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Characterization of Al-Si-Mg/Al_2O_3 Nano Composite Produced by Stir Casting Method

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Abstract. Al-Si-Mg reinforced with Al_2O_3 nano particles have been made by stir casting method. The vortex produced by stirrer is to distribute the Al_2O_3 nano particles in the molten aluminium. The volume fraction of Al_2O_3 nano particles was varied from 0.5, 1, 2, 3, to 5 Vf%, while the addition of magnesium was 3 Vf% as wetting agent to improve the wettability between Al_2O_3 nano particle and Al-Si-Mg matrix. The effect of Al_2O_3 on characteristic of Al-Si-Mg composites was studied. It is found that the presence of Al_2O_3 nano particle led to significant improve in mechanical properties, especially at addition of 0.5 Vf% Al_2O_3. The ultimate tensile strength reached to 154 MPa with 10.24 % elongation, while the hardness reached to 37.7 HRB followed by decrement in wear rate. The porosity level tend to increase with increasing of Al_2O_3 and caused decrement in mechanical properties.

Introduction

Composite materials are multiphase materials obtained through the artificial combination of different materials in order to attain properties that individual components cannot be attained by themselves. The properties are high specific strength, high specific modulus, good mechanical properties at high temperature, and good wear resistance obtained in metal matrix composites Metal matrix composite (MMCs) mostly use aluminium as a matrix because Al has low density, so the composite has high specific strength[1]. Aluminium is generally used because of easy to process, and high ductility. Ductility is an important factor, since the particle that used is very hard and brittle so the combination between two materials will improve the properties of aluminium. Alumina usualy used as reinforcement because it has good thermal stability, high hardness, and high young modulus[2]. However, the ductility of the MMCs deteriorates significantly with high ceramic particle concentration[3-5]. To fix this problem, alumina with nano-sized particles are used to strengthen the matrix while maintaining good ductility. Metal matrix nano composite can be made through variety of methods such as ultrasonic dispersion, mechanical milling, ball milling, and spray deposition. But ultrasonic dispersion only efficient in laboratory scale [6]. Stir casting has some important advantages such as better matrix-particle bonding, easier control of matrix structure, simplicity, low cost of processing, and near net shape [7]. However, it is extremely difficult for the stir casting method to distribute and disperse nano particles uniformly in metal melts due to large surface-to-volume ratio and their low wettability in metal melts, which induce agglomeration and clustering[8]. In this study nano alumina is expected to improve mechanical properties such as tensile strength but still remain ductility of nano composites. The aim of this study is to obtain the optimum volume fraction of Al_2O_3 addition to Al-Si-Mg alloy in order to achieve composite with maximum mechanical properties.

Experimental Method

Making of Al-Si-Mg/Al_2O_3 nano composite

Materials used for making nano composite were Al-Si-Mg as master alloy matrix, γ-Al_2O_3 with size approximately of 135 nm (supplied by US Nanomaterials Research, Inc) as particles reinforcement and commercially pure magnesium (supplied by PT Baralogam Multijaya, Indonesia) as wetting agent containing 3Vf%. The reinforcement content was varied from 0.5, 1, 2, 3 to 5 % Vf%.

First the reinforcement powder was mixed with 3 wt% stearic acid then crushing in the mortar and stamper to deagglomeration of nano particles. The mixture then heated in muffle furnace at 400^o C for 2 hours to evaporize stearic acid. To improve the wettability of particle in melt, particle is then preheated in 500^o C for 2 hours. Al-Mg-Si master alloy and magnesium was melted at 850^o C, then the alumina particle was poured into alloy melt after the dross was removed. The melt then was stirred at 500 rpm and flushed with Argon for 1 minute.

Characterization of Al-Si-Mg/Al_2O_3 nano composite

The mechanical properties of composites were measured including tensile strength, hardness, density, porosity, and wear resistance. Tensile testing was carried out using GOTECH AI-7000 LA 10 in accordance with ASTM E8M-09. The tensile testing was prepared three specimens for each variable. Hardness testing was carried out using Rocky machine with Rockwell B method in accordance with ASTM E18-11. For each sample, five hardness readings on randomly selected regions were taken in order to eliminate the segregation effects and get a representative value of the matrix material hardness. The density of composite was measured using Archimedean method. The porosity of composite was also determined. Wear testing was carried out using Ogoshi method with following parameter: load (P_0) 12.6 kg, sliding distance (l_0) 400 m, and sliding speed 1.97 m/s respectively. Sample was grinded using SiC paper #80 before testing. The thickness of disk used in this testing is 3 mm, with radius (r) of 10 mm. The trail was then measured using measuring microscope. The specific wear rate is calculated following the formula described by Jatisukamto et al[9]. Metallography preparation was conducted by grinding using emery paper started from 80#, #150, #240, #400, #600, #800, #1000, #1200 to #1500, then polished using TiO_2 powder to remove strach from grinding process. Keller's reagent (2 ml HF (conc.), 5 ml HNO_3 (conc.), 3 ml HCL and 190 ml aquadest was used as an etching agent. All preparataion samples were observed using OLYMPUS BX41M-LED optical microscope and further analysys using Field Emission Scanning Electron Microscope (FESEM) link to Energy Dispersive Spectrum (EDS) by INSPECT F50 FE-SEM.

Results and Discussion

Mechanical Properties of Al-Si-Mg/Al_2O_3 nano composite

The effect of Vf% nano alumina on tensile strength and elongation are shown in Fig 1. The addition of nano alumina can increase tensile strength of Al-Si-Mg matrix compared to matrix without nano alumina. The highest tensile strength is obtained at 0.5 % Vf Al_2O_3, then decrease with addition in the range between 1 Vf% and 5 Vf% Al_2O_3. Tensile strength increase is caused by grain refinement mechanism and the presence of nano alumina particle in Al-Si-Mg matrix that hindered dislocation movement[10]. Tensile strength is decreased because the nano alumina can not be wetted completely by aluminium as well as the presence of micro porosities with higher volume fraction of nano alumina.

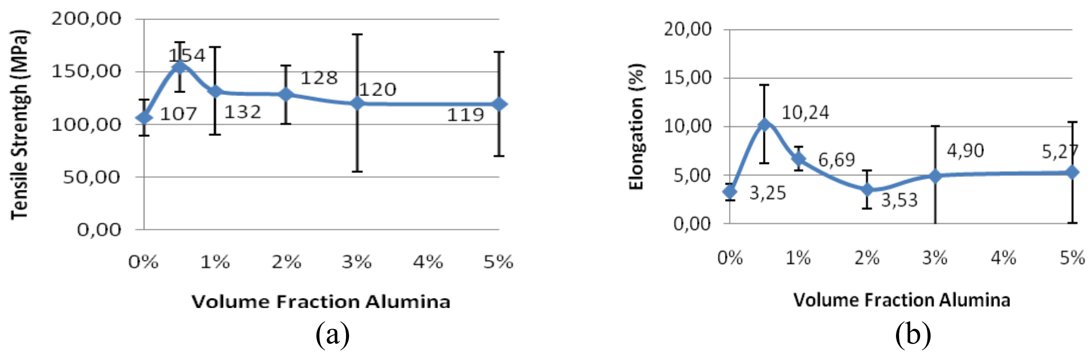
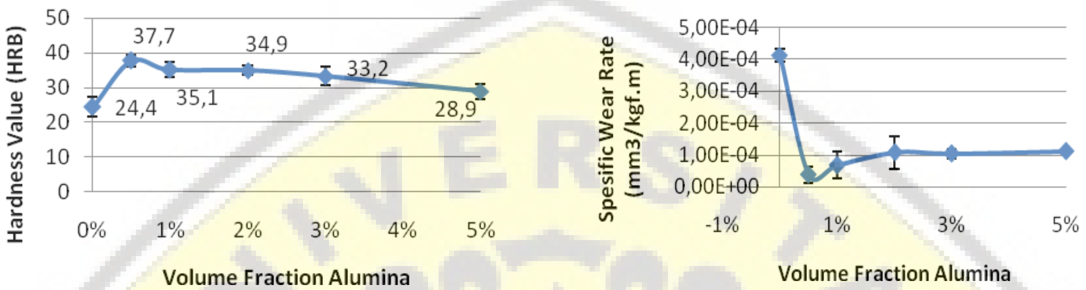


Figure 1. The effect of volume fraction of alumina on (a) tensile strength (b) elongation of Al-Si-Mg nano composite

In the other hand, the addition of nano alumina into Al-Si-Mg can increase the elongation of composite in almost volume fractions compared to Al-Si-Mg without alumina. The highest elongation is obtained at 0.5 Vf% Al_2O_3 which is the same as for tensile strength, which means that the addition of nano alumina up to 0.5Vf% can increase both tensile strength and elongation. The enhancement of elongation is caused by grain refinement mechanism. By this mechanism, tensile strength can be enchanced while maintaining good ductility[11]. This is occured because the strain distribution is more homogen and stress concentration reduction[12]. When the volume fraction is exceeded its critical, it will not have any significant effect on grain size[13]. Reduction of elongation at 2Vf% Al_2O_3 and little increased after addtion between 3 and 5 Vf% Al_2O_3 are caused by uneven distribution of alumina particle as shown in Fig. 1 b.

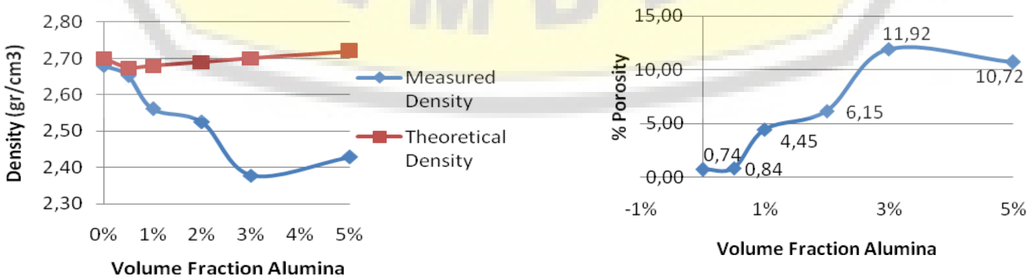


(a) (b)

Figure 2. Effect of volume fraction alumina on (a) hardness and (b) wear rate of nanocomposite

Fig 2 shows the hardness and wear rate of nano composite with different volume fraction of nano alumina. The addition of nano alumina on Al-Si-Mg matrix increased hardness as compared to alloy without nano alumina. The highest hardness and the lowest wear rate are obtained at 0.5 Vf% Al_2O_3. The increase of hardness and decrease of wear rate are caused by nano alumina particle that impede dislocation movement, and grain refinement mechanism which occured in this composies. The hard alumina particles effectively resist the micro cutting action of abrasives[14]. The increase of wear rate between 1 Vf% and 5 Vf% Al_2O_3 is caused by decreasing hardness value and low wettability of alumina.

Fig 3 shows the theoretical and measured density as well as porosity content in nano composite for different Vf% of alumina. Theoretical density tend to increase with higher of Vf% Al_2O_3 while measured density is decreased. The theoretical density increased significantly between 3 Vf% and 5 Vf% Al_2O_3 due to higher density of Al_2O_3 than that of Al (i.e. 3.7 gr/cm^3 Vs 2.7 gr/cm^3). However measured density is decreased with higher Al_2O_3 content due to the porosities increased. Porosity is attributed by poor wetting between Al_2O_3 particles and matrix. Porosity is also caused by gas entrapment during stirring process and therefore hindered liquid metal flow due to more particle clustering[15].



(a) (b)

Figure 3. Effect of volume fraction of alumina on (a) theoretical and measured density, and (b) porosity content of nano composite

Microstructural Observation of Al-Si-Mg/Al_2O_3 nano composite

Microstructures of nano composite with different Vf% Al_2O_3 is shown in Fig 4. The addition of nano alumina into Al-Si-Mg affected grain finer than that of without nano alumina. The finest grain is obtained at 0.5 % Vf Al_2O_3. The addition of Al_2O_3 between 1 Vf% and 5 Vf% generated the grain size larger compared to nano composite with 0.5 % Vf Al_2O_3, but still smaller than that of without nano alumina. The grain refinement mechanism at 0.5 % Vf is predicted by well distributed of nano alumina particles in Al-Si-Mg matrix that act as nucleating of grain formation[7]. Furthermore, the smaller grain size is caused by pinning effect of particle alumina that delay grain growth process[16]. The addition of nano alumina between 1 Vf% and 5 Vf% caused larger grain size because it is predicted of poor distributed of alumina in Al-Si-Mg matrix, so grain refinement only occur in some point.

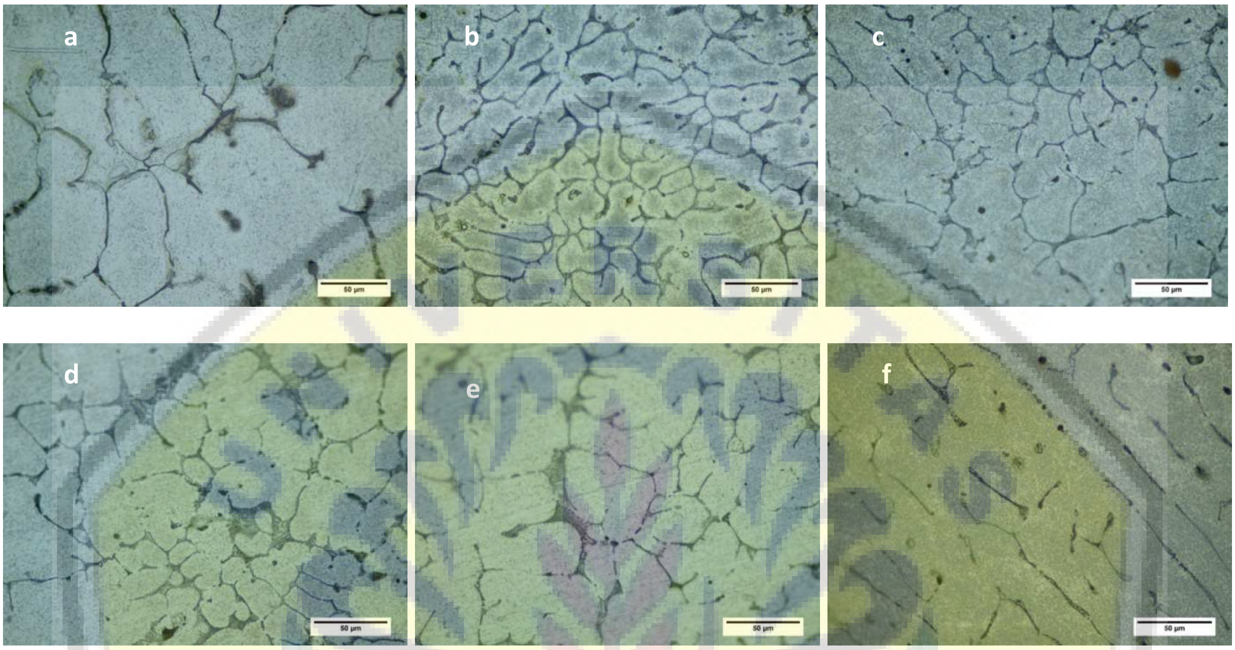


Figure 4. Optical microstructure of Al-Si-Mg with (a) 0 Vf% (b) 0.5 Vf% (c) 1 Vf% (d) 2 Vf% (e) 3 Vf% and (f) 5 Vf% of Al_2O_3

Furter microstructure observation using FE-SEM can be seen in Fig. 5 and the phases of each spot also detected using EDS in Table 1.

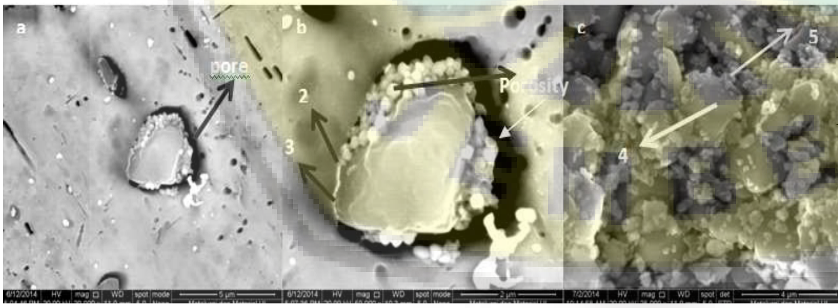


Table 1. Composition of spots in Fig.5

Spot	Composition (wt %)			
	Al	O	Si	Mg
1	55.23	17.74	24.31	2.72
2	55.27	10.29	31.96	2.48
3	56.00	10.66	30.82	2.52
4	59.45	40.55	-	-
5	59.99	40.01	-	-

Figure 5. FE-SEM observation of Al-Si-Mg/ 2Vf% Al_2O_3 at (a) 20.000x (b) 50.000 and (c)nano Al_2O_3 powder

The phase detected by EDS on spot 1 is nano alumina particles in Al-Si-Mg matrix or it is determined as nano composites since the major element is Al (55.23) and O (17.74), Si (24.31) and Mg (2,72) respectively.This means that nano alumina has reacted in aluminium matrix to form nano composites. To further analyze in interface region between alumina particles and matrix, so spot 2 and 3 was detected. In order to verify the presence of MgO or $MgAl_2O_4$ at interface, it needs to presence Mg around 40 % and O around 60 % for MgO, when the presence of Mg, O and Al around 17 % , 45 %, and 38 % respectively to form $MgAl_2O_4$. Spot 2 and 3 are not found the percentage that close to MgO or $MgAl_2O_4$.

Figure 5a and b show that there are agglomeration of alumina particle that stick at larger particle. In order to verify that this is alumina particles, SEM was conducted at nano alumina powder as shown in Fig.5c. It is noted that alumina particles used in this study is nano alumina in the form of agglomerate. The presence of pore at the interface between alumina particle and matrix at Fig. 5a and b are caused by low wettability between nano alumina and Al-Si-Mg.

Summary

Al-Si-Mg/Al_2O_3 nano composite was successfully manufactured using stir casting method. The addition of alumina particles increases mechanical properties of matrix, especially at addition of 0.5 % Vf Al_2O_3. Nano alumina particles in the matrix act as nucleation spot for grain refinement because it produces the smaller grain than that of without nano alumina. Furthermore, alumina particles also impede the dislocation movement that improve mechanical properties of the composite.

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