Study on Hardness and Wear of Aluminum AA332.0 Composites Reinforced Mg_2Si Via Stir Casting: A Review

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Abstract

Aluminum alloy $AlSi_{12}CuFe$ (AA332.0) is use as matrix material and Mg_2Si (≤ 10 – 15 μm) as reinforcement will study. Composites containing of 15wt. % and reinforcement develop by stirring casting route. The ingot alloy melts in a graphite crucible in an electric furnace at 750⁰C ± 5⁰C. This molten stir for 45 minutes and the Mg_2Si particles will add inside the vortex during stirring. After completion of the particle feeding, the molten will re-melt in the same temperature for another 15 minutes. The molten finely pours into the metal mould and allowed to solidify at room temperature. Full heat treatments will provide for the samples; solution treatment consist of heating in an electrical furnace at 500⁰C (±1⁰C) for 5 hours and then quenching in water at room temperature. The aging treatment shall be done at 170⁰C for 2 hours. Hardness analysis conducts by following the ASTM E384 – 09 using a Vickers hardness tester. The wear tests conduct using a pin on disc sliding wear testing machine following ASTM G99-05 protocol. The bulk density measure using the Archimedes principle according to ASTM B962 - 13 and porosity measure based on ASTM B963 – 13

Keywords Aluminum AA332.0, Mg_2Si, aluminum matrix composite (AMCs), stir casting

INTRODUCTION

As observed by many researchers, Aluminum Matrix Composites (AMCs) have been largely studied in many field, such as aircraft, automotive, military, electrical and electronics (Ali Hubi *et al*., 2011; Aydin & Findik, 2010; Liu *et al*., 2011; Sajjadi *et al*., 2012). Similarly, Corrochano *et al*., (2011) stated that, some of the AMCs also used as cutting tools, bearing part and medical equipments.

As reported by Baghchesara *et al*., (2012); Tahamtan *et al*., (2013)and Xuhong *et al*., (2011), AMCs are a unique materials because they impart a combination, such as high elastic modulus, tensile force, good fatigue resistance, low density and high wear resistance. As a consequence, they show a great change of mechanical properties depending on the chemical composition of the aluminummatrix reinforcement materials.

Nowadays, demands for developing AMCs for using in high performance engine, have been significantly increased. In terms of that, automotive industry takes the opportunity to develop an automotive parts from AMCs due to make it lighter, safer and more fuel-efficient. As highlighted by Williams, (2012), AMCs can be designed to be strong and light to provide better safety and fuel efficiency. Meanwhile, Sharma *et al*., (2013), found that, the AMCs used in the transportation sector can reduce the noise and lower the airborne emissions because AMCs are lightweight material; therefore the uses of fuel are lower. Generally, brake rotors, pistons, connecting rods and engine blocks are some of the successful applications of AMCs in the automotive industry.

To increase the high-temperature strength and enhance the heat resistance of the AMCs; a method of adding Cu, Ni, Fe, Mn, or some other elements have been used. There are many methods for adding the element to AMCs such as powder metallurgy, casting (Ali Hubi *et al*., 2011) and moltenmetal infiltration (Arora *et al*., 2011). However, common fabrication for AMCs is stir casting (Sharma *et al*., 2013), and the common reinforcement use of these methods is discontinuously reinforced composites such as particle (Cyriac, 2011).

ALUMINUM MATRIX COMPOSITES (AMCs)

Worldwide, there is an increasing require for the advanced materials in order to obtain the desired mechanical and physical properties. As it's known, aluminum generally cannot meet the requirements of harsh engineering environments; therefore the needs for AMCs with unique properties are growing.

AMCs are a new class of materials and are rapidly replacing conventional materials in various engineering applications and the fundamental advantage of AMCs over the unreinforced alloy is the improvement of mechanical properties (Emamy *et al*., 2013). As highlighted by Yufeng Wu, (2011), the AMCs market has been growing significantly in the past 10 years because of the extraordinary properties of the AMCs.

AMCs are used in many engineering field because of their high-specific modulus, strength, hardness and stiffness, excellent wear resistance, low thermal expansion coefficient, stability of properties at elevated temperature, reduced density, and competitive fabrication cost (Xuhong *et al*., 2011; Olaya-Luengas *et al*., 2010) high elastic modulus, tensile strength and wear resistance (Corrochano *et al*., 2011), and often fabricated with near-net shape processing techniques.

Matrix and Reinforcement

The terms matrix and reinforcement are frequently used. The matrix is a penetrated "soft" phase (i.e. excellent ductility, formability and thermal conductivity) in which are implanted the "hard" reinforcements (i.e. high stiffness and low thermal expansion). Gupta *et al*., (2013) proposed, the addition of reinforcement in the matrix can improve specific strength, stiffness, wear, fatigue and creep properties compared to conventional engineering materials. The authors also identified, the properties of AMCs are greatly influenced by the nature of reinforcement and its distribution in the metal matrix.

Matrix Material – Aluminum AA332.0

Aluminum is the most common matrix material used in metal-matrix composites because of its low melting temperature, and low density (Chung, 2010). Generally, aluminum alloy AA332.0 is essentially used for the manufacturing of pistons and applications that require the capability to survive with high thermal stresses. The chemical composition of AA332.0 contain with 8.5wt% – 10.5wt% Si, 2.0wt% - 4.0wt% Cu and 0.5wt% - 1.5wt% Mg and the specific formula is $AlSi_{12}CuFe$ (ASTM International B108/B108M-12, 2012).

Reinforcement Material – Mg_2Si

Mg_2Si is a compound that is dark blue or slightly purple in colour; hard intermetallic compound with a slightly high at melting point, low density and low coefficient of thermal expansion, high elastic modulus make it an appropriate candidate for reinforcing in the matrix alloy(Emamy *et al*., 2013;Wu *et al*., 2013).

Mg_2Si has a cubic structure in which the silicon atoms form a face-centered cubic (fcc) lattice and the magnesium atoms are located in the tetrahedral interstices (CaF z-type). It believes that Mg_2Si shows highest specific modulus as compared to other structural intermetallic such as Al and Ti alloys. However, the major disadvantage of Mg_2Si is severe brittleness, especially at low temperatures.

Research done by Aydin & Findik, (2010), Tang *et al*., (2011) and Ajith Kumar *et al*., (2013) reported that, Mg_2Si has the possibility to be once of effective reinforcement because of its low density (1.91 kg/m^3), high melting point (1085^{0}C), 120 GPa of Young's modulus, high micro Vicker's hardness of (600-700Hv) and low coefficient of thermal expansion of (7.5×10^{-6} K^{-1}).

Moreover, Ajith Kumar *et al*., (2013) highlighted that, the Mg_2Si greatly improve the heat-resistance and wear-resistance of the alloys. As knows, the Mg_2Si also increases strength and reduces ductility. The low ductility and high strength of alloy due to the large sized of Mg_2Si particles form in needle or Chinese script in eutectic phase (Ajith Kumar *et al*., 2013). Figure 1 represented the microstructure of Mg_2Si in alloy AA332-F.

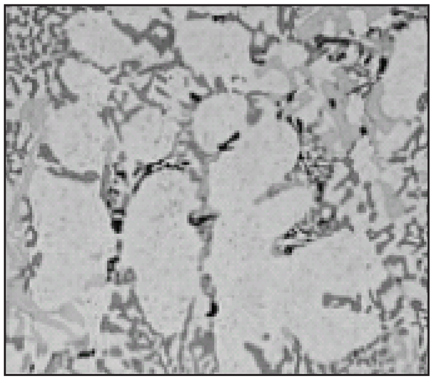

Figure 1 Microstructure of Mg_2Si in alloy AA332-F(ASM International, 1992)

CASTING

Based on Hehl & Peter, (2013), casting is the current activities involve to improve the structureand characteristics of manufacturing (i.e. strength properties and corrosion resistance). Cicek *et al*.,(2013) agreed that, the casting procedures such as adding minor alloying elements are possible controlling the microstructure and improving the mechanical and wear characteristics. Thus, two main development directions of manufacturing of AMCs are observed: casting and powder metallurgy (Ali Hubi *et al*., 2011); however, Bekir (2008) confirmed that, the tribological and mechanical properties of casting specimens were better than those of powder metallurgy.

Significant, casting as known is a manufacturing method that pours a liquid material into a hollow mould until the material cools into a solidified form; after removing from the mould, the solid material or part may be machined and heat treated for use. Casting is the most economical route to transfer materials into readily useable components such as for engine components, including engine blocks, cylinder heads, pistons, intake manifolds, and housings. As highlighted by Hehl & Peter, (2013), it can be very economically produced from conventional permanent mould, sand casting or investment casting, with silicon content ranging from 6% to 18%. However, it has some limitations due to the matrix alloy and density of the reinforced phases. For that reason, the volume fraction and the size of the reinforcements that can be added are very limited (Ali Hubi *et al*., 2011)

Commonly, aluminum-silicon (AlSi) alloys are the most common feed materials of the aluminum casting alloys. Alloys with silicon as a major alloying element are of significance in the industry and are widely used because of their superior casting characteristics, high corrosion resistance, low thermal expansion coefficient, weldability, and heightened mechanical properties (Fawzy Ibrahim, 2010). Generally, the most popular aluminum castings product are made from alloy of the 3xx family (Hehl & Peter, 2013); because this alloys owing to their good castability, fluidity, and low tearing tendency especially when approaching eutectic Al–Si compositional range.

Casting alloys are processed by all typical casting techniques such as sand, investment, gravity die, permanent mould, low-pressure die casting (LPDC), high-pressure die casting (HPDC), and squeeze casting (Hehl & Peter, 2013). Similarly, Cyriac, (2011), noted, pressure casting was commercially performed since the early 1980s. Meanwhile, Reikher & Barkhudarov, (2007) stated that the most widely used are sand casting, permanent mould casting, and die casting.

Stir Casting

Normally, stir casting is the most common process of composite production whereby the reinforcement ingredient material incorporated into the molten metal by stirring (Sharma *et al*., 2013). This involves stirring the melt with ceramic particles and then allowing the mixture to solidify. Another essential statement, Kathiresan & Sornakumar, (2010), noted that, the stir casting technique involves the introduction of pre-treated ceramic particles into the vortex of molten alloy created by the rotating impeller. Generally, stir casting usually be organized by fairly conventional processing equipment and carried out on a continuous and semi continuous basis by the use of stirring mechanism. Figure 2 represent the schematic of stirring mechanism.

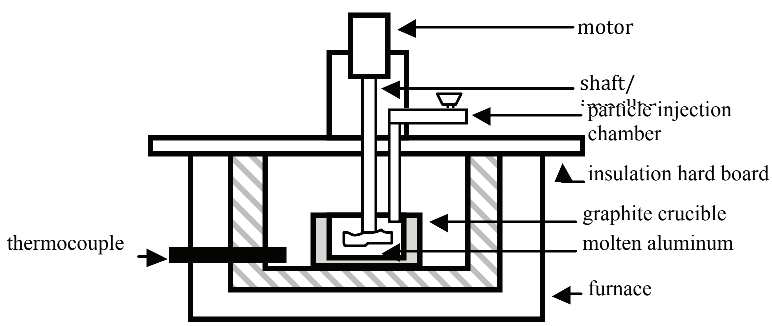

Figure 2 Schematic of stirring mechanism

According to Sharma *et al*., (2013), stir casting can characterized by following features: (a) content of dispersed phase limited (usually not more than 30% vol.); (b) distribution of dispersed phase throughout the matrix is not perfectly homogeneous and (c) the technology is relatively simple and low cost. A major concern related with the stir casting process is the segregation of reinforcing particles which is caused by the surfacing of the reinforcement particles during the melting and casting processes. The final distribution of the particles in the solid depends on material properties and process parameters such as the wetting condition of the particles with the melt, strength of mixing, relative density, and rate of solidification .The distribution of the particles in the molten matrix depends on the geometry of the mechanical stirrer, stirring parameters, placement of the mechanical stirrer in the melt, melting temperature, and the characteristics of the particles added (Sharma *et al*., 2013).

An interesting recent development in stir casting is a two-step mixing process (Sharma *et al*., 2013). In this process, the matrix material is heated to above its liquids temperature so that the metal is totally melted. The melt is then cooled down to a temperature between the liquids and solidus points and kept in a semi-solid state. At this stage, the preheated particles are added and mixed. The slurry is again heated to a fully liquid state and mixed thoroughly. The resulting microstructure has been found to be more uniform than that processed with conventional stirring.

EXPERIMENTAL METHODS

Aluminum alloy $AlSi_{12}CuFe$ (A332.0) is use as matrix material and Mg_2Si (≤ 10 – 15 μm) is select as reinforcement. The chemical compositions of the alloy $AlSi_{12}CuFe$ (AA332.0) (in wt. %) shown in Table 1

Table 1 Chemical composition of A332.0 (ASTM International B108/B108M-12, 2012)

Si	Fe	Cu	Mn	Mg	Ni	Zn	Ti	Al
11.0-13.0	1.2	0.5-1.5	0.35	0.7-1.3	2.0-3.0	0.36	0.26	reminder

Composites containing of 15wt.% reinforcement develop by stir casting route. The ingot alloy melt in a graphite crucible in an electric furnace at $750^0C \pm 5^0C$. This molten mass stir for 45 minutes. After the formation of vortex in the melt, the Mg_2Si particles will add inside the vortex during stirring. Before charging the Mg_2Si particles, it was preheated at 400^0C for 30 minutes to remove moisture and other volatile substances.

After completion of the particle feeding, the molten will re-melt at $750^0C \pm 5^0C$ for another 15 minutes. This will do to ensure homogeneous distribution of the particles inside the melt. The molten mass finely pours into the metal mould and allowed to solidify at room temperature.

Full heat treatments i.e., solution, quenching and aging are will done for the samples. Solution treatment consist of heating in electrical furnace, at 500^0C ($\pm1^0C$) for 5 hours and then quenching in water at room temperature (similar to 27^0C). After 1 hour, the samples remove from water and dry. The aging treatment shall be done in the same furnace at 170^0C for 2 hours.

Density and Porosity Analysis

The bulk densities of the samples will measure by using the Archimedes principle according to ASTM International B962-13, (2013) Standard. Water proof material use to tie sample and data for weight in the air, $W_a$will taken. All samples must soak in distilled water and then vacuum to remove the air bubble in the sample as long as 60 minutes. Afterward, the weight data on water, W_b are taken. The water will remove using cloth. The weight data after complete soaking, W_c will taken to the last stage. The percentages of bulk density of all samples determine using the Equation 1. The porosity analysis measures follow on ASTM International B963-13, (2013)protocols. The samples measure by Electronic balance and initial weight are will record. Percentages of porosity calculate according to the Equation 2.

$$\text{Percent of bulk density} = \frac{W_a}{W_c - W_b} \text{ X } 1 \quad (1)$$

where, W_a isweight in air, W_b isweight in water and W_c isweight sample after soaking.

$$\text{Porosity} = \frac{m_2 - m_1}{\rho} \text{ X } \frac{1}{v} \text{ x } 1 \quad (2)$$

where, $m_1$is mass of test piece (g), $m_2$is mass of test piece after absorbing (g), ϱ is density of test oil (g/cm^3) and V is volume of test piece (cm^3)

Microstructure Analysis

Microstructure analyses will done by using an optical microscope and the high magnifications ranging from 400X to 800X are chosen. A JEOL JSM-6064 LA Scanning Electron Microscope equipped with an Energy Dispersive X-ray Spectroscopy (EDS)use for analyzing the morphology of the samples. Keller's reagent is chosen to etch the surface wherever required.

Hardness Analysis

Standard Test Method for Microindentation Hardness of Materials(ASTM International E384-11, 2011) is a guide for hardness analysis. Vickers hardness tester equipped with a diamond indenter of square shaped base and an angle of 136^0 between face using as an equipment to measure the hardness. The measurement will be performing as an average value of 10 points taken for each sample with minimum deviation. The load applies for this measurement is 1 kgf and the indentation time is 10 second.

Wear Analysis

The dry wear tests of the specimens conduct using a pin on disc sliding wear testing machine by following the Standard Test Method for Wear Testing with a Pin-on-Disk Apparatus (ASTM International G99-05, 2010) protocol. The wear tests will conduct at load 5N, a constant sliding speed of 1.0 m/s and sliding distance 0.1, 0.5, 1, 5 and 10 km. An electronic weight balance with an accuracy of 0.1 mg uses to measure the weight of the samples before and after each test. By Equation3, the volume loss (mm^3) will determine by measure the density and weight loss from the specimens. Meanwhile, wear rate calculating using volume loss per sliding distance (mm^3/ m). The sliding distance and wear coefficient using the Equation4 and Equation5.

Volume loss (V) , where W is mass loss (g) and r is density (g/cm^3) (3)

Sliding distance (S) = , (4)

where, D is sliding diameter (mm), R is speed (rpm) and t is sliding time (s)

Wear Coefficient (K) = (5)

where, V is volume loss (mm^3), Hv is Vickers number (kg/mm^2), P is load (kg) and S is sliding distance (mm)

CONCLUSION AND EXPECTED RESULT

a) AMCs present a good of mechanical properties (such as high elastic modulus, tensile force, good fatigue resistance, low density and high wear resistance) depending on the chemical composition of the Al-matrix.
b) By adding Mg_2Si particles improve the hardness and wear resistance and after solution and aging heat treatment, the hardness and wear resistance were improve further;
c) The Mg_2Si morphology with 15wt% particle present in the *cross-like*;
d) The dendrite boundaries are surround by the pseudo eutectic constituent Al-Mg_2Si, where the Mg_2Si precipitates have the morphology of Chinese script;
e) Stir casting have potential controlling the microstructure, improving the mechanical and wear characteristics of producing Al based composites.

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