KEMENTERIAN PENDIDIKAN TINGGI

JOJAPS

eISSN 2504-8457

POLITEKNIK MALAYSIA PORT DICKSON

Journal Online Jaringan COT POLIPD (JOJAPS)

Characterization of Aluminum Matrix Composite Al-9Zn-0.1Mg-3Si Reinforced with Ceramic Particulate

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Abstract

Nowadays, aluminum alloys are widely used for automotive components such as piston, cylinder head and valve. To enhance its mechanical properties, it can be strengthen by ceramic particulate reinforcement. This research studied the effect of variation of ceramic particulate reinforcement in Al-9Zn-0.1Mg-3Si composite for piston application. The volumetric variations of ceramic particulate are 10% alumina, 10% SiC and 5% alumina + 5 % SiC. The composites are produced by squeeze casting process following with characterization testing of composition, hardness testing, optical and electron microscopy examination. The results showed that composite reinforced with 5% alumina + 5% SiC has the highest hardness of 55 HRB with less of porosity than other composites. Composite reinforced with 10% SiC revealed biggest porosity of 0.25%.

Key-word: - aluminum composite, ceramic particulate, alumina, SiC, squeeze casting

1. Introduction

The use of aluminium alloy as automotive components keeps increasing every year. This can be seen from the usage of aluminium alloys metal that secure the second place after the use of iron or steel metal [1,2]. Aluminum alloys are used to make piston, machine block, cylinder head, and valve. Since 2005, the number of vehicle in Indonesia reached 38,156,278, which consisted of 28,556,498 two wheels vehicles, and 9,559,780 four wheels vehicles [3]. Research at the global market showed that projection for ground transportation components will be needed in 2019 is increasing of 5,5 % since 2013 [4,5].

Improving properties of aluminum alloy can be achieved by reinforcing with ceramic materials such as Al_2O_3 (alumina), silicon carbide (SiC) and graphite, which named by composite materials [2]. Composite is combination of two or more material that is macroscopically different, forming a material with superior characteristics from its parent material. Based on the binding and reinforcement material, a few composites are known, they are polymer matrix composite, metal matrix composite (MMC) and ceramic matrix composite.

MMC is composite material with metal as the matrix and usually reinforced with ceramic. The ceramic particulates could influence the mechanical properties differently. Increasing ceramic reinforcement will enhance strength, hardness and wear resistance of composites, thus more challenging in its manufacturing. One important target in composite manufacturing is minimizing porosity in matrix. This aim could be accomplished with squeeze casting process. This process could increase physical and mechanical characteristic especially on composites material with aluminum and magnesium as matrix [6]. Squeeze on aluminum base alloy could produce cast with properties such in forging products [7,8]. Therefore, this research studied characterization of four-stroke piston that made from ceramic particulate reinforced aluminum matrix composites with varied of volumetric of SiC and alumina.

2. Methodology

The pistons are made from metal matrix composite of Al-9Zn-0.1Mg-3Si and reinforced with alumina powder (5µm), and SiC (37µm). The volumetric variations of reinforcement are 10 % alumina, 10 % SiC and 5 % alumina + 5 % SiC. The metal matrix is melt in crucible furnace at 800 °C, then the preheated ceramic particle is poured into the furnace and stirred with rotation of 7500 rpm. The pistons are produced with squeeze casting technology by applying pressure of 30 MPa in metal mold to minimize porosities. In order to avoid shrinkage factor during casting process, mold volume is added as much as 20 % of tolerance. Then pistons are characterized with chemical composition evaluation, hardness testing, metallography examination using optical and electron microscopy. The optical microscopy is used to examine the microstructure of composite and porosity of cast products. The electron microscopy is used to study the distribution of ceramic particle also the interface area.

3. Discussion

The result of chemical composition test, material of aluminum composite, and Mg, Zn, Si matrix with Squeeze casting method can be seen on Table 1. Chemical composition testing is conducted using Spectrometer after doing squeeze casting. This test is done based on ASTM E1251. The high content of Si substance could increase the fluidity of alloy, whereas Mg guiding element could affect the contact angle on the interface area because it is capable to increase driving force in wetting [9]. The high content of Mg could decrease contact angle because Mg is a very reactive metal with lowest superficial tension compared to Al and SiC, therefore their existence is very important for the process of Al and SiC infiltration as they could prevent the forming of Al_4C_3 that are hard and brittle.

Table 1 Chemical composition of Metal Matrix Composite Al-9Zn-0.1Mg-3Si Reinforced with Alumina and SiC

Reinforcement	Composition (%)			
	Si	Zn	Mg	Al
10 % Al_2O_3	3.42	9.01	0.05	balance
10 % SiC	12.71	9.6	0.06	balance
5 % Al_2O_3 + 5 % SiC	7.9	9.76	0.09	balance

Data from Brinell Hardness test result on aluminum composite with Zn, Mg, Si matrix, and reinforcement variation such as 10 % Alumina, 10 % SiC, and 5 % Alumina + 5 % SiC can be seen on Table 2. From the above data, it can be seen that the average score of hardness of each sample is different. Material with 10% alumina reinforcement has hardness average as much as 39 HRB. Reinforcement material 10% SiC has average score of hardness as much as 51 HRB. And material with 5% alumina + 5% SiC reinforcement has hardness average value of 55 HRB. Sample with 10% SiC has lower hardness compared to the one with 10% alumina and 5% alumina + 5%SiC reinforcement. From this data, it can be seen that the mix of alumina and SiC reinforcement is highly influencing the hardness of aluminum composite. Aside from squeeze process on the semisolid process of aluminum composite, mixing the two reinforcement of alumina and SiC could improve the microstructure, causing the hardness to increase.

Table 2 Hardness Value of Metal Matrix Composite Al-9Zn-0.1Mg-3Si Reinforced with Alumina and SiC

Reinforcement	Brinell Hardness Test Location					HRB Average
	1	2	3	4	5	
10 % Al_2O_3	39.3	37.0	38.8	39.1	39.5	39 HRB
10 % SiC	50.9	48.7	51,9	49.9	51.8	51 HRB
5 % Al_2O_3 + 5 % SiC	53.7	55,9	54.7	55.8	53.3	55 HRB

Metallography examination is meant to obtain a picture of micro and macro structures of aluminum composite sample surface through squeeze casting process with variation of reinforcement. Microstructure can be seen from the image below, which shows the metallography test result starting from 10 % alumina, 10 % SiC and 5 % alumina + 5 % SiC composites.

Figure 1 Microstructure of Composite Al-9Zn-0.1Mg-3Si Reinforced with Ceramic Particulate

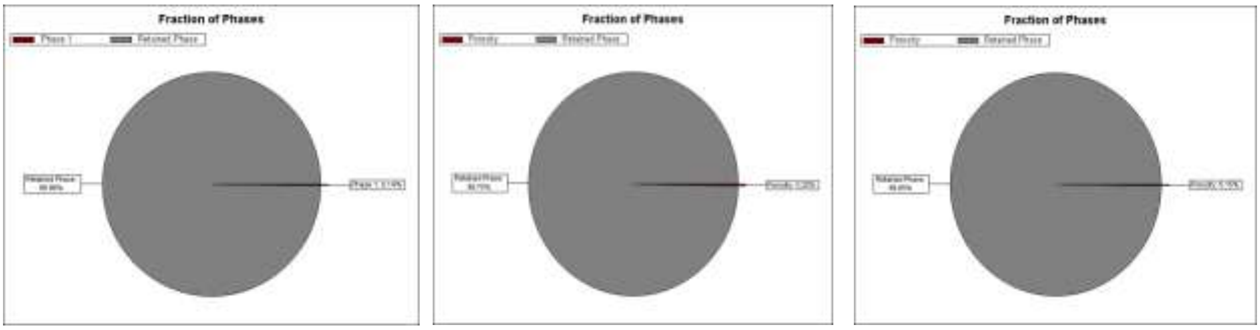
Figure 1 shows microstructure of aluminum composite with Al-9Zn-0.1Mg-3Si matrix using squeeze casting with pressure of 30 MPa. The result of microstructure observation shows that structure on aluminum composite with 10% alumina reinforces has dendritic shape. Low Zn element on Al-Zn-Mg-Si alloy (<30% weight) is harder to form dendrite grain structure on eutectic area [9]. Solubility of magnesium atom within pure aluminum on temperature 800^0C is enormous. Due to the solubility, magnesium is able to react well with alumina particle, so that Mg element could wet alumina particle [10]. The image also shows that microstructure of aluminum composite with 10% alumina reinforcement and matrix of Al-9Zn-0.1Mg-3Si alloy has differences that are the porosity happened quite a lot. The cause of porosity on aluminum alloy pouring is gas.

Hydrogen gas is formed due to liquid metal when stirring process started; it could oxidize with carbon monoxide and carbon dioxide. Therefore, on the observation of microstructure, porosity defect happens a large number in 10 % SiC aluminum matrix composite. Figure 1 also shows microstructure of aluminum with Al-9Zn-0.1Mg-3Si alloy and 5% alumina + 5% SiC reinforcement. The observation result shows a significant change compared to aluminum matrix with 10 % alumina and 10 % SiC composite.

Thus, the mixture of particles could increase the quality of specimen. This is caused by the role of alumina with small diameter that could stop the flow rate of dendrite, therefore the structure of 5 % alumina + 5 % SiC composite is still in dendritic shape, minimizing the porosity whereas the role of SiC particle with larger diameter increases the hardness of specimen.

From the result of four-stroke piston casting with Al-9Zn-0.1Mg-3Si material and variation of reinforcement using squeeze casting method, it is proven that this could reduce porosity defect. The result of porosity test could be seen in the Figure 2. Composite with 10 % SiC reinforcement has bigger porosity value than composite with 10 % alumina reinforcement with porosity percentage of 0.14%. The existence of porosity has caused a decrease in mechanical properties of composite. In general, the total of porosity is highly affected by SiC particle that has random orientation toward composite.

This cause the interface bonding between aluminum powder and SiC particle to form more pores than if aluminum powder were combined with alumina particle.Moreover, the porosity is closely related with compatibility; the smaller the powder size, the greater the contact surface area between grains. If the porosity is smaller, then the compatibility properties of material will be higher and the density will increase.



10 % Alumina 10 % SiC 5% Alumina + %% SiC

Figure 2 Porosity Measurement of Composite Al-9Zn-0.1Mg-3Si Reinforced with Ceramic Particulate

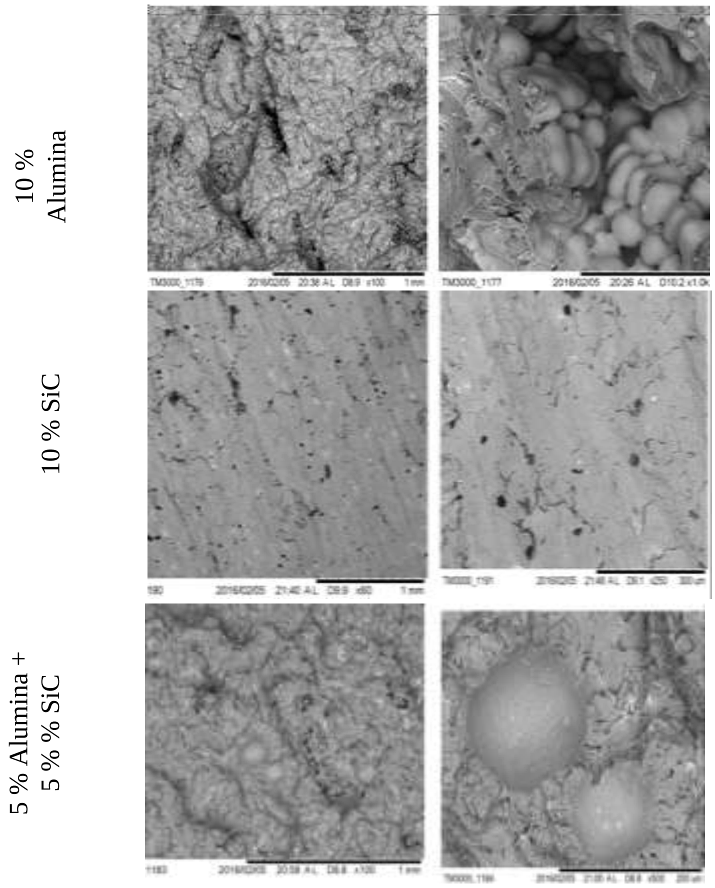


Figure 2 SEM Observation on Al-9Zn-0.1Mg-3Si Composite Reinforced with Ceramic Particulate

Figure 3 shows that alumina particle globule inside aluminum matrix. This happened because the process of mixing matrix with reinforcement was sub-optimal due to uneven stirring process. On the production process of 10 % alumina reinforced composite sample, the stirring process of aluminum matrix was done on the surface of the matrix, making the matrix and reinforcement not properly mixed. It is also seen that the structure resulting from the casting is still dendritic, which is caused by insufficient Mg element addition. Thus, Mg element as much as 0.1 wt.% has low wettability. SiC particles are seen to spread inside the aluminum matrix.

On 10 % SiC reinforcement composite, the stirring is good enough making SiC reinforcement particle to spread on the aluminum matrix. Even though the result of stirring on 10 % SiC composite sample is quite good, but there are plenty of porosities in the sample. This occurred because the matrix interface did not have enough wetting agents. Figure 3 also shows clearly that the particle of 5% alumina + 5% SiC are distributed very well in matrix, which seen from the surface without the existence of any void.

4. Conclusion

1. The highest hardness was Al-9Zn-0.1Mg-3Si composite with 5 % alumina + 5 % SiC reinforcement, with value of 55 HRB.
2. Microstructure on aluminum composite appeared to have more dendrites. The dendrite structure on 10% alumina composite appeared to be shorter, while the dendrite structure of 10% SiC composite appeared longer.
3. Composite reinforced with 10 % SiC has highest porosity value of 0.25 %.
4. Electron microscopy examination confirmed the existence of particle globule on aluminum matrix, caused by sub-optimal stirring process.
5. The Al-9-0.1Mg-3Si composite reinforced with 5% alumina + 5% SiC has highest hardness with small porosity percentage of 0.14 %.

Acknowledgment

This work was funded by Ministry of Research, Technology and Higher Education of the Republic of Indonesia. The authors are grateful to Ahmad Ashari for die design and pneumatic machine support for the squeeze casting process.

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