T6 Solutionizing Heat Treatment Parameter of A356 Alloy by Investment Casting

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Abstract. The heat treatment process is important to conduct on A356 Aluminum Alloy that broadly used in an automotive application. Analysis of the effect grain refinement, eutectic silicon modification of T6 solutionizing heat treatment parameter on strength development of A356 Aluminum Alloy were performed to become an important prospect of controlling the behaviour of materials as well as duration and temperature. In this study, there are three parameters condition were conducted which is duration Time (Hour) and Temperature (˚C) which is 465˚C in 8 hours, 500˚C in 7 hours and 535˚C in 6 hours, respectively. The study generated three responses that are tensile, hardness test and microstructure analysis of the different temperature and duration time, respectively following by water-quenching. The result showed that the modification of duration time and high temperature of solutionizing heat treatment have superior mechanical properties while the microstructure analysis showed the clear formation of refinement α-Al dendrite and eutectic silicon particle.

1. Introduction
Al-Si matrix alloys have been used widely as wear resistant materials in a varies engineering field and lighter than Al which is consists good in corrosion resistance and castability characteristics. The morphological of eutectic Si particles reaction to heat treatment remains bounded with good strength properties due to binary eutectic Al-Si [1]. To achieve the optimum physical and mechanical properties, the heating process called as heat treatment followed by cooling is the process of modifying the structure of crystalline and morphology of materials [2]. The study of the responses and influences of the Al-Si aluminium alloy makes it interesting from technical and academic viewpoints. The factors that control the optimum of the material's behaviour are respect to the modification of parameter and duration of heat treatment.

Nowadays, the material application for the transportation field is critical research where researchers studied that lightweight aluminium alloys are important to improve energy efficiency. The researchers also discuss the effects of thermal conductivity effects on alloying elements and analyze the precipitation in the heat treatment process decreasing thermal conductivity [3]. Besides that, the particular characteristics of aluminum-silicon cast alloy is low with density and low cost, high- capability with temperature and great stability, the alloys are applied in automotive applications widely. Nevertheless, these alloys are suffering from the low tensile force and fatigue resistance, low ductility, low wear resistance and poor machinability. Many researchers approach to adopt additional of the heat treatment to refine the sound structure of Si particles due to the presence of porosity and coarse grain [4].
A few studies have been conducted to investigate the effect of T6 heat treatment on mechanical properties such as tensile properties and the trend of fracture behaviour, also the microstructure of the modifies A356 alloy. The finding that the size of eutectic silicon particles was reduces compared to unmodified alloy due to the aspect ratio of eutectic silicon particles, mean diameter, and roundness [5]. [2] review the other research study on the influence on mechanical properties of Al- FA-Sic Hybrid MMCS when applied with heat treatment; they were concluded that it could be improving the ultimate tensile strength by adding Sic and fly ash. It improving much better by a heat treatment process that is the tensile strength increase from 120 MPa to 210 MPa for composition Al6061. It is well study that the eutectic modification the initial elemental composition impressed the morphology structure of microstructure and the size of the eutectic phase. [6] testified that during the T6 heat treatment experiment, the A356 aluminium alloy facing the fragmentation, necking and spheroidization on coarse plate-like eutectic silicon and long particles in that alloy. However, the prospect ratio of silicon particles and the average area fraction were decreased simultaneously. When the T6 heat treatment was applied, it is improving the tensile strength of the A356 aluminium alloy, hence it can eliminate the segregation of solute elements from dendritic solidification. The interfacial shear stress also improved by about 76.7 MPa to 102.7 MPa [6]. The study of improving the abrasive wear by researchers also presents the behaviour of the heat treated Al-Si alloy over the as-cast alloy was attributed to decreasing the fracture of inclination or disposition of the alloys because of the presentation of spheroidal Si particles after heat treatment. Also, the Si particles provide the protection to weaker and soften the α-Al phase after the heat treatment, it is increasing the hardness and be a greater strength [1]. Thus, this research will emphasize and focus on the influence and improvement modifying T6 solutionizing heat treatment parameter on A356 aluminium alloy in terms of morphology and mechanical properties by investment casting. The temperature and duration of heat treatment be an aspect of concern that important control for the behaviour of materials.

2. Experimental procedure

2.1. Samples Preparation
The experimental study has been extended out to look into the influence of modification of T6 solutionizing heat treatment on microstructure and mechanical properties on an Al-Si alloy. Aluminum-Silicon alloy (A356) is taken as matrix alloys with the chemical composition are presented in Table 1.

| Table 1. Chemical compositions of the material A356 alloy (wt.%) [6]. |
|-----------------|---|---|---|---|---|---|---|---|
| Alloys          | Si | Cu | Mg | Mn | Zn | Fe | Ti | Other | Al   |
| A356            | 7.5| 0.2| 0.4| 0.1| 0.1| 0.2| 0.2| 0.15  | Rest |

A pattern of wax is made exactly the shape of the specimen to be cast and shape of mould are used for investment casting process with cross-sectional area 20mm width x 12.5mm thickness x 200mm length as shown in Figure 1.

![Figure 1. Mould for the preparing of the wax pattern.](image-url)
The fully wax pattern is dipped in a refractory slurry which is water or grained silica and binders as a composition mixer of them with the viscosity of composition were measured by Zhan’s cup and take time around 30 to 40 seconds. The surface of the pattern is dipped by a layer of ceramic. The process continuously repeats until the pattern is dipped for eight layers to make sure the thickness of the ceramic shell is increased and each layer needs to be layered with stucco. Besides, each layer is allowed to dry in room temperature for 6 to 12 hours as shown in Figure 2. This is an important step to be considered to avoid the ceramic shell from any crack condition. The hardened ceramic shell is turned upside down in the furnace and needs to be heated to a temperature around 150ºC as the temperature rise about 1 hour and then uniformly for 1 hour and 30 minutes for the dewaxing purpose.

The ceramic mould then needs to be sintered around 800ºC for 3 hours for the temperature to rise and 2 hours as it to uniform the temperature for the sintering process. The mould becomes strengthen and any leftover wax or any contaminants inside the ceramic mould be eliminated as shown in Figure 3.

A356 Aluminum alloy was heated and melted in a crucible by using an electric furnace for 1 to 2 hours. The shell mould was preheated to 550ºC and the pouring temperature was set at 750ºC. The shell mould is cooling down and the shell is removed and knocking off from solidifying material by using the suitable hammer as shown in Figure 4.
2.2. Solutionizing heat treatment
The matrix alloy was subjected to T6 heat treatment with varied modifying parameter involving solutionizing following water-quenching. The modifying solutionizing parameter consists of 465 °C at 8 hours, 500 °C at 7 hours and 535 °C at 6 hours and quenched in water at ambient temperature, respectively.

2.3. Microstructural characterization
The samples of A356 alloy as-cast and solutionizing heat-treated conditions of dimension 25 mm thickness and 40 mm diameter cut for microstructural analysis. These samples polished following standard metallographic procedure and they etched with Keller’s reagent. The observation of microstructural was done by with optical microscopy (Model: Axioscope 2 MAT).

2.4. Tensile properties
The ultimate tensile strength and tensile strain of samples alloy as-cast and heat treated condition were carried out according to ASTM B557M as shown in Figure 5. Those samples were measured using Universal Testing Machine at room temperature under tensile loading with a load of 1000 N and speed of 2 mm/min.

![Figure 5. Samples of A356 alloy for the tensile test.](image)

Hardness measurements readings (nine) were carried out according to ASTM E-18 for each as-cast and heat treated samples in Hv scale using Matsuzawa Micro Vickers Hardness Tester at a constant load of 100 N for 10 seconds and the average value was taken. The metallographic polishing procedure of the samples must be done and before the Vickers hardness measurement.

3. Results and discussion

3.1. Microstructural characterization
Pictures of material microstructures before and after T6 solutionizing heat treatment presented in Figure 6. The optical microstructures of A356 alloy indicate phases in the microstructure are α-Al primary, eutectic silicon and Mg2Si for as-cast and heat-treated samples. Solidification process creates nucleation and this nucleation resulting in the combination of Al and Si microstructure called as a eutectic phase. By contrast, the transformation of the eutectic phase for the unmodified A356 alloy contains a coarse grain of α-Al dendrites primary and long needle-like eutectic Si particles, which causes poor ductility and brittleness due to higher contains of Magnesium that is increase the size of grain during solidification process.
Figure 6. Optical microscopy of (a) as-cast A356 alloy (b) at 465˚C in 8 hours (c) at 500˚C in 7 hours and (d) at 535˚C in 6 hours.

The heat treatment for all temperatures and hours resulted in a breakdown the coarse of Al dendrites and Si particles. Figure 6(d) show the high temperature with short hours create near spherical Si particle in the Al matrix but also uniform distribution of fine Si particles. The high temperature for a short period followed by rapid cooling (quenching) cause Magnesium diffuse more homogeneously across the interface. Modifying parameters of T6 heat-treated samples of A356 alloy indicates an alteration in morphological from long needle-like in the as-cast condition to spheroidal shape in the eutectic Si particles when the duration and temperature of heat treatment are varied.

3.2. Hardness properties

Figure 7 shows the Vickers hardness of the A356 alloy as a function of the solutionizing parameter. The result shows the values of hardness in as-cast condition and modified heat treated condition (465˚C in 8 hours, 500˚C in 7 hours and at 535˚C in 6 hours) were 60.58 Hv, 52.69 Hv, 83.31 Hv and 91.79 Hv, respectively. When the T6 solutionizing heat treatment is applied, the elimination process happened and it results the segregation of solute elements from dendritic solidification [6]. During the high rapid diffuse process at high temperature with a short period and rapid cooling, the distance between particles decrease until achieved at critical point of value, there are increasing the emphasize of stress needed to move dislocations and the material becomes hardened. It can show the highest hardness and tensile are achieved at high temperature with a short period of hour. Modifying the temperature and duration of T6 solutionizing heat treatment increasing the interfacial bonding strength of the eutectic phase after T6 heat-treated.
3.3. Tensile Properties

The ultimate tensile strength (UTS) and tensile strain of samples alloy as-cast and heat treated condition were carried out as shown in Figure 8. After T6 solutionizing heat-treated, the ultimate tensile strength (UTS) of samples alloy in modifying heat-treated condition (465°C in 8 hours, 500°C in 7 hours and at 535°C in 6 hours) were 117.27 MPa, 169.23 MPa and 195.23 MPa, respectively while for as-cast is 171.12 MPa. The highest temperature with the short heat-treated period show the significant improvement of tensile properties due to the refinement of microstructure, homogeneously uniform distribution of second phase particles (Mg) and elimination of porosities. The tensile properties of A356 alloy clear can be improved by modifying the interfacial bonding strength of Al-Si eutectic phase by the parameter of T6 heat treatment since the applying service loads on materials, the tensile strength is emphasize important in duty of resisting deformation.

Figure 7. Vickers hardness of the sample.

Figure 8. Ultimate tensile stress (UTS) vs Tensile strain (mm/mm).
4. Conclusion

This experimental study shows the influence of microstructure features on strength and hardness development of modifying in T6 solutionizing heat treatment A356 alloy was performed. The following conclusions are drawn:

- The as-cast A356 alloy present with needle-like eutectic silicon and α-Al. However, modifying T6 solutionizing heat treatment for 535°C (6 hrs) change the morphology of the silicon particles become obvious spheroidal and homogeneously distributed in the α-Al matrix grain boundary compared to 65°C (8 hrs) and 500°C (7 hrs).
- The hardness of A356 alloy with modifying T6 solutionizing heat treatment for 535°C (6 hrs) condition is improved and reaches 91.79 Hv compared to the as-cast condition, 65°C (8 hrs) and 500°C (7 hrs).
- The ultimate tensile strength with tensile strain for modifies T6 solutionizing heat treatment for 535°C (6 hrs) reaches 195.23 MPa with 0.03159 mm/mm strain higher compared to the as-cast condition, modifying T6 heat treatment for 65°C (8 hrs) and 500°C (7 hrs).
- T6 heat treatment with modifying solutionizing temperature and time with high temperature and short period hours found to be optimum for A356 alloy in modifying the morphology of eutectic silicon and refining the size of primary α-Al.

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