MICROSTRUCTURAL CHARACTERIZATION AND MECHANICAL PROPERTIES OF SEMISOLID A356 ALUMINIUM ALLOY

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ABSTRACT

A356 aluminium alloys have a wide application nowadays. The alloys have a mixture of many elements but the main elements for this alloys is aluminium metal with almost 92 %. A356 alloys was used in this study in order to determine which process will provides better properties, either conventional casting or cooling slope casting. The conventional casting process begins with pouring directly the molten alloys into the mold while the cooling slope casting process used cooling slope plate to facilitate the alloys to have globular microstructure before they entered the mold. Raw material of A356 aluminium alloy is heated until it achieved the molten state before pouring into the mold. In this study, there are two factors are used which were pouring temperature and cooling slope distance. The pouring temperature have 3 different input parameters that are 660°C, 680°C and 700°C respectively. Meanwhile the input parameters for cooling slope distance are 200mm, 300mm and 400 mm respectively. After the casting process, the billet is cut to produce small pieces to perform microstructure and hardness testing using ASTM E384 standard. Some the billet was undergo a CNC turning using ASTM E8M-03-200H standard to produce the specimen for tensile testing. The result of microstructure, hardness and tensile were compared to determine which process have better properties. The specimen that had undergone cooling slope and heat treatment have the finest globular microstructure, better hardness value and tensile strength compared to the conventional casting and cooling slope specimen. The cooling slope specimen provided fine globular microstructure, good hardness value and good tensile strength when compared to the conventional casting process.

ABSTRAK

aloi A356 aluminium mempunyai aplikasi yang sangat luas pada masa kini. Aloi ini mempunyai campuran banyak unsur tetapi unsur utama untuk aloi ini adalah logam aluminium dengan hampir 92%. Aloi A356 telah digunakan dalam kajian ini untuk menentukan proses yang mana dapat menyediakan bahan yang lebih baik, sama ada pemutus konvensional atau penyejukan pemutus cerun. Proses pemutus konvensional bermula dengan mencurah secara langsung aloi lebur ke dalam acuan manakala cerun proses pemutus penyejukan menggunakan penyejukan plat cerun bagi memudahkan aloi untuk mempunyai mikrostruktur globular sebelum mereka memasuki acuan. Bahan mentah daripada aloi A356 aluminium dipanaskan sehingga mencapai keadaan lebur sebelum dituang ke dalam acuan. Dalam kajian ini, terdapat dua faktor yang digunakan iaitu penuangan suhu dan jarak cerun penyejukan. Penuangan suhu mempunyai 3 parameter input yang berbeza yang 660 ° C, 680 ° C dan 700 ° C masing-masing. Sementara itu parameter input untuk jarak cerun penyejukan adalah 200mm, 300mm dan 400mm masing-masing. Selepas proses pemutus, bilet dipotong untuk menghasilkan kepingan kecil untuk melaksanakan mikrostruktur dan kekerasan ujian menggunakan ASTM E384 standard. Sebahagian daripada billet itu menjalani CNC beralih menggunakan ASTM E8M-03-200H standard untuk menghasilkan spesimen untuk ujian tegangan. Hasil mikrostruktur, kekerasan dan tegangan dibandingkan untuk menentukan proses mempunyai ciri-ciri yang lebih baik. Spesimen yang telah menjalani cerun dan rawatan haba penyejukan mempunyai mikrostruktur yang terbaik bulat, nilai kekerasan yang lebih baik dan kekuatan tegangan berbanding pemutus konvensional dan penyejukan spesimen cerun. Spesimen cerun penyejukan disediakan mikrostruktur globular halus, nilai kekerasan yang baik dan kekuatan tegangan yang baik jika dibandingkan dengan proses pemutus konvensional.

DEDICATION

This study is dedicated to beloved all members of my families especially
Che Zaviah Binti Abdullah as my mother,
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my siblings and my friends.

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CHAPTER 1

INTRODUCTION

This chapter will discuss briefly about the background of material study, problem statements, objective of the research and the scope of the research.

1.1 Background of study

Aluminium alloys are alloys in which aluminium (Al) element is the dominant element. The common elements used in aluminium alloys are copper, magnesium, manganese, silicon, tin and zinc. Alloys composed mostly of aluminium metal have been very important in aerospace manufacturing production since the development of metal-skinned aircraft part.

Aluminum alloys A356.0 are generally made of a 7% Si, 0.3% Mg alloy with 0.2 Fe (max) and 0.10 Zn (max). These alloys have very good casting and machining characteristics. Typically they are used in the heat-treated condition. Corrosion resistance is excellent and it has very good weldability characteristics. Typically this alloy is used in castings for aircraft parts, pump housings, impellers, high velocity blowers and structural castings where high strength is required. The A3xx in front of an alloy denotes a higher purity version of the chemical composition.

In the other hand, semisolid metal (SSM) processing, also known as thixoforming, is a technology for metal forming that was patented by Spencer during his Ph.D. studies under the supervision of Prof. Flemings at the Massachusetts Institute of Technology (MIT) in the early 1970s. Nowadays, the thixoforming process has found a number of manufacturing applications due to its ability to supply or provide production of high quality parts at costs that are comparable to or lower than conventional forming techniques such as casting or forging.

Semisolid metal (SSM) processing refers to the process of creating feedstock materials made from alloys by pre-heating a material to a temperature between solid and liquid temperature to produce partially solid and partially liquid material. The process involves metal which is nonferrous metals such as aluminium, copper, silicon, zinc and magnesium. As well as possible, the percentage of solid in metal is from 30% to 65% solid, hence can be counted as semisolid metal.

The key of the SSM processing is the production of slugs with a non-dendritic microstructure. Thus, production of feedstock with thixotropic properties is a key step for successful SSM processing. Furthermore, SSM technologies can be divided into two main categories based on the starting material status either:

(1) From a liquid alloy through controlled solidification (by activating crystal multiplication of a growing solid or by increasing the nucleation rate) under specific conditions, or

(2) From the solid state through heavy plastic deformation and re-crystallization.

Nowadays, there are many ways or methods for feedstock production which have been developed over the last 40 years. The most effective methods, as well as those most commonly used in commercial practice, are listed below:

1) Mechanical stirring
2) Magnetohydrodynamic Stirring
3) Spray casting
4) Chemical grain refining
5) Liquidus casting
6) Cooling slope (CS)
7) Stress-Induced and Melt-Activated (SIMA) process

This study will focus more about Cooling Slope (CS) casting process. As mentioned above, Cooling Slope (CS) casting process has been introduced or developed as this cooling slope technique is the simplest non-agitation process that can be utilized to produce feedstock with a near-globular solid fraction in a liquid matrix. It is a continuous casting process that works by applying a low superheat to the metal at a uniform temperature near to or just above the liquidus temperature.

Cooling slope is a simple semisolid casting process with very less equipment and low running costs. In cooling slope casting process, flow is achieved by the molten metal is being poured into the cold slope to be gathered and collected in a mold. The nucleation of granular crystals occurs at the contact surface of the cooling plate and due to fluid movement which is accelerated by gravity, the nucleation on the slope wall removes the molten metal into a heating mold, thus ensuring that the spheroid size is fine. The molten metal contains a large amount of nuclei crystals that will solidified in the mold, resulting in a fine globular microstructure.

1.2 Problem Statement

The main reason behind the usage of Semi Solid Metal (SSM) processing over the conventional casting process is the disadvantages of the conventional casting process. The conventional casting or sand casting does not provide the fine globular microstructure on the product that represents the thixotropic behavior. The thixotropic behavior must have fine globular microstructure or equiaxed microstructure. It can be achieved by the increasing shearing rate that will lower the viscosity of the alloy that usually used for further process, thixoforming. But in this process, the required outcome is the globular microstructure without further process. However, the conventional casting product has the form of dendritic microstructure. Thus, the dendritic arm spacing will produce gaps between each other that prevent thixotropic behavior from occurs.

The conventional casting product usually can have either 3 major disadvantages in terms of microstructure which is holes or porosity, shrinkage and crack. All of these disadvantages may make the product be unusable. Thus, the SSM process is being used to overcome these problems.

The application of the semisolid A356 aluminium alloy can be found in the automotive parts and aerospace or aircraft parts. For an example, aircraft pump parts, automotive transmission cases, aircraft fittings and control parts, water-cooled cylinder blocks. It is due to the advantages of the alloy which is excellent castability and good weldability, pressure tightness, and good resistance to corrosion.

1.3 Objectives of research

1) To determine the microstructure of semisolid A356 aluminium alloys.
2) To determine the mechanical properties of semisolid A356 aluminium alloys.
3) To analyse the hardness value of semisolid A356 aluminium alloys.

1.4 Scopes of research

Within these 6 months, a preparation for a proposal must be done to study the microstructural characterization and mechanical properties of semisolid A356 aluminium alloy. The raw material of the alloy will be cut into 10 specimens and will undergoes further heating process to a poured temperature which is below than melting temperature of aluminium. The specimens will be divided into two casting process, which is a specimen will undergoes conventional sand casting and the remaining will undergoes the cooling slope casting process. After the casting process is done, the microstructure of all the specimens will be determined by using Optical Microscope. Next, the alloys will undergo Hardness Test and Tensile Test by using Vickers Hardness Machine and Universal Testing Machine (UTM). The purpose of both tests is to determine the mechanical properties of the alloy which is the yield strength, ultimate tensile strength, modulus of elasticity and elongation at break.

CHAPTER 2

LITERATURE REVIEW

This chapter will expose the literature review of existed researches on the properties of semisolid A356 aluminium alloys. In addition, the microstructure and the mechanical properties will be included. This chapter begins with the review on the aluminium alloy.

2.1 A356 Aluminium alloy

Cast aluminium A356 alloy is one of the most well-developed aluminium alloys due to its outstanding properties. It is widely employed in numerous automotive and industrial weight sensitive applications, such as aeronautics and space flight, because of its low density and excellent castability.

Actually, in most cases high-level mechanical properties are needed for industrial applications, so the performance of this alloy has been subject of many micromechanical investigations (L´opez et al., 2003; Gokhale and Patel, 2005; Yu et al., 1999; Yang et al., 2005). Since the strength and hardness of alloys mainly depend on their microstructure, a lot of efforts have been made to refine the microstructure of the castings in order to enhance the mechanical properties of aluminium A356 alloy (Zhang et al., 2008).

The volume fraction of eutectic in these alloys is about 45 %. This and the distribution of liquid fraction as a function of temperature reduce the difficulties to reheat these alloys to a defined liquid fraction just above the eutectic temperature. They also show a good casting behavior in terms of flow length, joining of flow fronts and little tendency to form hot cracks during solidification. These advantages significantly widen the process window during reheating and forming, allowing detect-free components to be produced. In addition, these alloys show good corrosion behavior and they offer a wide range of mechanical properties, including conditions of high strength or high elongation to fracture which can be adjusted by heat treatment procedures and by the choice of Mg content (0.25 – 0.45% in A356).

One difficulty when introducing the semisolid metal (SSM) process is that usually it is not sufficient to substitute the only the process for a given part geometry. In most cases a process-specific redesign will be required to achieve substantial benefits. This especially holds of the goal is to achieve significant weight saving, that is, by substituting steel forging by semisolid forming of aluminium.

Table 2.1 Chemical composition of A356 aluminium alloy (mass fraction, %)

Elements	**Si**	**Mg**	**Mn**	**Zn**	**Cu**	**Fe**	**Al**
Percentage	6.93	0.38	0.23	0.26	0.25	0.11	Balance

The chemical composition of this alloy is given in Table 2.1. A356 alloy belongs to a group of hypoeutectic Al−Si alloys and has wide applications in automotive, marine and other sectors due to its excellent combination of properties such as good fluidity, low coefficient of thermal expansion, high specific strength and good corrosion resistance. The liquidus and solidus temperatures of this alloy are 610 °C and 575 °C, respectively (Khosravi, Eslami-Farsani, & Askari-Paykani, 2014).

2.2 Semisolid A356 Aluminium alloy.

Nowadays, semisolid forming processes of aluminium alloys are being developed extensively for manufacturing part owing to the particular properties of semisolid slurries resulting from mechanical or electro-magnetic stirring during solidification. The use of material from semisolid state will increases the die life in die casting process owing to the lower temperature involved compared with the fully liquid alloy and reduces the stresses during forging compared with fully solid state (Nguyen Thanh & Suéry, 1995).

In the other hand, there is a study conducted that related to the semisolid aluminium alloy which is rheological studies. Rheological studies of semisolid metal slurries are essential to understand and design rheocasting and thixocasting processes. The semisolid slurries used in the rheo or thixo forming processes shows complex non-Newtonian flow behavior and also shows the reliance on the temperature. Some popular casting alloys such as A356, A357, A380 at semisolid state forms the foundation for semisolid manufacturing.

In the semisolid state, the aluminium alloy slurry is being used to be pushed in order to fill a die or mold. Thus the components can be produced with improved mechanical properties, high dimensional accuracy and structural integrity.

Nowadays, A356 aluminium alloy has been chosen for the present work. It is commonly used for rheo or thixo forming process due to its wide difference between solidus and liquidus temperatures, excellent castability, good weldability, pressure tightness, high strength to weight ratio and good resistance to corrosion (Das, Samanta, Chattopadhyay, Dutta, & Barman, 2012).

The semisolid forming (SSF) process can manufacture products that can compete with the mechanical properties of aluminium forging parts, even though a die may have a complex shape. Furthermore, the applications of the SSF process have been studied in the fields of compact electronic parts and automotive parts. It is due to the SSF process has advantages over conventional forming processes in the areas of reduction of forming force, increase of die life, reduction of product defects and improvement of processes (Cho & Kang, 2000).

Semi-solid metal (SSM) processing was first discovered by Flemings and his co-worker in the early 1970s. The key of the SSM is the production of slugs with a non-dendritic microstructure. To develop this microstructure, a number of methods have recently been proposed, including mechanical and electromagnetic stirring and controlled nucleation. Controlled nucleation is especially interesting in that it does not need stirring and is simple and less expensive.

Based on this method, the cooling slope casting process was developed: a simple semi-solid casting process with very low equipment and running costs. In cooling slope casting, the melt with low superheat is cast via a cooling slope. The crystals nucleate by heterogeneous nucleation on the slope wall and inside the melt and are washed away from the wall by fluid motion. The melt, containing a large number of these nuclei crystals, solidifies in the die, resulting in a fine globular microstructure (Thuong, Zuhailawati, Seman, Huy, & Dhindaw, 2015).

Semisolid metal (SSM) processing is a promising technology for forming alloys and composites to near-net shaped products. It is over 30 years since the concept of semisolid metal processing was first discovered through the observation of thixotropic behaviour of a partially solidified melted material which has a fluidity of machine oil when the normal dendritic structure is broken up. Semisolid metal processing is different from the conventional metal forming technologies, which use either solid metals/alloys (solid state processing) or liquid metals/alloys (casting) as starting materials. SSM processing uses semisolid metal slurries, in which non-dendritic solid particles are dispersed in a liquid matrix. There are two routes for processing in the semisolid state; 'thixocasting', where the slurry is first cast as a billet and then reheated back to the semisolid condition before component shaping, and 'rheocasting', which involves producing a non-dendritic slurry usually by the application of melt shearing during solidification followed by component shaping (Patel, Liu, Shao, & Fan, 2008).

Semisolid metals processing (SSM), can be known as thixoforming, is a technology for forming metal specimen that was patented by Spencer during his Ph.D. studies under the supervision of Prof. Flemings at the Massachusetts Institute of Technology (MIT) in the early 1970s. Nowadays, the thixoforming process has found a number of manufacturing applications based on its ability to deliver production of high quality parts at costs that are comparable to or lower than conventional forming processes such as casting or forging. Some examples of these applications are engine suspension mounts and steering knuckles for some automobile brands.

Semisolid metal processing technologies can be grouped into two main categories based on the status of the starting material, liquid routes and solid routes. In recent years, a number of methods have been developed to make fine globular microstructures for feedstock production. Substantial efforts in research of feedstock production have been carried out over the years, and the intention of this paper is to review the various processes, highlight any differences between them, and present a review of the potential mechanisms that lead to microstructural alterations during the preparation of SSM slurries (Mohammed, Omar, Salleh, Alhawari, & Kapranos, 2013a).

With the discovery of shear thinning and the thixotropic behavior of partially solidified alloys under vigorous agitation, a new era in forming technology was started, namely semisolid metal (SSM) processing. This new technology provide several advantages, such as improving die filling, less air entrapment and less oxide inclusions due to higher viscosity compared with fully liquid melts, longer die life, shorter solidification time, reduced cycle time and therefore higher productivity due to lower heat content and lower process temperature and reduced shrinkage, and thus near net shape or even net shape production due to the partially solidified slurry.

There are two fundamental routes of SSM processing, which are ‘rheocasting’ and ‘thixocasting’ that proved their feasibility in industrial trials. The ‘rheocasting’ routes involves the preparation of an SSM slurry from liquid alloys and transfer of the prepared slurry directly to a die or mould for component shaping. Meanwhile, the ‘thixocasting’ routes is basically a two steps process, involving the preparation of a feedstock material with thixotropic characteristics, reheating the solid feedstock material to semisolid temperature and shaping the semisolid slurry into components. Both routes aiming at the formation of an ‘ideal’ slurry that exhibits an accurately specified volume fraction of fine and spherical solid particles uniformly distributed in the liquid matrix.

The process of semi-solid casting offers a number of advantages such as improved mechanical properties, good surface finish, and low segregation and so on. The key to the process is to obtain semi- solid slurry free of dendrite, with the solid being present as non-agglomerated, fine and spherical particles, and with minimum entrapped liquid in the solid. The semisolid slurries are obtainable by a number of methods with and without liquid agitation such as single slug production method, low superheat casting, low superheat pouring with a shear field, swirled enthalpy equilibration device process, cooling slop, twin roll casting equipped with a cooling slope, and partial melting (Abbasi-khazaei & Ghaderi, 2012).

Even though a die can have complex shapes, the semisolid forming (SSF) process can manufacture products that can compete with the mechanical properties of aluminium forging parts. Moreover, the application of the SSF process on the fields of automotive parts and compact electronic parts have been studied actively, because the SSF process has advantages over conventional forming processes in the areas of reduction of forming force, increase die life, reduction of product defects and improvement of process.

Figure 2.1 A356 aluminium alloys billets.

In the thixoforming process, when the temperature of billets is not constant, the solid fraction is different. Thus, in lower temperature region, it is difficult to have sufficient fluidity to fill the die on forming, while in higher temperature regions, a uniform product cannot be obtained, due to the flowing out of the liquid-phase from the solid-phase during the forming process. Therefore, the behavior of semisolid material (SSM) should be investigated to fabricate a product that has same mechanical properties in the thixoforging process (Cho & Kang, 2000).