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Effects of SiC particulate-reinforced on the fluidity and mechanical properties of Aluminium Matrix Composite through stir casting route

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Abstract. Stir casting method has been widely known to produce Aluminum matrix composite (AMC). Fluidity is a critical parameter to determine casting component with free of defects, especially for thin wall part. This study aimed to analyze fluidity and mechanical properties of AMC. Analysis of fluidity of molten metal was performed using a carbon steel spiral permanent mold. Moreover, hardness and density are characterized to investigate of additional reinforcing phase. Experiment results show that the fluidity length of AMC melts increase with the additional percentage of SiC particulate. Furthermore, hardness and density result show maximum hardness is obtained in a maximum composition of SiC particulate. Analysis morphology using SEM revealed that the failure mode of fracture is the combination of ductile and brittle mode.

1. Introduction

Aluminum matrix composites (AMC) are combination two or more materials with aluminum alloys as matrix composite which are designed for specific purpose. AMC development is expected to fill the requirement of structural components that cannot be filled by conventional materials, especially components in extreme conditions. The combination of metals and ceramics in the fabrication of AMC is expected to produce superior material for advanced industrial applications.

In aerospace and automotive industry, weight reduction of a component is a classic issue in term of cost saving. Ductility and toughness properties of Aluminum alloy properties are suitable to combining with Silicon carbide properties which is excellent high strength and high modulus to fill the advance industry requirements. Fabrication of AMC can be classified into three type; liquid state process, solid-state process and liquid-solid process. Stir casting method is one of liquid state process which is the simple and least expensive to produce components [1]. In stir casting method, reinforcement material commonly in powder shape is mixed with molten metal using stirrer to obtain homogeny distribution of reinforcing phase in molten metal. Mechanical properties of AMC casting product with some reinforcement such as alumina and SiC have been reported. In the certain composition of reinforcement has significant contribution for mechanical properties of casting product [2-4].

In aerospace and automotive industry, components with thin wall can be observed easily. Fabrication complex shape component such as thin wall component with casting route should consider the fluidity properties of molten metal [5]. In foundry environment, definition of fluidity or mold-

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filling ability is the ability of molten metal to flow to fill the narrow space in the mold before it freezes.

Fluidity is one of critical parameter in casting to produce casting part with free of defects especially for casting method rely on gravity force. Fluidity of molten metal can be determined many factors such as pouring temperature, mold temperature, weight percentage, type of composition and homogeneity of particle distribution [6-8]. Generally, measurements of fluidity properties were conducted using the vacuum fluidity and the spiral tests with distance of flow metals before freezing as indicator measurement.

Normally, maximum value of fluidity properties is achieved on pure metal or eutectic composition which is related to the solidification structures [9, 10]. This behavior is in line with Al-Zn binary alloys fluidity as shown on the Figure 1.

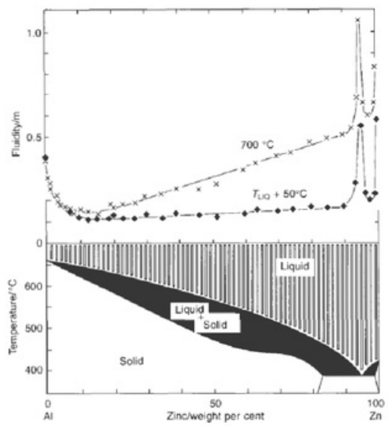

Figure 1. Fluidity of Al-Zn alloys as a function of Zinc levels with pouring temperature 700 °C [11]

Al-Zn binary alloys fluidity at a given pouring temperature initially decreases rapidly as the amount of zinc element increases. Fluidity of Al-Zn increases again as the alloy composition approaches the eutectic point. Moreover at near eutectic point fluidity of Al-Zn increase significantly. Flemings [12] has derived theoretical model prediction for monolithic alloy fluidity as

$$L_f = \left[\frac{\rho_s\, av}{2h\,(T_m - T_o)}\right](H + C\Delta T)$$

where ;

L_f : length of fluidity
ρ_s : density of the solid alloy
a : radius of the spiral fluidity channel
v : velocity of the fluid
H : latent heat of fusion
C : heat capacity
ΔT : superheat of the melt
T_o : mold temperature.
T_m : melting temperature
h :heat transfer coefficient.

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Based on theoretical models developed by Flemings many of the factors that determine the length of fluidity result. This equation can be expanded to predict the composite material by modifying the density, heat capacity variable and latent heat of fusion [13].

Measurements of fluidity length of composite aluminum alloy with reinforcing ceramics have been conducted by previous author [7, 14-16]. Their result show that fluidity properties of composite aluminum alloy has strong correlation with the additional of type, sizes of reinforcing particle. Moreover parameter process such as pouring temperature and holding time also has strong contribution to determine length of fluidity.

Aluminum matrix composites composition play important role to influence of fluidity value which is responsible to avoid defect formation on cast part. Significant composition change when reinforcing phase is added to the molten aluminum alloy. This present study aimed to investigate the effect of SiC addition on the fluidity and mechanical properties of the Al-Zn alloy.

2. Experimental Method

In this study, Aluminum matrix composites (AMC) sample was fabricated using stir casting with Silicon Carbide (SiC) as reinforcing phase. Silicon carbide (SiC) is categorized as ceramic material comprising to carbon and silicon which is melting point at temperature 2830 °C. Al-Zn was utilized as matrix material with chemical composition as shown on Table 1. SiC with various composition (5, 10 15 and 20 wt %) was mixed into the molten metal during stir process was performed. Stirring process is necessary to avoid particle segregation due to the density difference between matrix and reinforcing phase [17]. In this work, the melt was stirred using blade which was connected to electric motor. Stirring speed of blade was adjusted on 350 rpm with stirring time 3 minute. The melt of molten metal of Al-Zn with reinforcing phase was poured at temperature 750 ºC into the spiral permanent mold. K-type thermometer was utilized to measure temperature of the melt before pouring was conducted. Analysis of fluidity of molten metal was performed using a carbon steel spiral permanent mold as shown on the Figure . Moreover, effects of additional reinforcing phase on AMC are characterized in term of hardness and density properties.

Table 1. Chemical composition of aluminium alloy used as the base material in this work.

elements	Al	Zn	Cu	Fe	Pb	Ni	Ti	Cr	Sn
wt %	Reminder	3.38	1.83	1.10	0.16	0.09	0.07	0.06	0.04

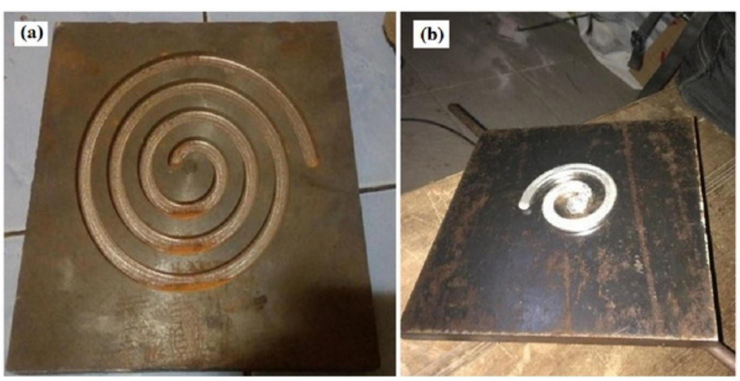

Figure 2. (a) The spiral permanent mold (b) spiral sand mold specimen

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3. Results and discussion

Fluidity of Al-Zn alloys with various percentage of Silicon Carbide (SiC) at temperature 750 ºC as shown on the Figure 3. AMC fluidity properties increase with the additional weight percentage of SiC. Increasing significantly of was obtained before 10 wt% while after 10 wt% SiC the fluidity length tend to plateau condition with additional percentage of SiC. At temperature above 740ºC occurs reaction between aluminum alloy with SiC resulting the formation of Al4C3 [13]. The additional of SiC into aluminum melt is believed to increasing the amount of Al4C3 content in the melt which decreasing the fluidity length.

During additional SiC into liquid aluminum alloy at melting temperature, solid fraction of composite melt will increase which can be determined as

$$fs,t = fp + fs\ (1\text{-}fp)$$

where fs,t is the total solid fraction; fs is the matrix solid fraction; fp is the particle solid fraction. The Increasing composite of solid fraction can decrease fluidity properties of the composite aluminum alloy[15].

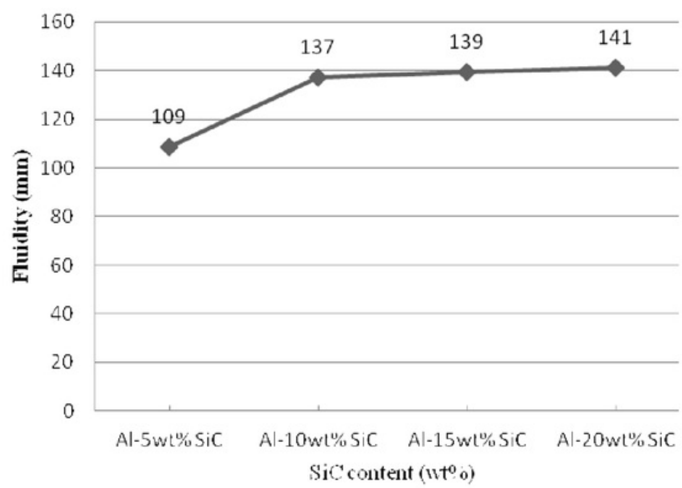

Figure 3. Fluidity results of Al-Zn for various composition of SiC with pouring temperature 750 ºC

Hardness value is ability of material resistant to plastic deformation plastic against indentation with an applied load. In this work hardness measurement was conducted using Vickers hardness number (VHN). Figure shows hardness result of AMC with pouring temperature 750 ºC, hardness value tend to increase linearly with the increasing reinforcing phase percentage. The significant hardness value increasing was obtained between range 5 wt% until 10 wt% of SiC. After 10 wt% SiC composition the hardness value of AMC increase gradually. In others world, SiC as reinforcing phase has significant role to determine hardness properties of Al-Zn before composition of SiC 10 wt%.

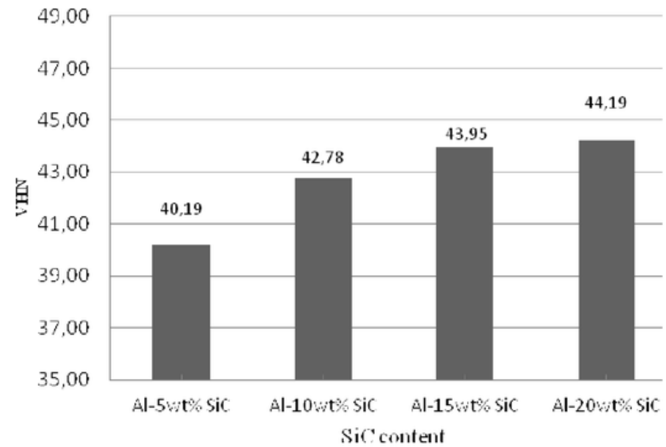

Figure 4. Hardness results of Al-Zn for various composition of SiC with pouring temperature 750 ºC

The addition of SiC powder to liquid aluminum gives an increased density value of AMC. Figure 5 shows an increase in the value of linear density by increasing the number of SiC.

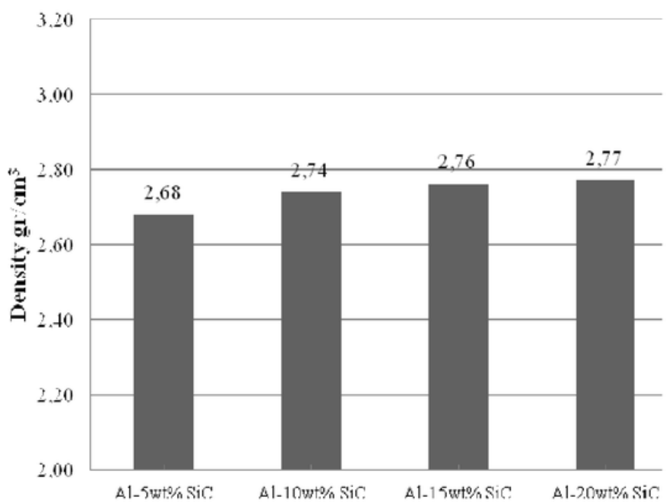

Figure 5. Density results of Al-Zn for various composition of SiC with pouring temperature 750 ºC

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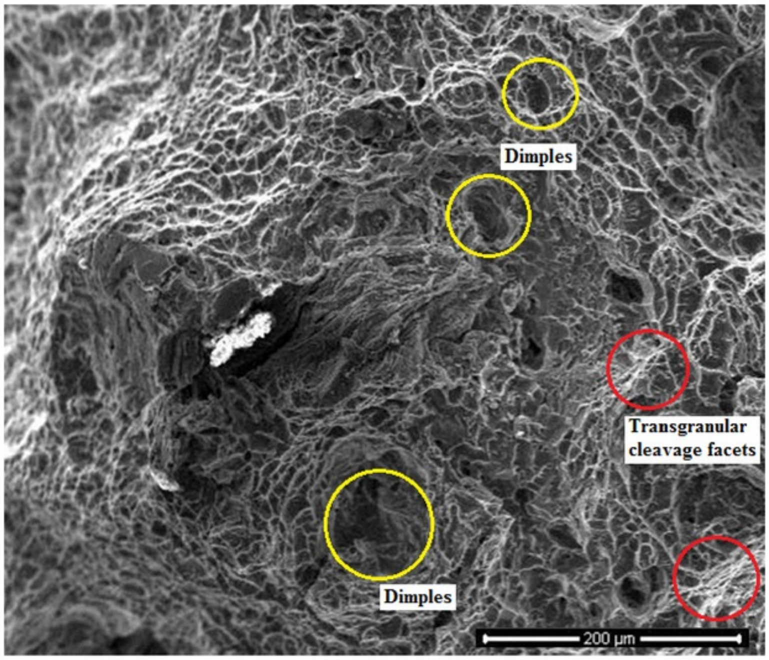

Figure 6. SEM images of fracture surfaces of the AMC samples

Specimen was broken to analysis surface morfology cross section of AMC specimen which conducted using SEM images as shown on the Figure 6 . SEM observation shows that the failure of AMC due to a combination of brittle fracture and dimple ductile fracture. Fracture britlle of AMC is indicated by transgranular cleavage facet as shown on with red circle on the Figure 6. Some dimples have been found on surface of the sample which are indicated ductile fracture as shown on yellow circle. Moreover, SEM analysis revealed that inclusion was observed on microstructure of cast part. Formation of inclusion on the cast part was believed due to stirring process result.

4. Conclusion

Effects of SiC particulate-reinforced on the fluidity and hardness properties of Aluminum Matrix Composite through stir casting route from the experimental results the following conclusions are drawn: The fluidity length of AMC melts increase with additional percentage of SiC particulate, the significant increase of fluidity length of was obtained before 10 wt% SiC particulate. The Vicker's hardness value of the composites increases with additional of SiC particles. SEM analysis on surface morphology revealed that the failure mode of fracture is combination of ductile and brittle mode.

References

[1] Mavhungu ST, Akinlabi ET, Onitiri MA, Varachia FM. Aluminum Matrix Composites for Industrial Use: Advances and Trends. Procedia Manufacturing. 2017;7:178-82.

[2] Balasubramanian I, Maheswaran R. Effect of inclusion of SiC particulates on the mechanical resistance behaviour of stir-cast AA6063/SiC composites. Materials & Design (1980-2015). 2015;65:511-20.

[3] Sijo MT, Jayadevan KR. Analysis of Stir Cast Aluminium Silicon Carbide Metal Matrix Composite: A Comprehensive Review. Procedia Technology. 2016;24:379-85.

[4] Singh J, Chauhan A. Characterization of hybrid aluminum matrix composites for advanced

applications – A review. Journal of Materials Research and Technology. 2016;5:159-69.
[5] Timelli G, Bonollo F. Fluidity of aluminium die castings alloy. Int J Cast Metal Res. 2007;20:304-11.
[6] Zhang ZL, Zhang ZF, Xu J, Zhang H, Mao WM. Effect of Mechanical Stirring and Air Pressure on the Fluidity of SiCp/A357 Composites. Materials Science Forum. 2017;898:1000-6.
[7] Emamy M, Abbasi R, Kaboli S, Campbell J. Fluidity of Al based metal matrix composites containing Al2O3and SiC particles. Int J Cast Metal Res. 2013;22:430-7.
[8] Shi CJ, Zhang Z, Chen XG. Characterisation of Al–B4C composite microstructures and their effect on fluidity. Can Metall Quart. 2013;51:462-70.
[9] Morando C, Fornaro O, Garbellini O, Palacio H. Fluidity on Metallic Eutectic Alloys. Procedia Materials Science. 2015;8:959-67.
[10] Di Sabatino M, Arnberg L. Effect of grain refinement and dissolved hydrogen on the fluidity of A356 alloy. Int J Cast Metal Res. 2013;18:181-6.
[11] Campbell J. Castings: Elsevier Science; 2003.
[12] Flemings MC. Solidification Processing: McGraw-Hill; 1974.
[13] Yarandi FM, Rohatgi PK, Ray S. Fluidity and Microstructure Formation During Flow of AI-SiC Particle Composites. Journal of Materials Engineering and Performance. 1993;2:359-64.
[14] Shi CJ, Zhang Z, Chen XG. Microstructure and fluidity evolution during recycling of Al–B4C metal matrix composites. J Compos Mater. 2011;46:641-52.
[15] Zhang ZL, Zhang ZF, Xu J, Mao WM. Rheological Behavior and Fluidity of Semi-Solid SiCp/A357 Composites with Different SiC Addition Levels. Solid State Phenomena. 2016;256:126-32.
[16] Kolsgaard A, Brusethaug S. Fluidity of aluminium alloy AlSi7Mg–SiC particulate composite melts. Mater Sci Tech-Lond. 2013;10:545-51.
[17] McLean A, Soda H, Xia Q, Pramanick AK, Ohno A, Motoyasu G, et al. SiC particulate-reinforced, aluminium-matrix composite rods and wires produced by a new continuous casting route. Composites Part A: Applied Science and Manufacturing. 1997;28:153-62.

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