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Al6061 Reinforced Al2O3 Metal Matrix Composite Produced by Double Blade Stir Casting

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***Abstract*— Demand for materials with excellent mechanical properties and lightweight increase in a recent year especially for high-performance applications. Aluminum reinforced Al_2O_3 composite (AMC) provide this superior property. Therefore in this research, aluminum alloy 6061 was used as a matrix and Al_2O_3 with 10 and 15 Vf-% as a reinforced for making metal matrix composites while magnesium as a wetting agent was used various from 8, 10 to 15 wt-% to improve the wettability between Al and Al_2O_3 since aluminum was poor wetting with ceramic. Al alloy 6061 was melted at 800 ^oC and magnesium was added into Al molten, then Al_2O_3 particles were poured into the melt. The process using double stirrer with a rotational speed of 1000 rpm for 3 minutes to distribute all Al_2O_3 particles in the Al melt and all the gas bubble formed was removed by flushing an Argon for 2 minutes. The composites produced then characterized both mechanical properties and microstructural analysis. The focus of this research is to investigate the effect of Al_2O_3 and Mg on the mechanical properties of composites. The result showed that the optimum tensile strength was 202 MPa which was obtained in composite with 10% Vf-% Al_2O_3 and 10 wt-% Mg. Moreover, hardness and wear resistant to composite increased with the addition of Al_2O_3 and Mg content due to good wetting in composites with 10 wt-% Mg. The double blade stirrer has contributed to the random distribution of Al_2O_3 particles in the molten Al. The microstructure observations showed that the composites yield pores and impaired the mechanical properties of composites.**

***Keywords*— aluminum composite; Al alloy 6061; Al_2O_3 particles; magnesium; double blade stir casting.**

I. INTRODUCTION

Metal–matrix composites (MMCs) as a candidate material in the future due to lightweight and strength for broad application. This material has been developed by other researches [1]–[3]. In this category, the ceramics can be used as a reinforcement in MMCs to improve their properties including tensile strength, hardness, wear resistance, and excellent corrosion resistance. MMCs is a combination of ductility of metallic matrix alloys with high strength of ceramic reinforcements and lead to higher strength both tension and compression as well as higher service temperature capabilities. Due to these properties, MMCs has been used for an automotive application. There are some techniques for making MMCs materials, depending on the reinforced and matrix; the techniques may vary considerably. These techniques are classified into liquid phase or casting processes, liquid-solid processes, and solid-state processes or powder metallurgy [3]–[5]. Among those process, stir casting is widely used for making MMCs. This process allows a conventional metal processing route to be used, hence minimizes the final cost of the product, and significant sized components can be fabricated. There is some method of stirrer including single and double stirrer as well as up-down. There are some factors that should be concerned in casting composites [5]: (i) The particles reinforced distribution is difficult to be (ii) Wettability between particles reinforced and matrix, (iii) Porosity or void formation in the interface (iv) Chemical reactions between the reinforcement material and the matrix alloy.

Therefore, wettability plays an essential role in order to improve the mechanical properties of the metal matrix composite. Besides wetting, the distribution of the reinforced was also important therefore stirrer is useful to distribute the particles reinforced in the molten metal. There is a problem found in making metal matrix composite such as settling of the reinforcement particles during casting that caused cluster distribution which impairs the mechanical properties of composites. The mechanical stirrer used should be made by ceramic which resists at the melting temperature of the metal. The stirring speed should not be too high but should be continuous for a few minutes before the metal melt is poured into a mold through the bottom of the crucible. The vortex formation during stirring is used to create and maintain the proper distribution of the reinforcement in the molten matrix alloy [6].

Technically, stirring helps in distribution all particles into the liquid metal homogenously and maintaining the particles reinforced in suspension. On the other hand, air bubbles and all the other impurities on the surface of the melt could be trapped in the liquid, therefore, remaining porosity and inclusions in the cast product. To remove all air bubbles in the liquid metal so, an inert gas such as argon or nitrogen must be flushed. The successful MMCs was formed when liquid can spread correctly on a solid surface. It was described by wetting between molten metal and solid ceramic. The proposition of the wetting of the ceramic by molten metal is one of surface chemistry and surface tension, therefore magnesium was added to reduce the surface tension of Al melts [7]. This wetting agent can reduce the surface tension of metal melts and hence wet the ceramic particles to form an interface zone. It also forms some phase in the particle-matrix interface, which removes oxygen on reinforcing particle surface. In this study, Al6061/ Al_2O_3 metal matrix composites will be carried out by double blade stir casting, and the effect of Mg and Al_2O_3 on mechanical properties as well as microstructural analysis will be investigated.

II. Material and Method

A. Research Materials

The materials used in this work were Al6061 as a matrix, Al_2O_3 with the particles size of 60 μm as a reinforcement and Mg as a wetting agent. The composition of Al6061 is in Table 1.

TABLE I
THE COMPOSITION OF AL 6061 (WT.-%)

Al	95.2	Cr	0.062
Si	0.798	Fe	0.194
Mg	3.07	Zn	0.003
Cu	0.275	Mn	0.023
Ni	0.094	Sn	0.069
Ti	0.015		

Al6061 reinforced Al_2O_3composite was produced by a stir casting method using double blade stirrer. The amount of Al_2O_3 was 10 vf-%, and 15 vf-% and Mg varied from 8, 10 and 15 wt-% respectively to improve the wetting system between Al 6061 and Al_2O_3particles reinforced.

B. Research Method

The casting process using the electric furnace which is heated until the temperature achieved 750°C, while $Al_2O_3$was heated at 1050°C to remove all of the moisture. After all Al6061 alloy were completely melted then Al_2O_3 prepared was poured into the molten Al. The melt was degassed using Ar gas and then was stirred using double blade stirrer coated by zirconia with a rotational speed of 500 rpm for 2 to 3 minutes. The melt would become more viscous because of the reinforcement particles were distributed inside it. The melt then poured into a permanent tensile test mold.

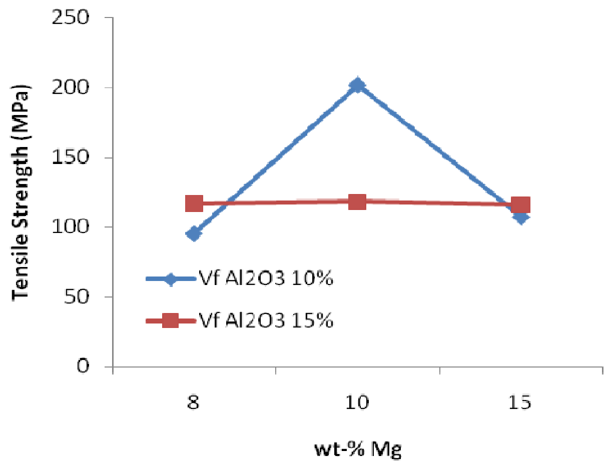
C. Characterization of materials

The tensile test specimens were prepared from the mold has dimensions of 32 mm of gage-length and 6 mm of diameter following ASTM E8 standard. Other characterizations such as hardness and wear tests were also measured. Density and porosity of composites were measured following densitometry method. To observe the microstructure and phases of the composite, the specimens were prepared by using metallographic preparation. First, the specimens were ground using 80, 120, 240, 500, 700, 1000, 1200 grit of emery papers, then they were mechanical polished and finally cleaned with water. The samples then analysed by Field Emission-Scanning Electron (FESEM) link to Energy Dispersive Spectra (EDS), to identify the formation of the phases in the composites.

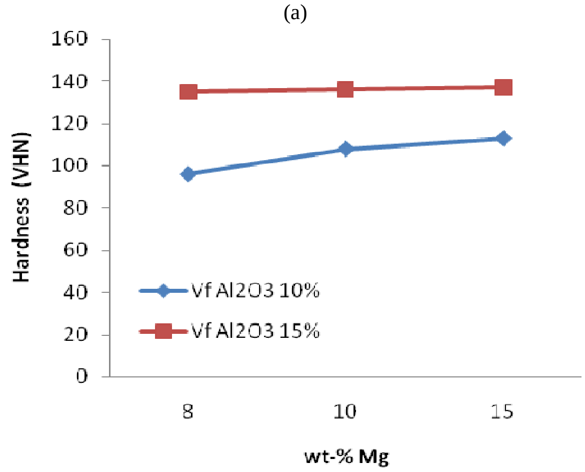
III. Results and Discussion

A. Effect of Al2O3 Particles and Magnesium on Mechanical Properties of Al6061/ Al2O3 Metal Matrix Composites.

The mechanical properties of Al6061/Al_2O_3 metal matrix composites are shown in Fig. 1, including tensile strength, hardness, and wear rate.



(a)



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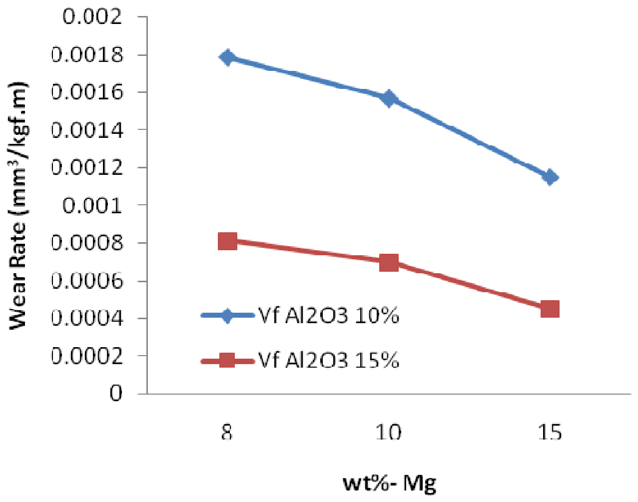


(c)

Fig.1 Effect of Mg on mechanical properties of Al6061/Al_2O_3 metal matrix composites produced by double blade stir casting. a) Tensile strength, b) Hardness, c) Wear rate.

The optimum tensile strength is obtained at 10wt-% Mg and 10vf-% Al_2O_3 with the value of 202 MPa (see Fig. 1a). The composites with 15vf-% Al_2O_3 showed that the tensile strength is slightly increased with increasing of Mg, but the value was lower than composites with 10wt-% Mg and 10vf-% Al_2O_3. The addition of higher content of Al_2O_3, viscosity inside of the melt will become higher, and it will be harder for the viscous melt to surround the particles. This along with inherent poor wettability of the particle and will promote more porosities in the matrix where the crack will nucleate 15 vf-% Al_2O_3 and reduced strength. It is also confirmed that higher ceramic particles contained in the molten Al generated collision among particles and remain agglomerates or cluster distribution which impaired mechanical properties [8] (also see Fig.3). This such trend is also found in other investigation for nano Al_2O_3 [9]–[12].

The hardness of composites in Fig 1b showed that increasing of Mg and Al_2O_3 generated increasing hardness, this is because molten Al has reduced surface tension with Mg and the wettability between Al and Al_2O_3 has improved. The hardness increased with a higher content of Al_2O_3 particles since by nature this particle has much harder than that of the aluminum matrix which is also found by Mujeeb et al. [13]. The presence of new phases analyzed by EDS such as Mg_2Si in the form of Chinese script is also contributed to the strength and hardness (see microstructure of composites). The wear resistance that we can determine from represents the wear volume loss of matrix alloy as a function of sliding distance, here the wear rate has a reverse correlation with the hardness of composite as shown in Fig 1c, it means the lower wear rate the higher wear resistance

The volume loss of the composites decreases with increasing of Al_2O_3 and magnesium content. It is observed that Al_2O_3 particles increase the hardness of the composites. Furthermore, the addition of magnesium improved the wettability, so the hardness of composites increased and caused the wear rate decreased.

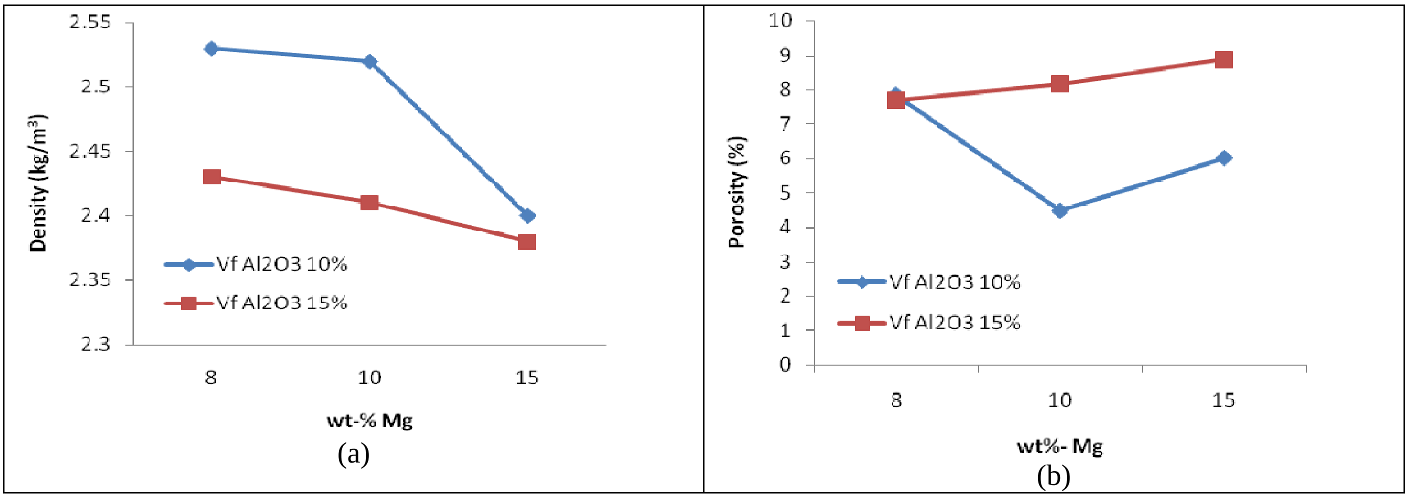


Fig. 2 Effect of Mg on density (a) and porosity (b) of Al6061/Al_2O_3 metal matrix composites produced by double blade stir casting.

The density and porosity of composites are shown in Fig. 2. The density of composites decreased with higher Mg content while on the contrary porosity increased. The density for composites with 10 vf-% Al_2O_3 is higher than 15vf-% Al_2O_3but tend to decrease with increasing Mg. It is assumed that density decreased and porosity increased due to some ceramic particles cannot be wetted perfectly by Al and remain pores. Therefore, the presence of Al_2O_3in the aluminum matrix will be a barrier to produce a perfect bonding interface.

The formation of porosity in the composites due to: the presence of hydrogen gas in the liquid aluminum, increasing of Al_2O_3 and stirring methods. According to J. Hashim [6], the casting of metal matrix composites will be present in the hydrogen gas in a liquid. This gas will be drawn into the mixing stage and entrapped in the liquid Al then porosity produced (also seen Fig. 5)

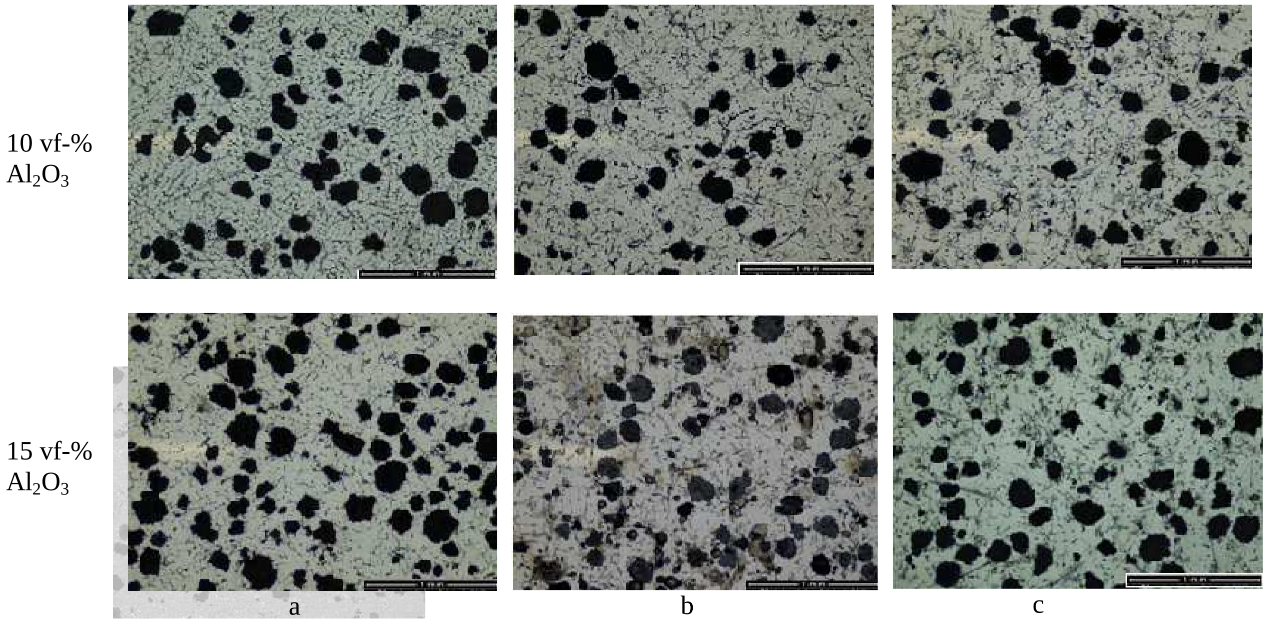


Fig. 3 Distribution of Al_2O_3 particles with different Mg and Al_2O_3 content in an Al 6061 matrix on metal matrix composites produced by double blade stir casting. a) 8wt-% Mg, b) 10 wt-% Mg and c) 15wt-% Mg

B. Microstructural analysis of Al6061/ Al2O3 Metal Matrix composites.

The distribution of Al_2O_3 on Al6061 matrix is seen to be a random distribution, and double blade stirring has contributed to distribute Al_2O_3 particles well as shown in Fig. 3 for both composites with 10 vf-% and 15vf-% Al_2O_3 and different of Mg content respectively. The microstructure of the Al matrix is consist of α-Al dendrite which surrounded by Si eutectic as seen in Fig.4a. Higher vf-% Al_2O_3 generated higher grain refinement of α-Al, and Si eutectic due to Al_2O_3 particles hindered the dendrite growth. According to Mandal et al. [10], the finer dendrites in the matrix could increase the tensile strength and hardness which is in line with the result of present work, except the tensile strength for composites with 10 wt-% Mg and 15Vf-% Al_2O_3.

C. The interface of Al/Al2O3 Composites

The interface between the Al matrix and Al_2O_{3p} was investigated by a Scanning Electron Microscope link to EDS in Fig. 4b-d. There was a metal oxide layer formed on the surface of Al_2O_{3p} which contained Mg, Al, O, and Si elements. The metal oxide layer, such as MgO and $MgAl_2O_4$, was formed during a process where Al_2O_3 particles continued to react with Alto form $MgAl_2O_4$ at the interface.

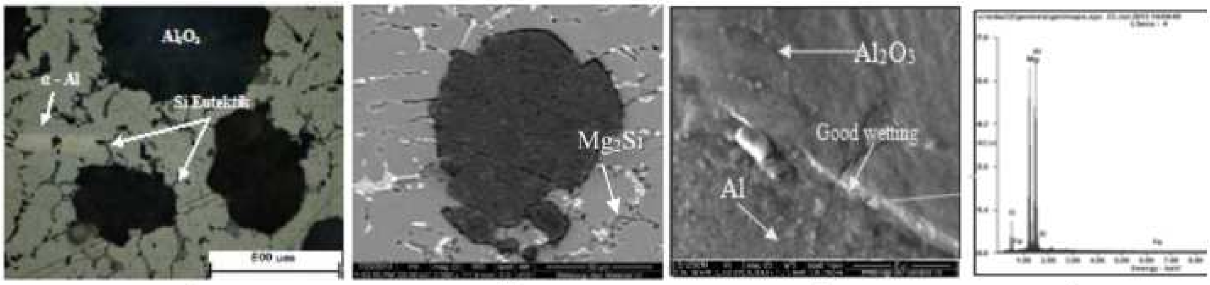


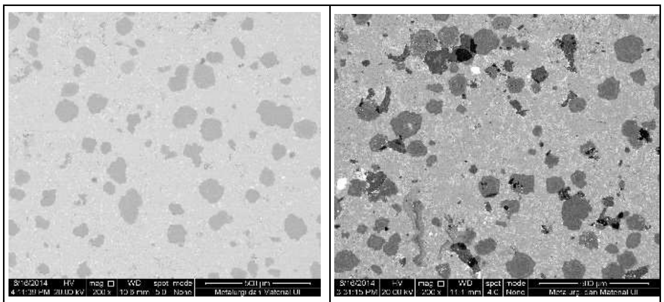
Fig. 4 Microstructure of Al/Al_2O_3 composites with 10wt-% Mg and 10 vf-% Al_2O_3 taken at higher magnification. a) matrix phase, b, c) Interface zone between Al and Al_2O_3, and d) EDS analysis of interface zone content in an Al6061 matrix on metal matrix composites produced by double blade stir casting

The spinel phase will reduce the surface tension of Al melt, so Al_2O_3will be wetted during the stir casting process. Indeed the wetting between the Al matrix and Al_2O_3 is good enough for composites with 10wt-% Mg and 10 vf-% Al_2O_3.

D. Effect of Alumina Particles and Magnesium on Microstructure

SEM examination has been carried out to observe the microstructure of composites with high magnification. So we can see the porosity, distribution of reinforcing particle, and matrix. For this examination, we chose samples with highest UTS, which is 10vf-% Al_2O_3-10wt-% Mg. and 15vf-% Al_2O_3-15wt-% Mg. Fig 5.a shows the microstructure of sample 10vf-% Al_2O_3-10wt-% Mg and Fig 5.b shows the microstructure of sample 15vf-% Al_2O_3-15wt-% Mg with a random distribution of particles and porosity.

It is known that porosity is considered to be one of the major factors responsible for the failure of casting alloy products. Therefore it is essential to determine the porosity of each sample.



(a) (b)

Fig.5 SEM micrograph of Al/Al_2O_3 composite with 10 vf-%Al_2O_3-10 wt-% Mg (a) and (b) microstructure of Al/Al_2O_3 composite with 15 vf-%Al_2O_3-15 wt% Mg

Therefore it is essential to determine the porosity of each sample. From Fig. 2b can be seen that the addition of Al_2O_3 generally increase the porosity level since Al_2O_3 particles reinforced is not perfect wetted by molten aluminum and remain porosity [14]. The porosity itself takes place due to excess hydrogen in the casting process when exciting works, especially when the method is not to vacuum, increased surface area contact with air, gas trapped during stirring see also Fig. 7, casting distance from the crucible to the mold, and shrinkage during solidification [6]. EDS analysis in Fig 6 is shown in Table 2.

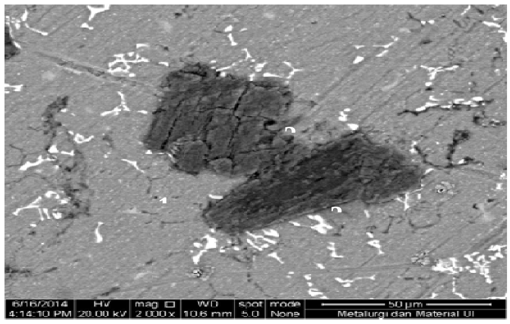


Fig. 6 SEM micrograph of Al/Al_2O_3 composite with 10 vf-%Al_2O_3-10 wt-% Mg link to EDS to identify phase presence in composite

TABLE II

PHASES AT INTERFACE COMPOSITE WITH 10VF-%AL2O3-10 WT-% MG

Spot	Al	O	Mg	Si	Phase
1	92.48 at%	1.82 Wt%	5.42 Wt%	0.28 Wt%	Al-Mg Matrix
2	58.59 at%	33.62 Wt%	7.53 Wt%	0.26 Wt%	$MgAl_2O_4$
3	64.89 at%	14.85 Wt%	19.93 Wt%	0.33 Wt%	$MgAl_2O_4$

Spot 1 is an aluminum matrix which is a content of Al element. The phase presence with black color in spot 2 is alumina particle which indicates in that region oxide has been formed with 58.59% Al and 33.62% oxygen. The spot 3 interfaces zone of an aluminum matrix and reinforced particles with spinel phase or $MgAl_2O_4$. In this study, show that the Al/Mg ratio approach to 2. So, in this interface indicate the presence of spinel ($MgAl_2O_4$).

E. Fracture Surface on Al/Al2O3 Composites

The fracture surface of Al/Al_2O_3 was taken from the tensile test sample is shown in Fig. 7. The fracture of the composites was caused by porosity present in the matrix as well as poor wetting between matrix and reinforcement. Large porosity found at composites with 15wt-% Mg and 15 vf-% Al_2O_3, this porosity formed because the vortex flow during mixing will draw gas into the liquid metal and stuck in the metal to form gas porosity [15].

Large porosity due to poor wetting will cause impair mechanical properties of composites. It is evident that the tensile strength of these composites decreased. The failure of composites has also involved the nucleation of crack and propagated along with the reinforcement/matrix interface [16]. The interface cracking can create a new surface at the interface between particles and matrix then remain particles deboning which caused fracture of composites which is also occurred in current work.

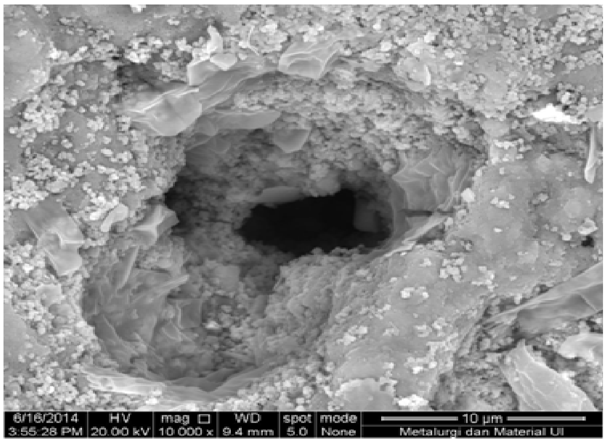


Fig.7 Fracture surface of Al/Al_2O_3 composites taken from the tensile sample with 15wt-% Mg and 15 vf-% Al_2O_3.

IV. CONCLUSIONS

In this work, Al6061/Al_2O_3 metal matrix composites have been successfully produced by the double blade stir casting process, and the characterization of composites can be concluded as follows: The optimum tensile strength and wear resistance of composites are obtained at 10wt-% Mg and 10 vf-% Al_2O_3, while hardness and porosity increased with a higher content of Al_2O_3. The distribution of Al2O3 in the Al6061 matrix is a random distribution for all composites, and double blade stirring has contributed to distributeAl2O3particles on the Al matrix well. The metal oxide layer formed in the interface is MgO and MgAl2O4, as a reaction product between Al6061 and Al2O3 generated good interface bonding between Al and Al2O3 particularly for composites with 10wt-% Mg and 10 vf-% Al2O3.

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