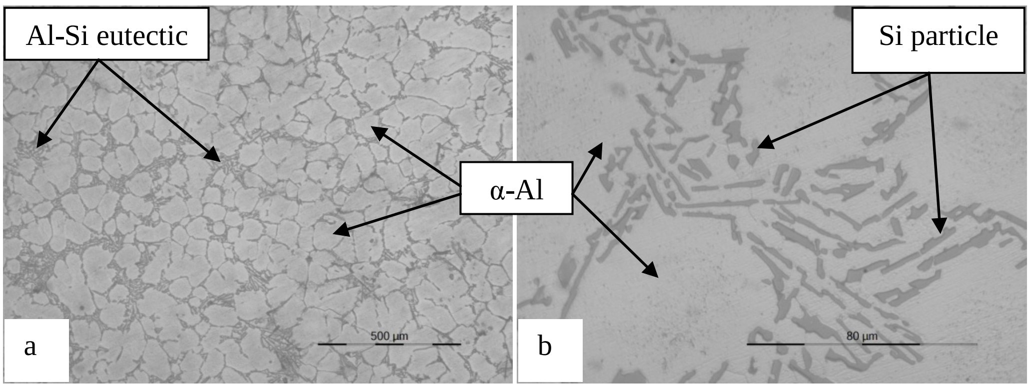


Figure 4.1: AC microstructure. (a) Magnification 5× and (b) Magnification 50×

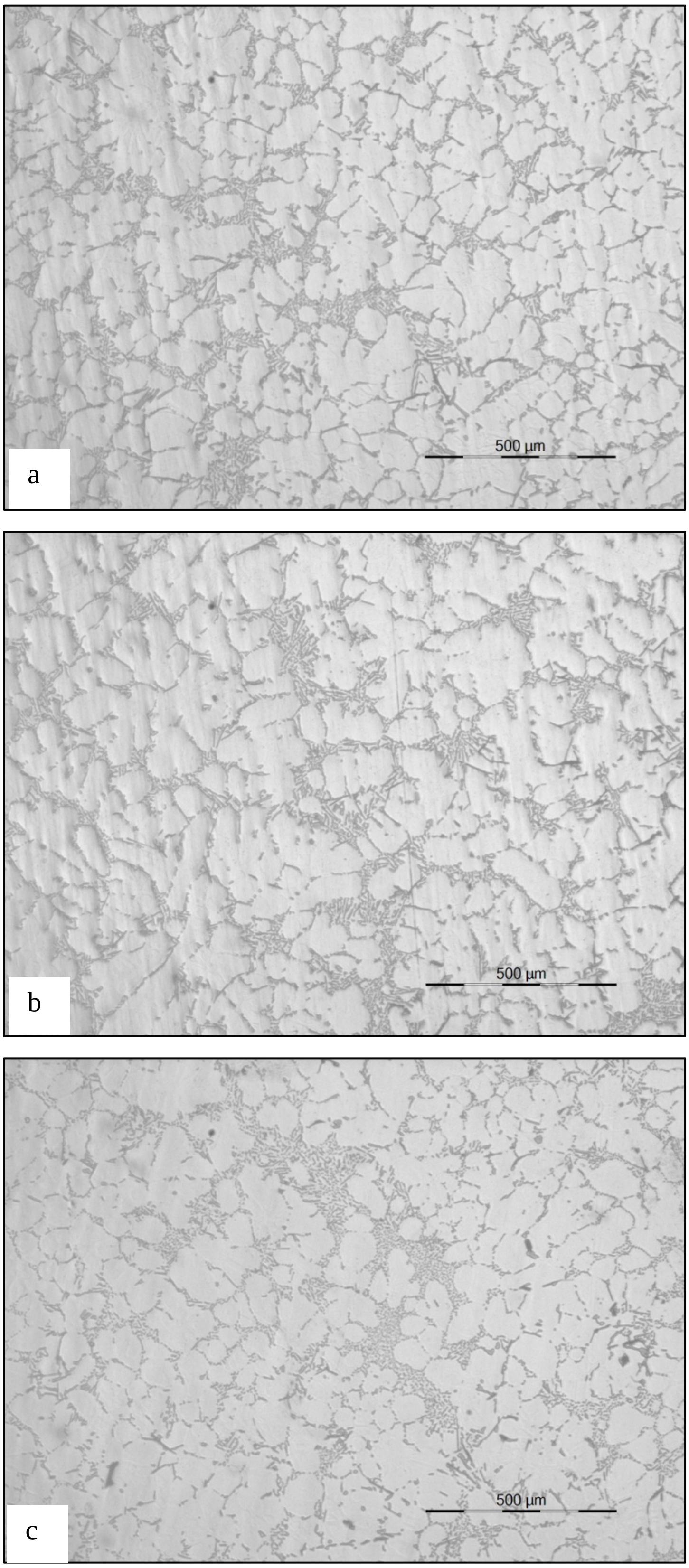


Figure 4.2: 530 ST, b) 540 ST, c) 550 ST with magnification 5×

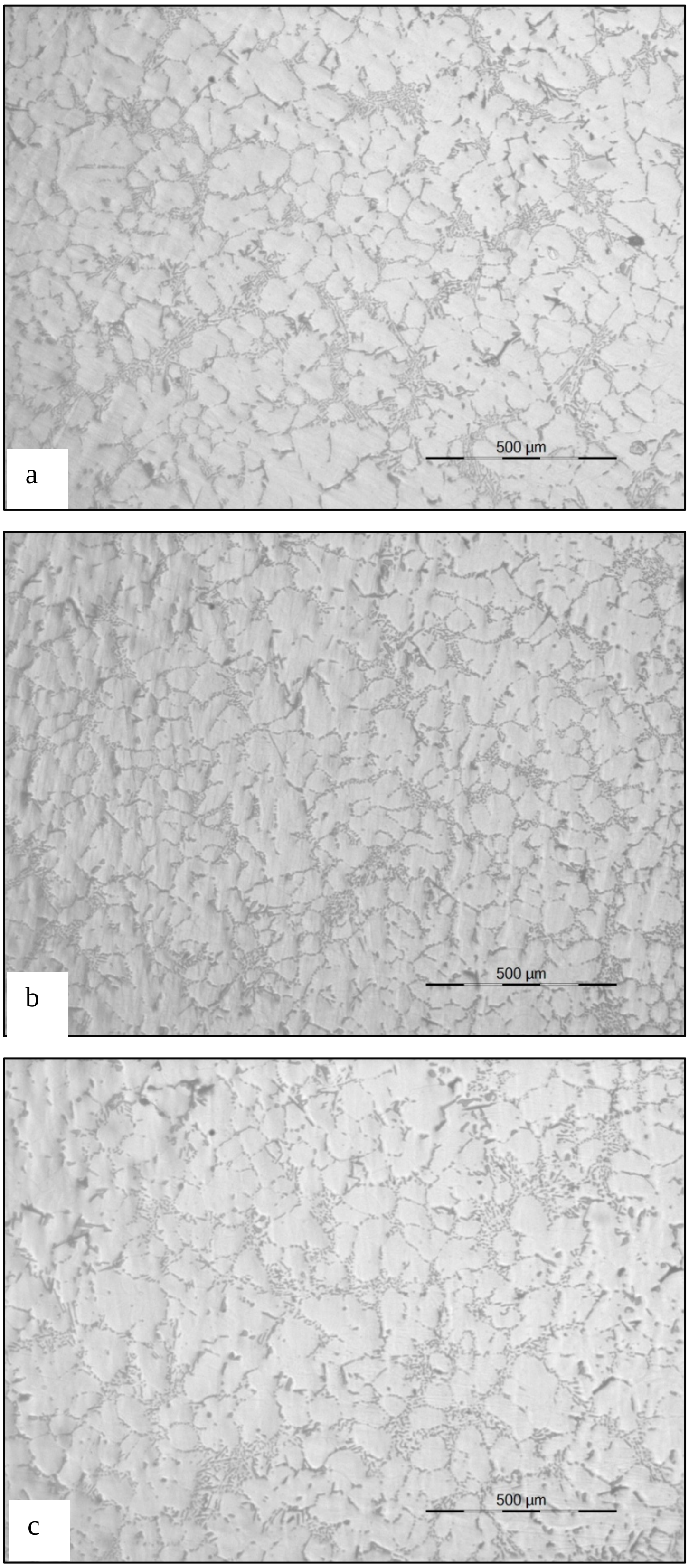


Figure 4.3: a) 530 T6, b) 540 T6, c) 550 T6 with magnification 5×

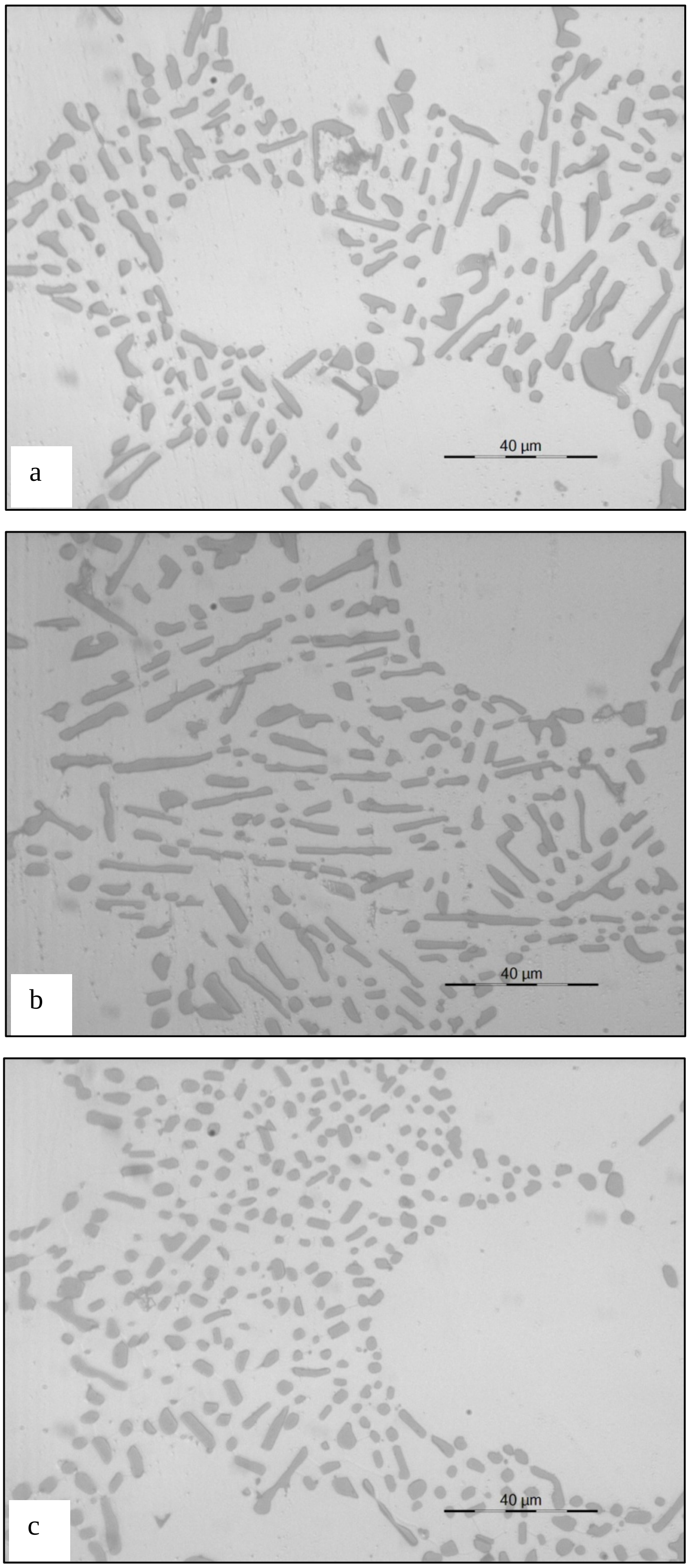


Figure 4.4: a) 530 ST, b) 540 ST, c) 550 ST with magnification 50×

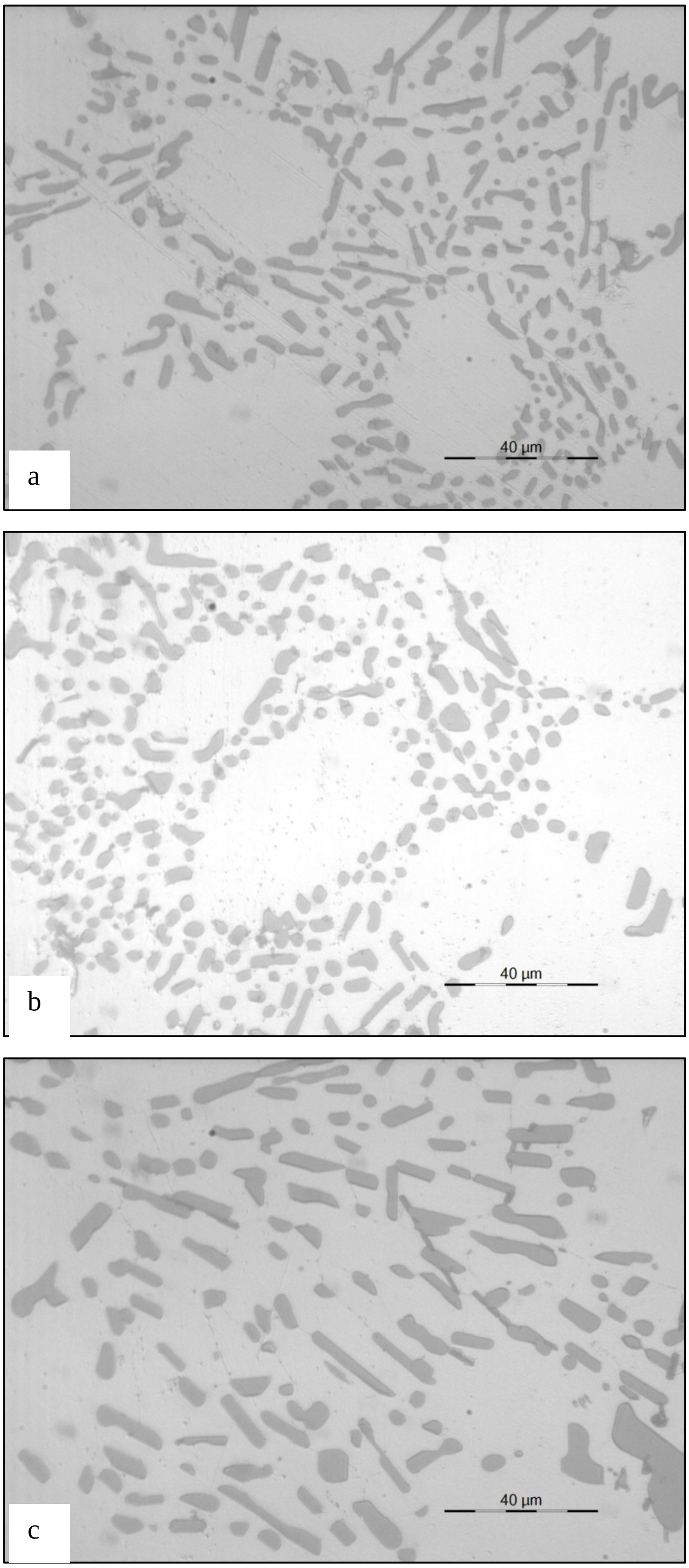


Figure 4.5: a) 530 T6, b) 540 T6, c) 550 T6 with magnification 50×

Table 4.1: Si particle statistic

Specimen	No. of Eutectic Si Particle						Average Si Size
	0 ≤ A <20 μm²	**20 ≤ A < 40 μm²**	**40 ≤ A< 60 μm²**	**60 ≤ A < 80 μm²**	**80 ≤ A < 100 μm²**	**Total 0 ≤ A ≤ 100**	
AC 4	66	36	18	14	8	142	74.186
530 ST	277	67	32	19	15	410	28.632
540 ST	342	106	54	34	10	546	25.488
550 ST	515	123	40	17	14	709	20.528
530 T6	356	90	42	13	10	511	23.594
540 T6	629	131	46	24	9	839	18.654
550 T6	187	72	35	29	19	342	38.674

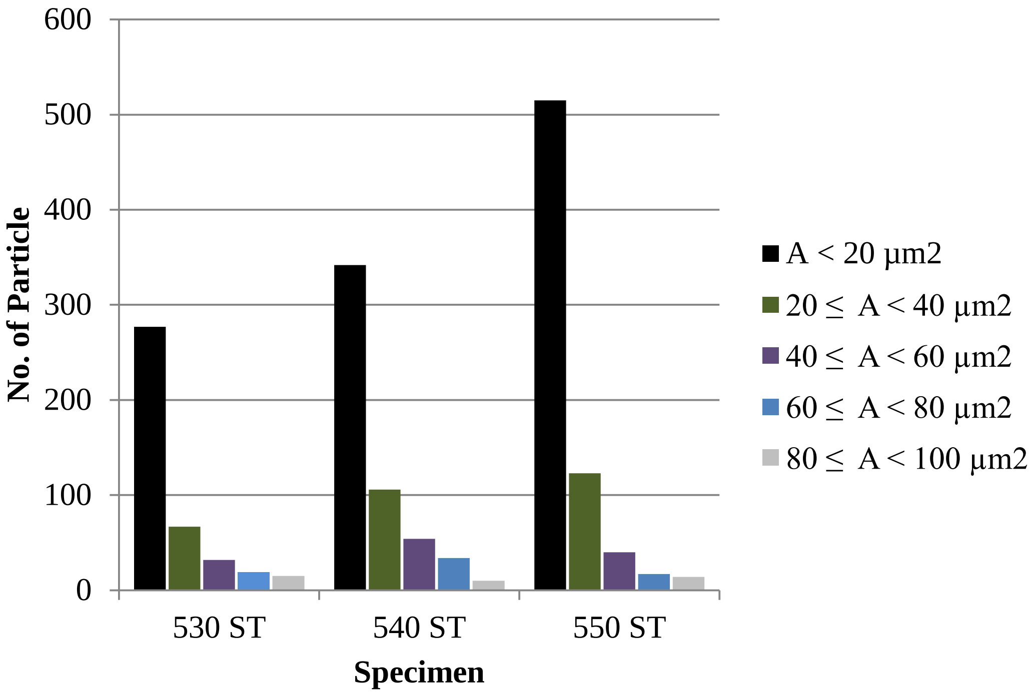


Figure 4.6: Si particle distribution (ST condition)

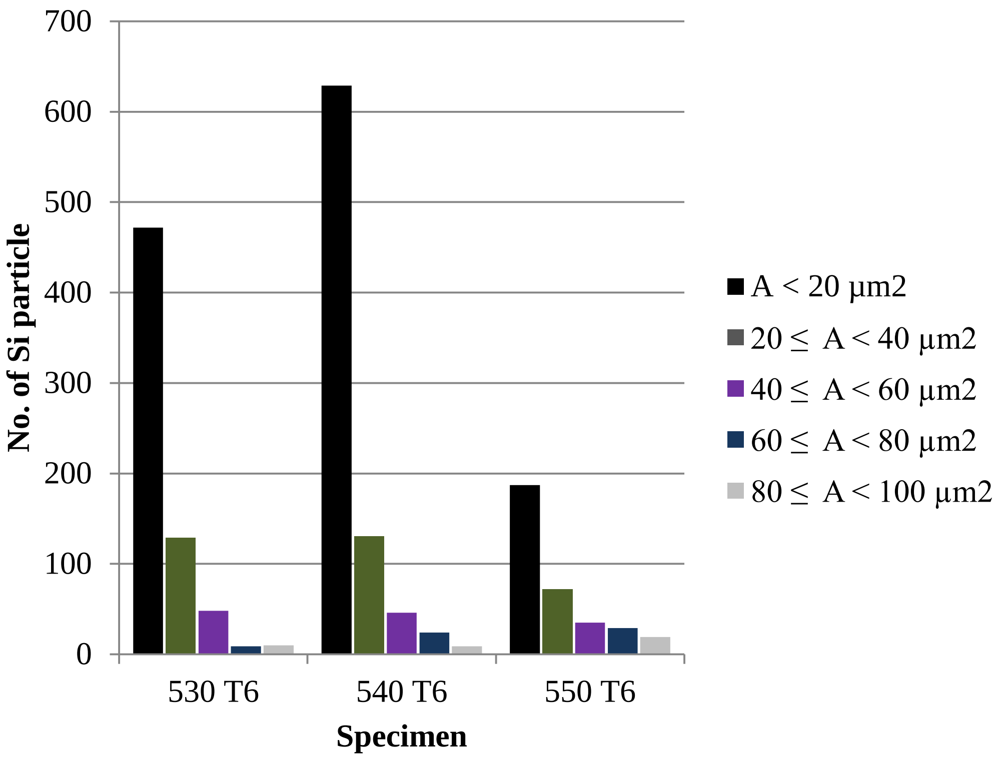


Figure 4.7: Si particle distribution (T6 condition)

Table 4.1 shows the statistic of Si particle for different condition. Si particle with size ranging from 0 μm² to 100 μm² are further divided into five (5) equal smaller size ranges. The data is further simplified in Figure 4.6 and Figure 4.7. Figure 4.6 shows distributions of Si particle for ST condition while Figure 4.7 shows the distribution for complete T6 condition.

Number of Si particle with area range of $0 \leq A < 20$ μm² increased as ST temperature increased. This particular range ($0 \leq A < 20$ μm²) is chosen to be the interest of this study due to its relatively high number of Si particle exist in the range compared to others and due to its strong relation with micro hardness, which will be discussed in the later part of this paper. As stated in Section 2.3.2 of this paper, high ST temperature provide higher diffusion rate, causing the eutectic Si particle to be dissolved and diffuse into the α-Al matrix at higher rate compared to lower ST temperature. These are the reasons for high existence of Si particle in the $0 \leq A < 20$ μm² size range for ST temperature of 550 °C. Si particle dissolved in a much lower rate for lower ST temperature, resulting in less number in the discussed range.

After completing T6 heat treatment, eutectic Si particle in the $0 \leq A < 20$ μm² size range is still dominating the statistic compared to the other size range. The number of Si particle in the $0 \leq A < 20$ μm² range increased as ST temperature prior to completion of T6 treatment is increased and it is expected to be higher for 550 T6 condition but that is not the case (Figure 4.7). There is major different in Si particle number in the size range of interest for 550 °C solution treated specimen after AA compared to the other two specimen. There is not much of a different in eutectic Si particle number before and after completing T6 treatment for the other four ranges.

The purpose of AA is to obtain a uniform distribution of small precipitates, which gives a high strength. ST at 550 °C produce eutectic Si particle with an average size of 20.528 μm² which is smaller than the size produced by ST at 530 °C and 540 °C. Smaller eutectic Si particle indicate the hardening agents are better dissolved and made available for precipitation hardening. For different Si particle size went through the same AA regime, specimen with smaller eutectic Si particle size experiencing the same effect as if it went through longer AA regime at low temperature or, experiencing the same effect as if it went through a short AA regime at higher temperature. Due to its smaller eutectic Si particle size, the 550 °C solution treated sample experiencing over aged AA regime. Over aged AA regime caused the eutectic Si particle to combine together and coarsen (increase in size as evident in Table 4.1 and Figure 4.5c) and become weaker than in the peak aged condition (Kuntongkum et al., 2008). Kuntongkum et al. (2008) finds that number of eutectic Si particle decrease as ST temperature prior to AA increased more than 540 °C (effect of over ageing). The same findings are obtained in the present study (Table 4.1). Over ageing also increase the dispersion of eutectic Si particle (Figure 4.5c).

4.3 MICRO HARDNESS TEST

Table 4.2: Micro hardness test result

Condition	Micro Hardness (HV)					Average
	1	2	3	4	5	
AC 4	52.9	61.1	62.5	62.8	56.2	59.1
530 ST	79.1	78.3	81.8	86.5	90	83.14
540 ST	83.2	78.1	79.1	76.2	89.5	81.22
550 ST	87.8	88.1	91.2	74.3	94.1	87.1
530 T6	1318	131.4	131.4	141.4	137.1	134.62
540 T6	133.6	119.7	127.9	134.6	146.7	132.5
550 T6	112.2	107.5	97.4	105.8	106.4	105.86

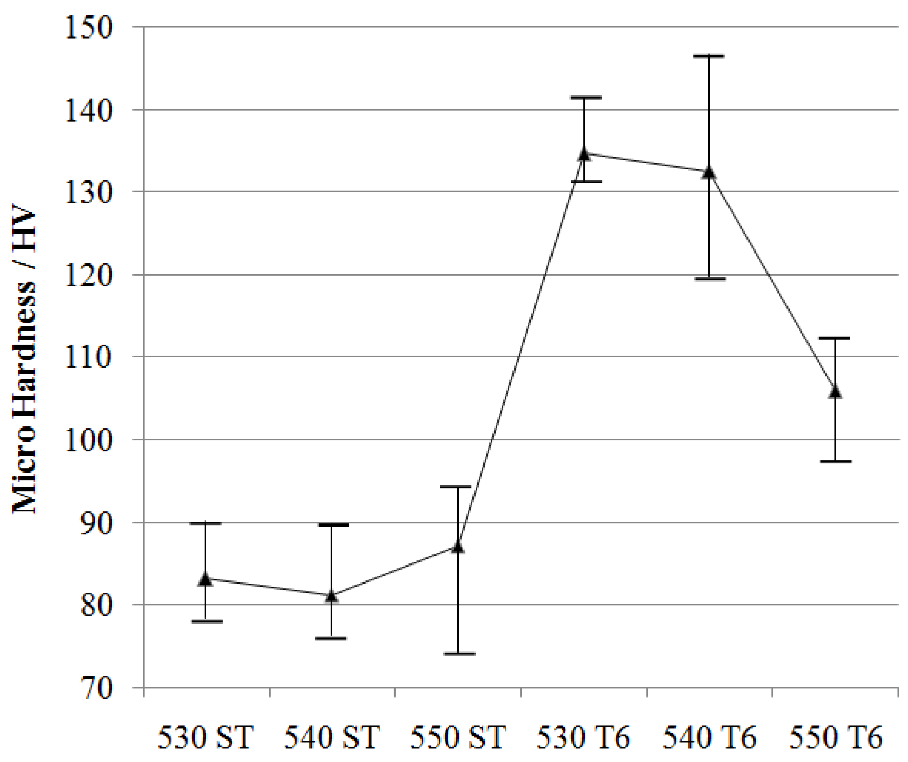


Figure 4.8: ST temperature versus micro hardness

The average hardness of 530 °C and 540 °C solution treated specimen are almost the same for solution treated condition as shown in Table 4.2. ST at 550 °C gives highest hardness value of 87.1 HV for solution treated condition. The size and shape of Si particle plays important role in affecting the hardness of the alloy. Figure 4.4 shows that the shape of Si particle for 530 °C and 540 °C solution treated specimen are almost the same, these explain the small difference in their hardness. Although their shape does not differ much, Si particle shape for 530 °C sample is slightly rounded and short and dispersed wider compared to that of 540 °C sample (Figure 4.4 a and b), result in slightly higher hardness.

The more globular shape and small sized Si particle in the 550 °C sample contribute to its high hardness in ST condition (Figure 4.4c). The force exerted by the indenter is distributed evenly between the many and small Si particles in 550 °C ST sample, which increase the difficulty for the indenter to penetrate deeper into the alloy, result in small indentation, thus giving high value of hardness.

After completing the T6 heat treatment, again, it can be seen that the difference in hardness between samples solution treated at 530 °C and 540 °C is small. Although the size of Si particle does not differ much between the two samples, their shape do differs with 540 °C sample having more globular Si particle shape (Figure 4.5 a and b).

After completing the T6 heat treatment, sample that solution treated at 550 °C result in lowest hardness. The shape and size of 550 °C sample coarsen after completing the treatment and the Si particle are widely dispersed between each other (Figure 4.5 c). In this kind of microstructure, the indenter surface tends to land on the soft Al phase, which results in low hardness. Due to the wide dispersion of the Si particle, the area of Si particle available to distribute the forces exerted by the indenter become less and more force land on the soft Al phase, resulting in lower hardness. As mentioned in the previous subsections, unsuitable AA regime for the prior ST could be the reason for result acquired. 550 °C solution treated specimen experiencing over aging, making the Si particle to combine and coarsen, thus, lowering its hardness.

4.4 TENSILE TEST

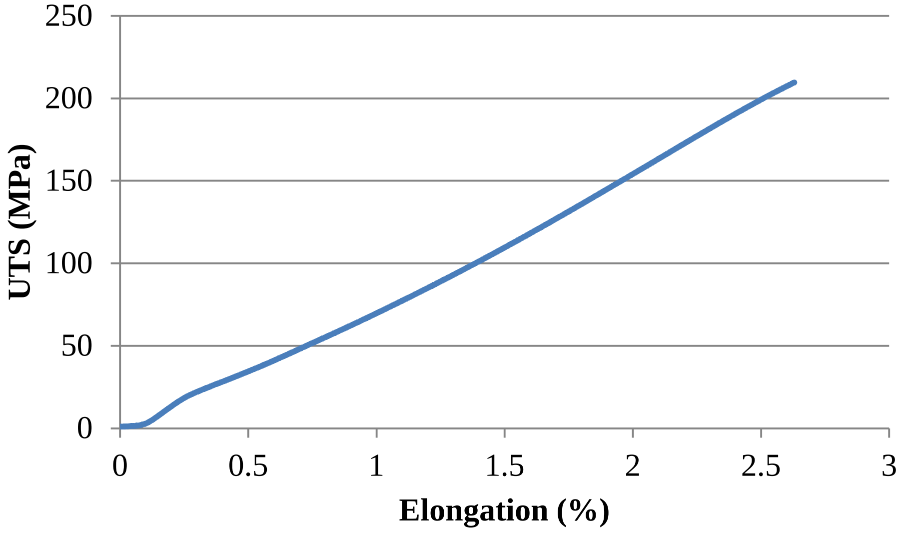


Figure 4.9: UTS versus Elongation for 530 T6 sample 1

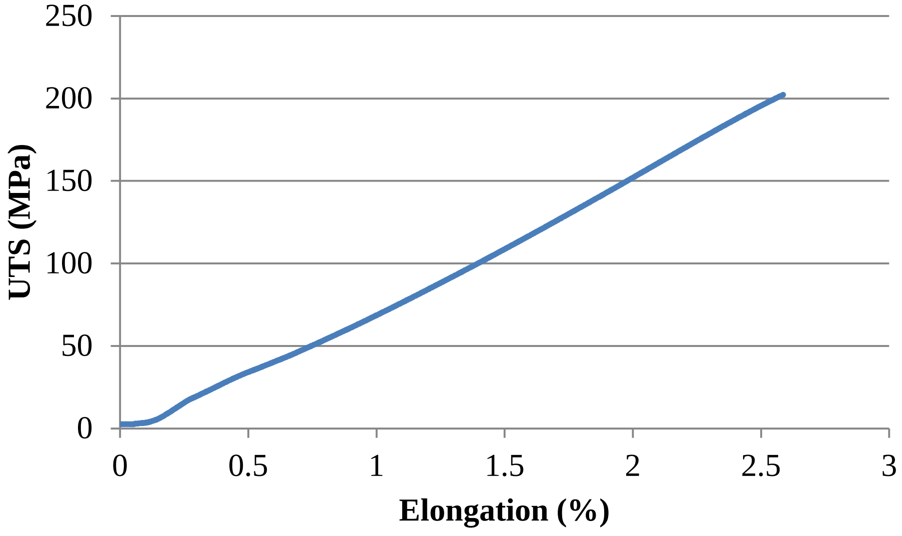


Figure 4.10: UTS versus Elongation for 530 T6 sample 2

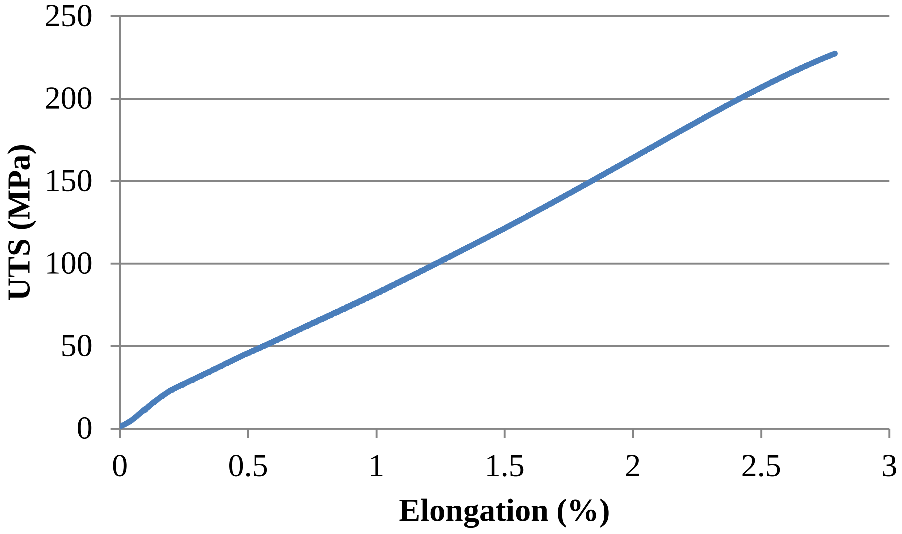


Figure 4.11: UTS versus Elongation for 540 T6 sample 1

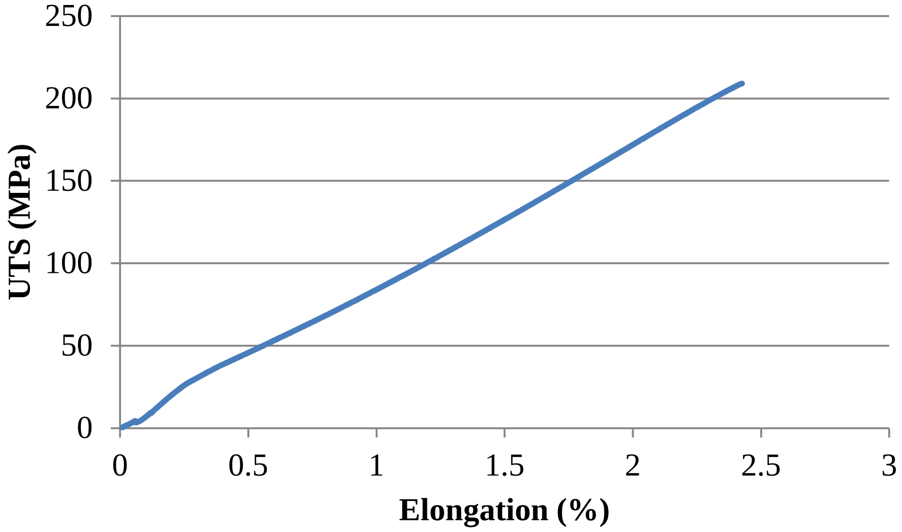


Figure 4.12: UTS versus Elongation for 540 T6 sample 2

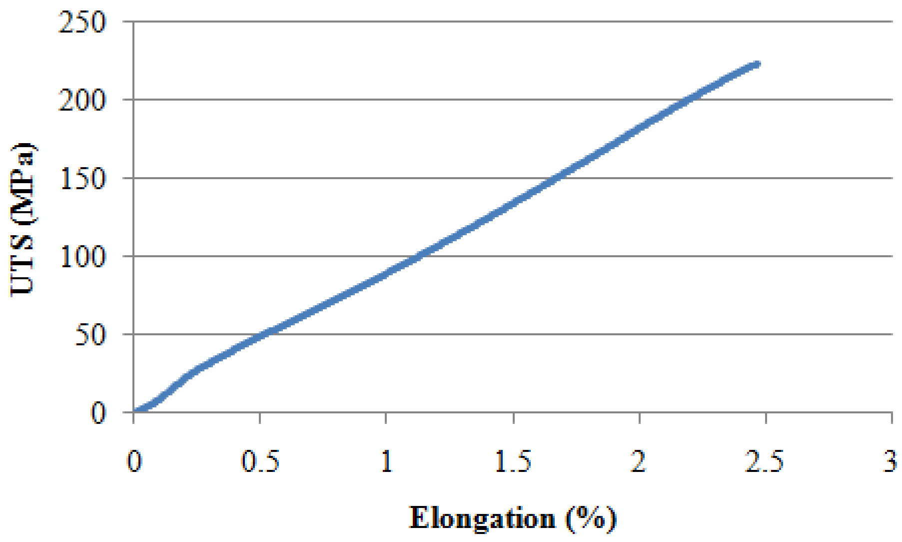


Figure 4.13: UTS versus Elongation for 550 T6 sample 1

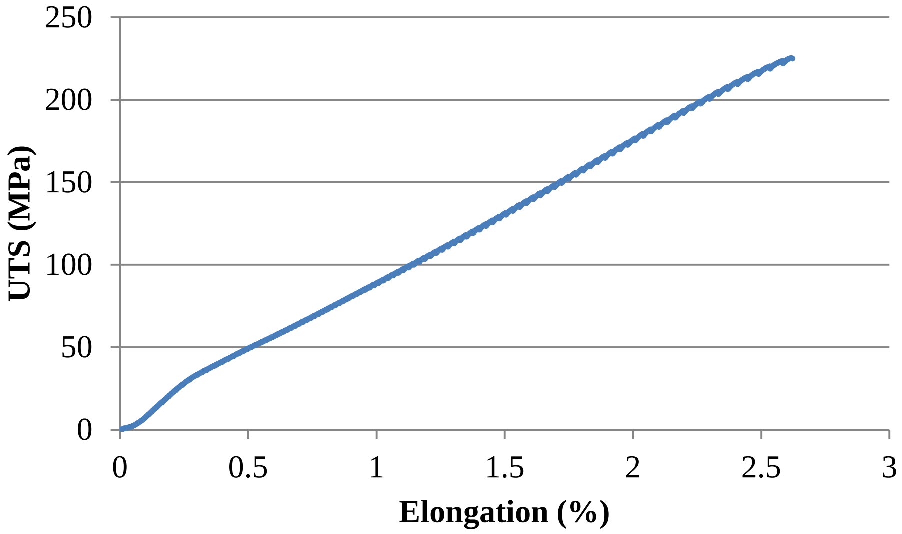


Figure 4.14: UTS versus Elongation for 550 T6 sample 2

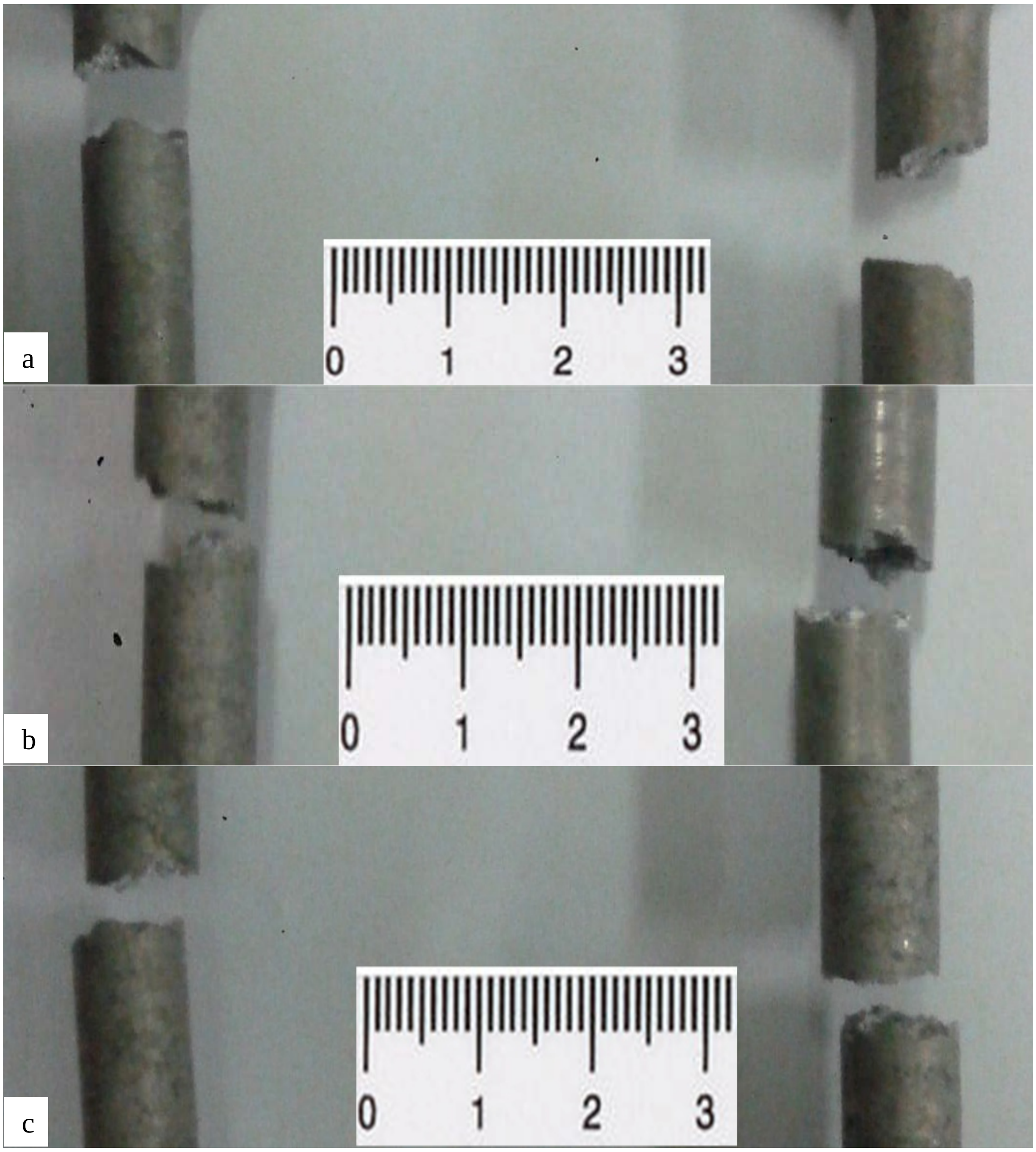


Figure 4.15: Fracture profile for (a) 530 T6 (b) 540 T6 (c) 550 T6 samples

Table 4.3: Tensile test result

Name	Specimen1	Specimen 2	Average
	UTS (MPa)		
530	213.47	206.296	209.883
540	230.819	209.074	219.947
550	223.423	225.213	224.318
	YS (MPa)		
530	81.231	145.885	113.558
540	206.766	184.562	195.664
550	129.101	207.800	168.451
	Elongation (%)		
530	3.11429	3.04829	3.08129
540	3.35579	2.42594	2.89087
550	2.47029	2.61763	2.54396

Table 4.3 shows the tensile test findings of A356 Aluminum alloy which went through complete T6 heat treatment under three different ST temperature. The Ultimate Tensile Strength (UTS) of A356 alloy increased with increase in ST temperature prior to AA (Figure 4.16). The elongation of this alloy on the other hand, decreases as ST temperature increase. The yield strength (YS) of A356 aluminum alloy increases with increase in ST temperature from 530 T6 until 540 T6 and the value is expected to be higher for 550 T6 but that was not the case as can be seen in Figure 4.16.

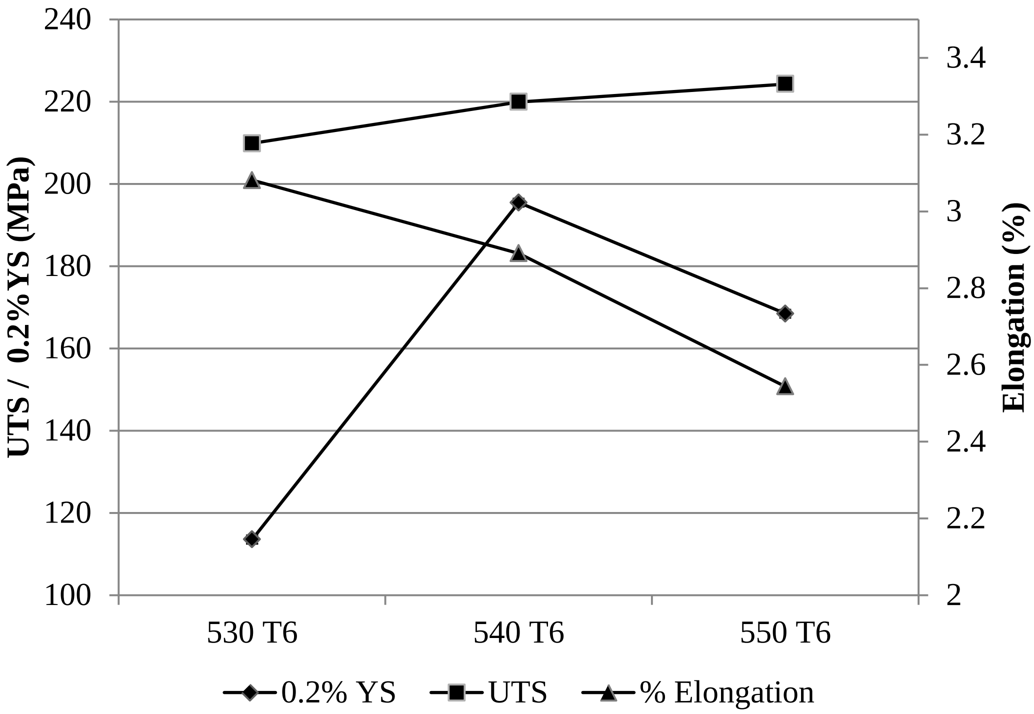


Figure 4.16: Yield Strength (0.2% YS), Ultimate Tensile Strength (UTS) and Elongation for 530 T6, 540 T6 and 550 T6

The trend of increase in UTS and decrease in elongation observed in this study is in good agreement with other researcher (Caceres et al., 1999, Sjölander et al., 2011). Sjölander et al. (2011) and Ran et al. (2008) were both agreed that coarse microstructure (having large and elongated Si particle) is the reason for low elongation to fracture and this is in good agreement with the findings of this study (Table 4.1, Figure 4.5c, and Figure 4.16). This could also be one of the reasons for the low YS acquired by the 550 T6 sample as can be seen in Figure 4.16.

Quenching rate also affect the yield strength of A356 alloy as discussed in section 2.3.2 of Chapter 2. Specimen solution treated at 530 °C and 550 °C were experiencing low and high quench rate respectively. This explains for the low yield strength acquired by the sample solution treated at 530 °C and 550 °C.

The observed behavior highly depends on the size (area) of eutectic Si particle, the presence or formation of β' (rods/elongated) eutectic Si particle, which decrease ductility as stated by Kuntongkum et al. (2008) and the dispersion of Si particle. Larger Si particle size increases the tendency of crack formation (Goulart et al., 2006).

The elongation to fracture depends strongly on the ability of Si particles in the Al-Si eutectic to stop the motion of dislocations (Caceres et al., 1999). ST makes the Si particles distributed more homogeneously in a fine microstructure and the dislocations interact with the Si particles individually. Consequently the dislocations pass the Si particles and accumulated at the grain boundaries where the fracture takes place, resulting in a high elongation to fracture (Caceres et al., 1999). According to Caceres et al. (1999), the low elongation to fracture is caused by the coarse Si particles which become an obstacle for the dislocations causing it to pile up at the Al–Si eutectic (where fracture could occur).

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 CONCLUSION

1. Si particle size, shape, and dispersion affect the mechanical properties of cast A356 alloy. Higher ST temperature produce smaller and more globular Si particle before completing T6 heat treatment.

2. Highest hardness before artificial ageing was achieved by ST the A356 alloy at 550 °C due to the small Si particle produced (average size of 20.528 μm^2).

3. After completing T6 heat treatment, highest hardness was achieved by solution treatment at 530 °C with average Si particle size of 23.594 μm^2 was produced.

4. Lowest hardness after artificial aging is the result of ST at 550 °C (105.86 HV) due to its large (38.674 μm^2) and highly dispersed Si particle.

5. After completing T6 heat treatment, A356 alloy which were solution treated at 540 °C have higher tensile strength due to its globular Si particle shape and small Si particle (average size of 18.652 μm^2).

6. Elongation decreases while UTS increases as ST temperature increased from 530 °C to 550 °C.

7. A356 sand cast aluminum alloy having equiaxed α-Al structure solution treated at 530 °C have comparable hardness with sample solution treated at 540 °C before and after completing T6 heat treatment with lower energy usage as added benefit.

5.2 RECOMMENDATION

1. Theoretically, the α-Al grain would be finer if the time required to bring the molten alloy to the desired pouring temperature is shorten (increase cooling rate). The α-Al grain grows as the molten alloy cools down (Mao et al., 2001), and more than 10 minute is required for the molten metal to cools down to the desired pouring temperature in this experiment and this give enough time for the grain to grow. The same argument also applies after the alloy is poured; the cast need to be cooled to room temperature as soon as possible as it solidifies to stop/minimize grain growth. Too high cooling rate induce thermal stress but that will be relief during solution treatment.

2. For this experiment, no degassing agent was added to the alloy during melting process. Degassing agent reduce porosity, which presence reduce mechanical properties of the alloy especially its tensile strength by reducing the area available to withstand the force applied onto it.

3. Unmodified melt was used for this experiment, meaning no grain refiner or modifier was added. Grain refiner, as its name implies, help in refining the α-Al grain. Small and globular grain structure is desired in most casting because ST temperature and time could then be reduced as it depends on the morphology of the grain. If the effect of the grain refiner is coupled with LPT cast method, a fine grain should be produce. Modifier modifies the plate like Si particle into fine particles (Mallapur et al., 2012)

4. In this study, the solution treatment was done for 2 hours at three different temperatures which produce different Si particle shape and size. Specimen which was solution treated at 550 °C produce small and globular Si particle (20.528 μm^2) and give highest hardness (87.01 HV). Unfortunately, after completing T6 heat treatment, this particular sample produce the largest (38.674), widely dispersed, and long-rod-like Si

particle and having the lowest hardness compared to the other specimen. The AA regime used in this study was the same (6 hour at 170 °C) for the different ST temperatures prior to AA. The hardness of 550 ST specimens after completing the T6 heat treatment seems promising if the AA regime was tailored to suit. Therefore, the relation between Si particle size produced after ST (especially for 550 ST) and temperature and time required for AA need to be studied to optimize the T6 heat treatment for A356 sand cast aluminum alloy having equiaxed α-Al structure.

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APPENDIX A

GATING SYSTEM CALCULATION

The first step to design a gating system is to identify the required choke area, only then the runner and gates can be determined. The choke area is determined by using Bernoulli's equation as shown below (Rao, 1998). The formula used in designing the runner system is:

$$A = \frac{W}{d\,t\,C\sqrt{2\,g\,H}}$$

Where

A = choke area, mm^2

W = Casting mass, kg

t = Pouring time, s

d = mass density of the molten metal, $kg.\,mm^3$

Risering and Design Calculation

In sand casting process, a good riser design will ensure sufficient feeding of molten metal. The design of riser can be calculated by using Caive's Method which is proposed by Chcorinov (Rao 1996). Chroninov had proposed that the solidification process is directly proportional to the square of ratio volume to the surface area of casting.

$$T_s = K\left(\frac{V}{SA}\right)^2$$

Where

T_s = solidification time in unit seconds

V = volume of casting

SA = surface area

K = mould constant

Calculation of the volume for the casting product (cylindrical dog bone):

V= (16cm x 2cm x 0.2cm) – 2 x [(5cm + 6cm) /2 x 0.5cm x 0.2 cm]

=6.4 cm^3 – 1.1 cm^3

=5.3 cm^3

Calculation for the total surface area for the casting:

SA= 2 x (2 cm x 16 cm) + 2 x (2 cm x 0.2 cm) + 6 x (5 cm x 0.2 cm) + 4 x (0.2 cm x 0.5 cm) – 2 x [(5 cm +6 cm)/2 x 5 cm]

= (6.4 + 0.8 + 6.0 + 0.4 – 5.5) cm^2

= 65.7 cm^2

Calculation of the modulus geometric for the casting, M casting

= V casting / A casting

= 5.3 cm^3 / 65.7 cm^2

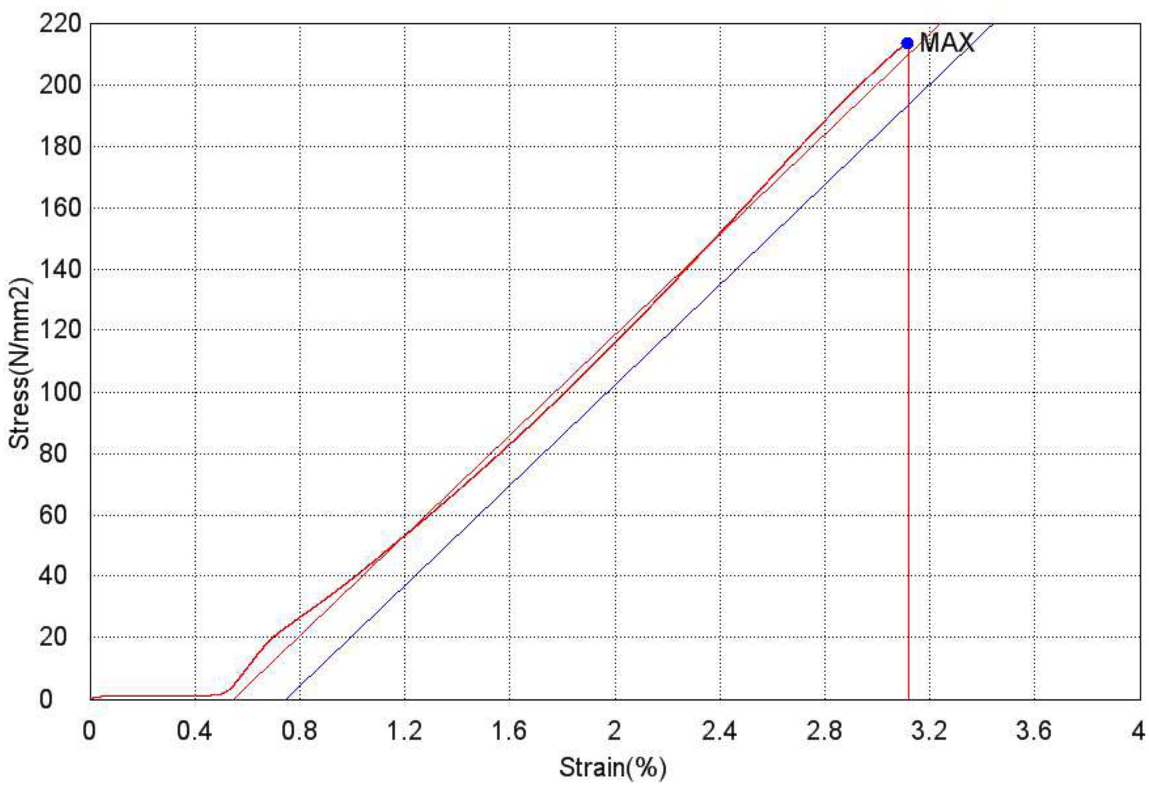
= 0.08 cm

APPENDIX B1

TENSILE TEST RESULT FOR 530 T6 SPECIMENT 1

Key Word		Product Name	
Test File Name	530 2hr (1).xtak	Method File Name	
Report Date	2012/03/15	Test Date	2012/03/14
Test Mode	Single	Test Type	Tensile
Speed	1mm/min	Shape	Rod
No of Batches:	1	Qty/Batch:	1

Name Parameters Unit	Max_Force Calc. at Entire N	Max_Disp. Calc. at Entire mm	Max_Stress Calc. at Entire N/mm2	Elastic Stress 20 - 200 N/mm2	YS1_Stress 0.2 % N/mm2
530 2hr (1	16760.9	3.11429	213.407	8154.60	81.2309

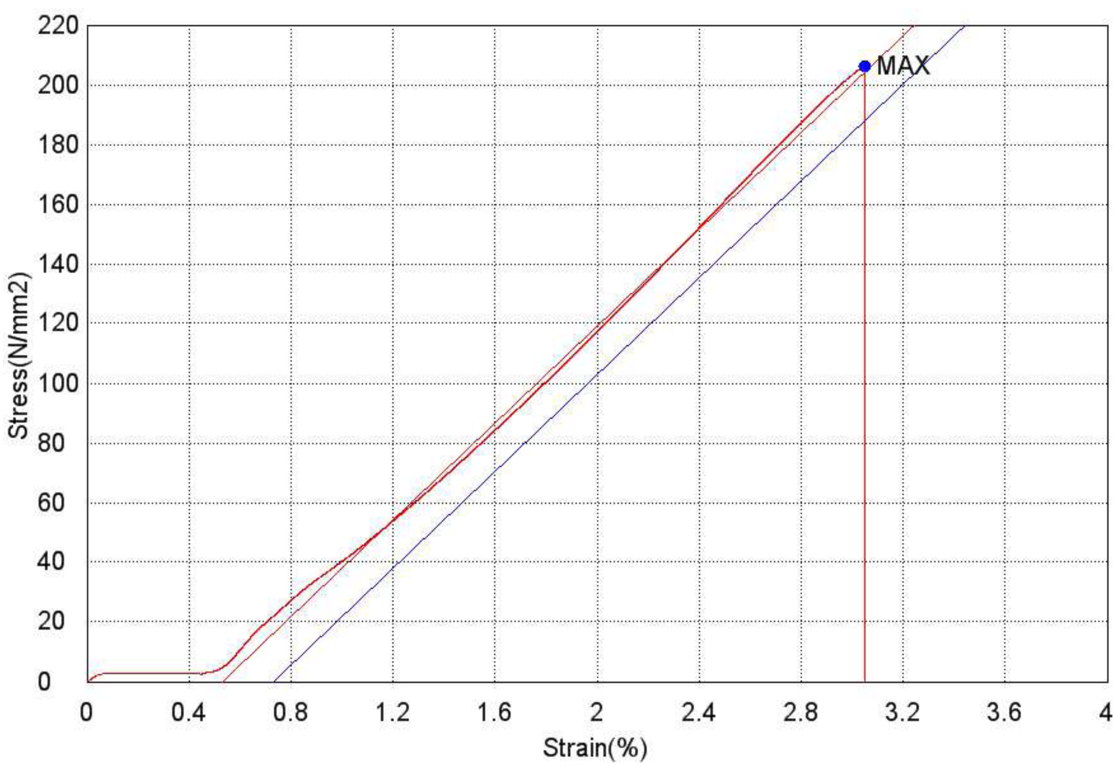


APPENDIX B2

TENSILE TEST RESULT FOR 530 T6 SPECIMENT 2

Key Word		Product Name	
Test File Name	530 2hr (2).xtak	Method File Name	Method AzrulAmir MA08
Report Date	2012/03/15	Test Date	2012/03/14
Test Mode	Single	Test Type	Tensile
Speed	1mm/min	Shape	Rod
No of Batches:	1	Qty/Batch:	1

Name Parameters Unit	Max_Force Calc. at Entire N	Max_Disp. Calc. at Entire mm	Max_Stress Calc. at Entire N/mm2	Elastic Stress 20 - 200 N/mm2	YS1_Stress 0.2 % N/mm2
530 2hr (2	16202.5	3.04829	206.296	8107.68	145.885

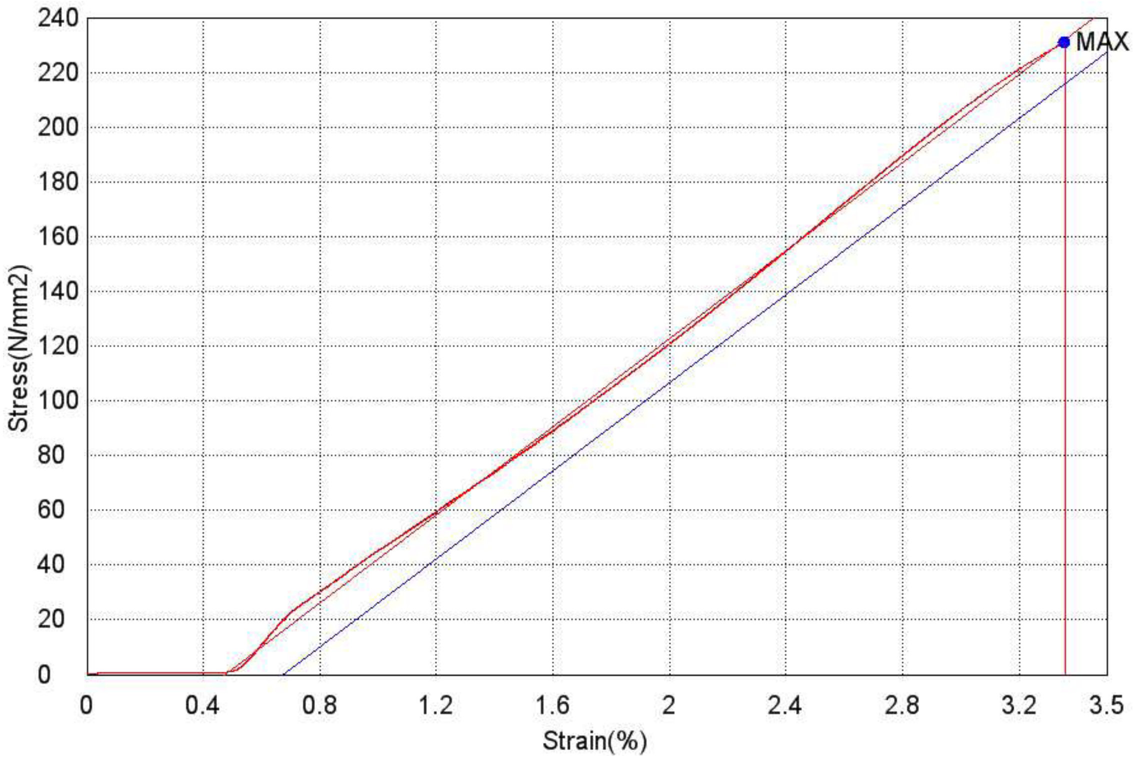


APPENDIX B3

TENSILE TEST RESULT FOR 540 T6 SPECIMENT 1

Key Word		Product Name	
Test File Name	540 2hr (1).xtak	Method File Name	Method AzrulAmir MA08
Report Date	2012/03/15	Test Date	2012/03/14
Test Mode	Single	Test Type	Tensile
Speed	1mm/min	Shape	Rod
No of Batches:	1	Qty/Batch:	1

Name Parameters Unit	Max_Force Calc. at Entire N	Max_Disp. Calc. at Entire mm	Max_Stress Calc. at Entire N/mm2	Elastic Stress 30 - 210 N/mm2	YS1_Stress 0.2 % N/mm2
540 2hr (1	18128.4	3.35579	230.819	8043.57	206.766

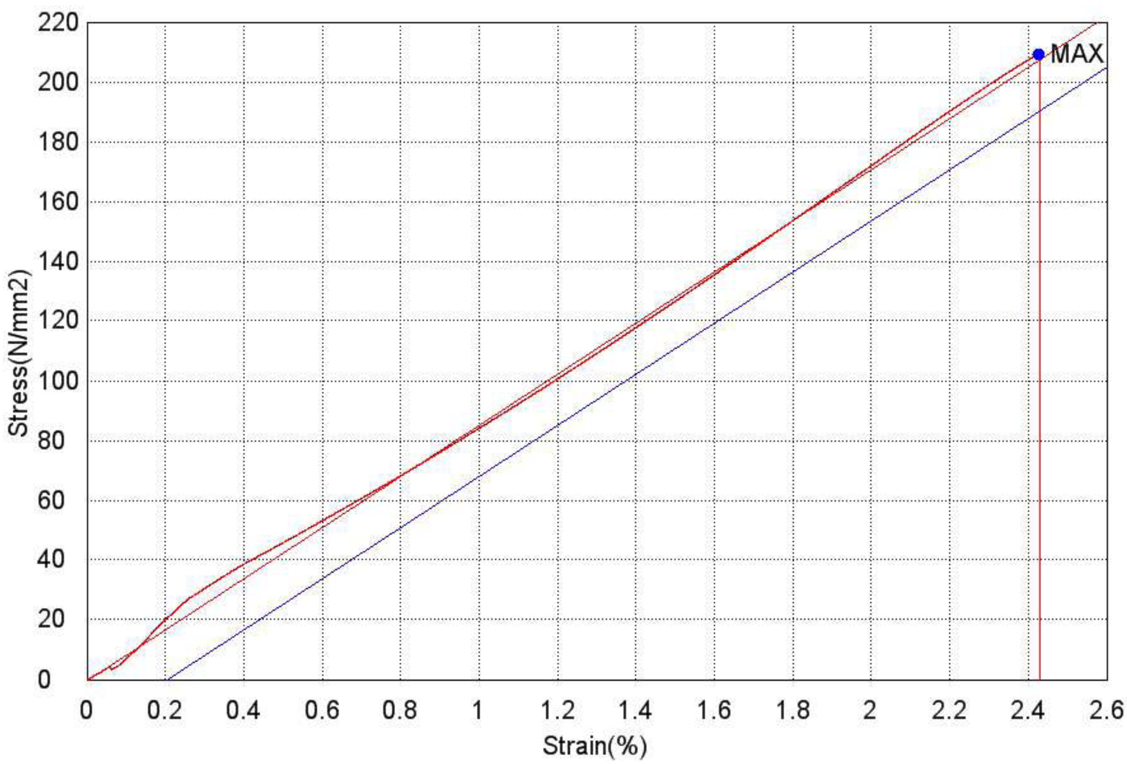


APPENDIX B4

TENSILE TEST RESULT FOR 540 T6 SPECIMENT 2

Key Word		Product Name	
Test File Name	540 2hr (2).xtak	Method File Name	Method AzrulAmir MA08
Report Date	2012/03/15	Test Date	2012/03/14
Test Mode	Single	Test Type	Tensile
Speed	1mm/min	Shape	Rod
No of Batches:	1	Qty/Batch:	1

Name Parameters Unit	Max_Force Calc. at Entire N	Max_Disp. Calc. at Entire mm	Max_Stress Calc. at Entire N/mm2	Elastic Stress 40 - 200 N/mm2	YS1_Stress 0.2 % N/mm2
530 2hr (2	16420.6	2.42594	209.074	8555.06	184.562

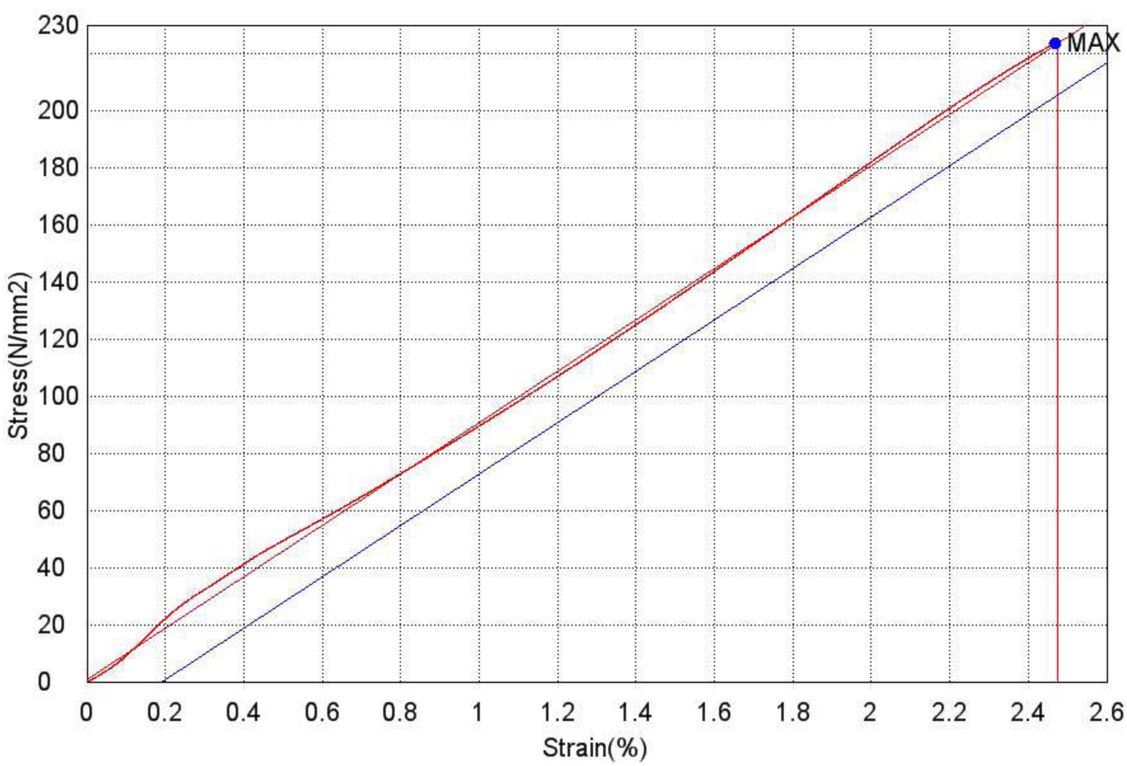


APPENDIX B5

TENSILE TEST RESULT FOR 550 T6 SPECIMENT 1

Key Word		Product Name	
Test File Name	550 2hr (1).xtak	Method File Name	Method AzrulAmir MA08
Report Date	2012/03/15	Test Date	2012/03/14
Test Mode	Single	Test Type	Tensile
Speed	1mm/min	Shape	Rod
No of Batches:	1	Qty/Batch:	1

Name Parameters Unit	Max_Force Calc. at Entire N	Max_Disp. Calc. at Entire mm	Max_Stress Calc. at Entire N/mm2	Elastic Stress 40 - 220 N/mm2	YS1_Stress 0.2 % N/mm2
550 2hr (1	17547.6	2.47029	223.423	9001.19	129.101



APPENDIX B6

TENSILE TEST RESULT FOR 550 T6 SPECIMENT 2

Key Word		Product Name	
Test File Name	550 2hr (2).xtak	Method File Name	Method AzrulAmir MA08
Report Date	2012/03/16	Test Date	2012/03/14
Test Mode	Single	Test Type	Tensile
Speed	1mm/min	Shape	Rod
No of Batches:	1	Qty/Batch:	1

Name Parameters Unit	Max_Force Calc. at Entire N	Max_Disp. Calc. at Entire mm	Max_Stress Calc. at Entire N/mm2	Elastic Stress 40 - 220 N/mm2	YS1_Stress 0.2 % N/mm2
550 2hr (2	17688.2	2.61763	225.213	8525.29	207.800