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Investigation on the Mechanical Properties of A356 Alloy Reinforced AlTiB/SiC_p Composite by Semi-Solid Stir Casting Method

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Abstract. Employing the semi-solid stir casting method to strengthen MMCs by SiC_p particle was the simplest way in the casting process. The strength and toughness of a composite material can be obtained through a combination of the A356 / Al7Si composites and SiC_p particle. The purpose of this study was to investigate the difference in the mechanical properties of Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites, as well as the changing effects on the extra level of SiC_p particle. Al_7Si was used as matrix strengthened by SiC_p with the percentage variations of 10, 15, 20 wt%. The additional level of 1.5 wt% AlTiB aimed for increasing the matrix grain refinement. The semi-solid stir casting method was performed to spread the SiC_p particles evenly in the liquid matrix. The results of the study were the tensile strength value of as much as 143 MPa or the increase of 22.16%. The biggest yield strength on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite was averagely as much as 106 MPa. The highest impact toughness was averagely amounted to 4.74 J/mm^2. The lowest porosity value was averagely 2.10%. The morphology of the composite between the reinforcing particle and the matrix was able to unite and to be dispersed evenly. The present study was conducted through density test, tensile test, impact test, microstructure test, and SEM.

Keywords: Mechanical properties, A356 Alloy, Semi-solid stir casting

1. Introduction

Recently, the development of Metal Matrix Composites (MMCs) in science and technology is considered a critical need. The Al-Si composite has a major role in the field of aluminum composite casting. The material has been widely used in the production of automotive, planes, outer space materials and industrial construction because of its excellent resistance. The composite material can be welded easily, and it is resistant towards high corrosion, and it also has other superior properties [1-2].

The production of MMCs combines the aluminum composite of A356 / Al_7Si as matrix and the particle of ceramics silicon carbide (SiC_p) as the reinforcement. The addition of the composite of Titanium Diboride (TiB) as the grain refiner is performed because its property could increase the metal strength and toughness [3]. SiC_p is employed as the reinforcement because it has an excellent mechanical property with the density of 3.2 g/cm^3, the yield strength of 600 MPa, the hardness of 2480 Knop (2170 HB), and the modulus of elasticity of 400 GPa, and it does not cause oxidation on metal

[4-5]. The A356 composite has several strengths such as having light property (density of 2.7 g/cm^3), the yield strength of 172 MPa, and the corrosion resistance. Nevertheless, it has low level of hardness of as much as 60 HB [5]. Moreover, Mg (1 wt%) is added to improve the wettability of Al_7Si matrix towards SiC_p particle. The function of improving the wettability is to wet the entire surface of the reinforcing particle that may affect an increase on the strength of matrix bond with the SiC_p particle [6-7].

The results of the study about $AlSi_7Mg_2$ matrix reinforced by SiC (5-15 wt.%) indicated the attained maximum tensile strength on SiC (10 wt.%) was as much as 280MPa. The hardness value increased on SiC (15 wt.%), i.e. that was 98HB, was increased of as much as 48% [8]. The employment of A356 matrix, the reinforcing SiC particle and the graphite with the SiC (0-9 wt.%) could cause the maximum hardness value on SiC (9 wt.%) of as much as 144VH. However, in this case, the hardness increased, but the elongation decreased [9]. In the case of Al6062 Matrix with the reinforcing particles (5, 10, 15, 20 wt.%), the results of the study showed that the highest hardness value was attained on SiC (20 wt.%), that was 83 HRB [10]. A study about the employment of 98.41 % Matrix with the SiC reinforcing particles (5, 10, 15, 20, 25, 30 wt.%) indicated that the best hardness value was obtained on the SiC percentage of 25%; that was 45.5 BHN [11]. A study investigating AlTiC and AlTiB with variations of 0.2%, 0.5%, and 1% showed that the addition of 1% TiB caused the grain size to become smaller [12]. The Al7178 composite with the variations of TiB (1, 2, 3, 4 wt.%) indicated that, with the addition of TiB between 1-4 wt.%, the grains underwent a significant decrease with the addition of 1 wt.% TiB; that was as much as 140 µm, on 4 wt.% to be 55 µm [13]. A study employing the AlTiB master alloy with the variation from 0.03% to 0.15% indicated that the smallest grain size was 50 µm, attained on the variation of 0.13 % TiB [14].

The mixing process of the SiC_p ceramic particle in the liquid matrix of aluminium composite has two main weaknesses. First, the SiC_p particle of which surface is not usually wetted by liquid matrix. Second, the SiC_p particle tends to settle or float on the liquid matrix surface. It may cause an uneven distribution of SiC_p particles on the matrix surface [6]. The study conducted by employing the semi solid stir casting was aimed to ease the mixing process of SiC_p particle into the liquid matrix [15]. The purpose of this study was to investigate the differences in the mechanical properties of Al_7Si_1Mg/SiC_p composite and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite as well as the changing effects toward the addition of SiC_p particle. This present study employed the semi solid stir casting method.

2. Experimental Method

The experiment of composite Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1,5}TiB/SiC_p$ composites was done by employing the semi solid stir casting method. In this case, the A356 / Al_7Si alloy played a role as matrix. Besides, 1 wt.% Mg was used to incerase the wettability. Then, 1.5 wt.% of TiB was added to refine the grains on the matrix. Next, The SiC_p played a role as the reinforcement on the Al_7Si matrix. The variations of SiC_p employed are 10, 15, 20 wt.%. Table 1 below shows the compositions of chemical materials used.

Table 1. Chemical composition of materials

Materials	Chemical composition (%)								
	Al	Si	SiC_p	Fe	Ti	B	Mg	Mn	Other
Al_7Si / A356 (ingot)	92.39	7.26	-	0.147	-	-	0.07	0.008	0.125
Mg (ingot)	0.022	0.013	-	0.003	-	-	99.93	0.012	0.02
AlTiB (ingot)	93	0.16	-	0.16	5.00	0.98	-	-	0.05
SiC_p (powder)	0.03	-	98.6	0.1	-	-	0.03	-	1.24

There were several steps conducted during the casting process. First, preparing the materials to be casted, including Al_7Si, Mg, and AlTiB. Then, those materials were cut by machine according to the variations of the casting compositions. After that, the materials were set aside to get the wt.%

composition set. The variations of the casting compositions could be seen on Table 2. Then, the Al_7Si, Mg, and Al-TiB were added to the electric furnace stir casting shown in Figure 1a.

Table 2. Variations in the composition of foundry

Composition (wt.%)	Al_7Si (gram)	Mg (gram)	AlTiB (gram)	SiC_p (gram)	Total (gram)
Al_7Si_1Mg/SiC_p 0%	990	10	-	-	1000
Al_7Si_1Mg/SiC_p 10%	890	10	-	100	1000
Al_7Si_1Mg/SiC_p 15%	840	10	-	150	1000
Al_7Si_1Mg/SiC_p 20%	790	10	-	200	1000
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 0%	975	10	15	-	1000
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 10%	875	10	15	100	1000
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 15%	825	10	15	150	1000
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 20%	775	10	15	200	1000

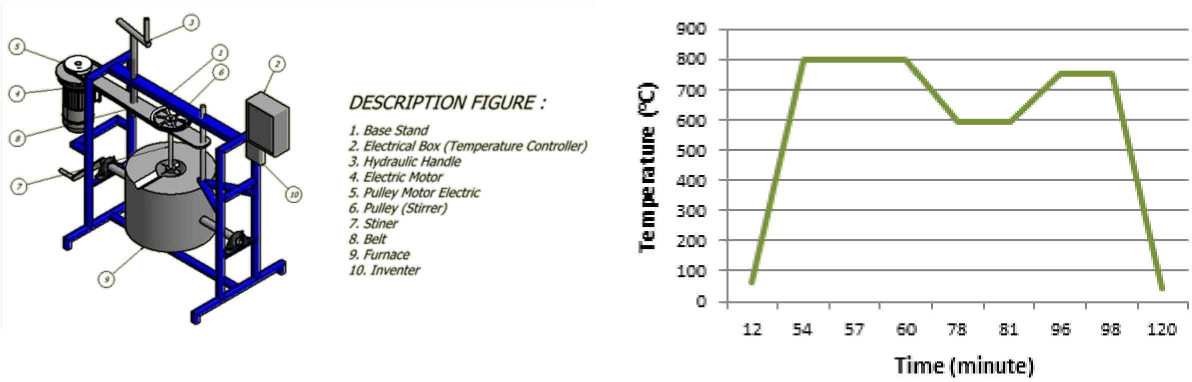


Figure 1. (a) Electric furnace stir casting, (b) Temperature vs. time semi solid stir casting process

Then, they were heated to the temperature of 800 °C to get a liquid state. On the other hand, the temperature was lowered to 590 °C to get a semi solid state. Meanwhile, the SiC_p particle was heated separately place inside an electric oven at a temperature of 400 °C for 120 seconds. After that, the SiC_p was added to the electric furnace stir casting and stirred thoroughly by using a mechanical mixer. The mixing speed of the mixer was 500 rpm for 180 seconds. The metal mold was also heated to the temperature of 300 °C. After all materials were mixed and stirred in semi solid state, the temperature was increased to 750 °C to get a casting condition. The casting product was refrigerated at room temperature of 36 °C which could be seen in Figure 1b, the graphic of semi solid temperature vs. time. After that, the composite was cut according to the test specimen. The composite specimen was tested by employing density test, tensile test, impact test, and microstructure photo and SEM. Figure 2 below illustrates the specimen of casting product.

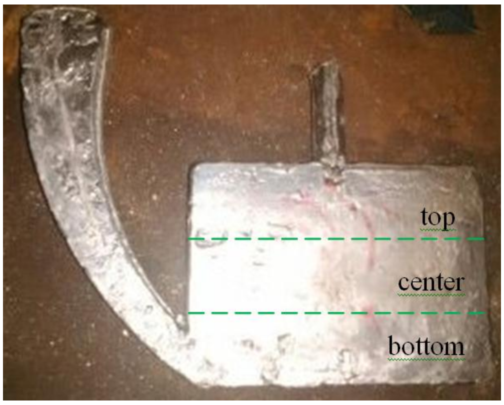


Figure 2. Casting Product Composite

3. Results and Discussion

3.1. Density and Porosity

The specimens for the density test had the size of 2 x 2 x 2 cm by using a VIBRA digital balance. The density test results and its measurement on the porosity of Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites are shown on Table 3.

Table 3. Density test results and porosity calculations

Composites (wt.%)	ρ_{actual} (g/cm^3)	$\rho_{theoretic}$ (g/cm^3)	Porosity
Al_7Si_1Mg/SiC_p 0%	2.63	2.66	1.50
Al_7Si_1Mg/SiC_p 10%	2.65	2.71	2.58
Al_7Si_1Mg/SiC_p 15%	2.66	2.72	2.57
Al_7Si_1Mg/SiC_p 20%	2.69	2.76	2.89
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 0%	2.64	2.68	1.49
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 10%	2.65	2.73	2.19
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 15%	2.67	2.76	2.22
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 20%	2.70	2.78	2.51

The graphics of the density and porosity of the Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites are shown on Figure 3.

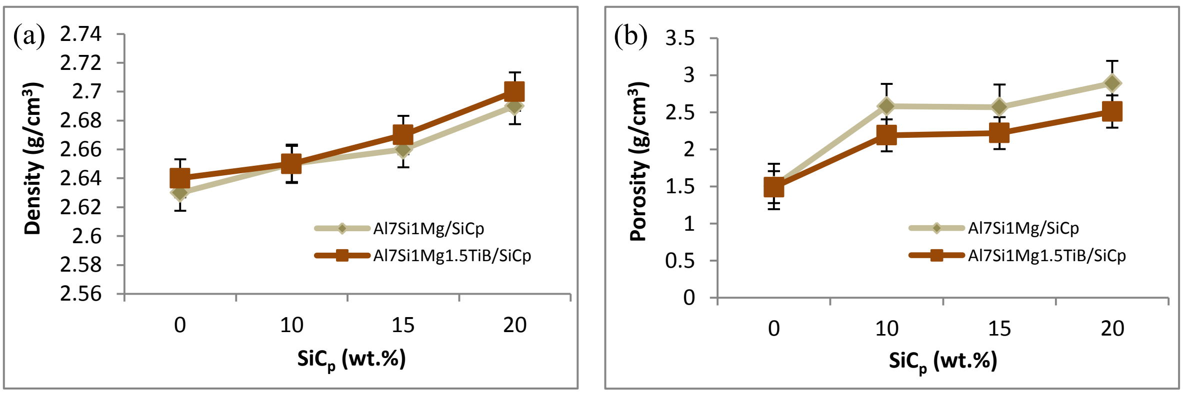


Figure 3. Graph (a) composite density, (b) composite porosity

The density graphic indicated that the Al_7Si_1Mg/SiC_p composite underwent an average increase of 1.2%. Whereas, the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite went through a decrease on the variation of SiC_p

of 15 wt.%, and increased of as much as 1.4% on the variation of SiC_p of 20 wt.%. Figure 3b showed that the porosity of the Al_7Si_1Mg/SiC composite increased averagely of as much as 28 %. Whereas, the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite decreased on the variation of SiC_p (15 wt.%), and then, increased of as much as 10.9% on the variation of SiC_p (20 wt.%). On the process of stir casting, the porosity might potentially occur. This occurence may be caused by the chemical reaction between matrix and reinforcing particle, so that it may result in the trapped gas during the mixing process. Consequently, the more the number of SiC_p, the more the gas reaction occurs leading to the porosity tendency to increase. These results, according to the results of previous research, indicated that porosity may potentially occur in the process of stir casting because of the chemical reaction between the reinforcing particle and matrix which caused gas, as well as gas which was trapped during the stirring process [6]. The addition of 1% Mg could reduce the porosity. Therefore, Mg would reduce the layer of SiO_2 on the surface of SiC_p, and form $MgAl_2O_4$ with high wettability on the interface [16]. The porosity formed on the interface of matrix and reinforcing particles would disap+pear or get reduced [17].

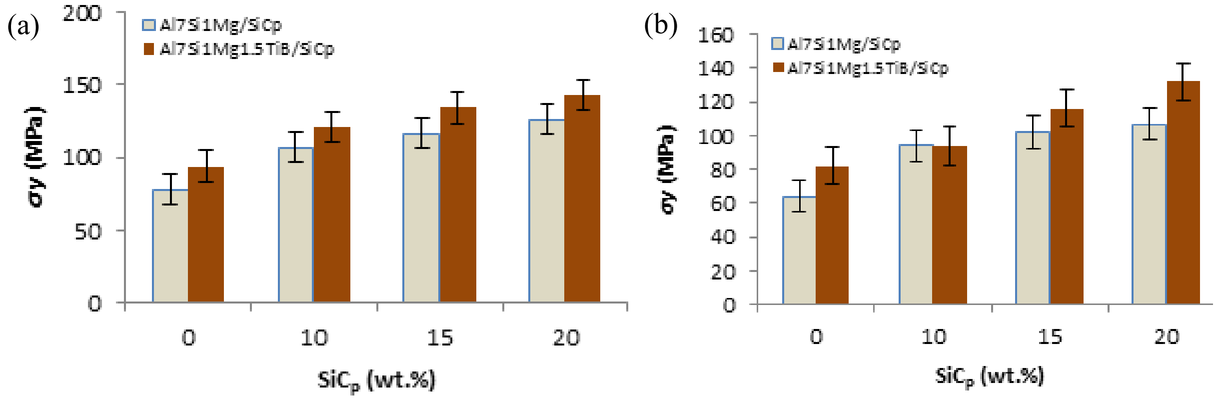
3.2. Tensile Test

The tensile strength was acquired from the measurement of maximum load divided by cross-sectional area of tensile test specimen. The tensile test was conducted according to the testing standard of ASTM E 8M-04 [18]. The following Table 4 presents the result of the tensile test.

Table 4. Test results of tensil strength measurement

Composites (wt.%)	σ_u (MPa)	σ_y (MPa)	%EL
Al7Si1Mg/SiC_p 0%	77	64	1.01
Al7Si1Mg/SiC_p 10%	106	94	1.21
Al7Si1Mg/SiC_p 15%	116	102	1.64
Al7Si1Mg/SiC_p 20%	125	107	2.41
Al7Si1Mg1.5TiB/SiC_p 0%	93	82	1.16
Al7Si1Mg1.5TiB/SiC_p 10%	120	94	1.86
Al7Si1Mg1.5TiB/SiC_p 15%	134	116	2.46
Al7Si1Mg1.5TiB/SiC_p 20%	143	132	2.98

The effect of SiC_p percentage to the tensile stength of Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites is shown in Figure 4.



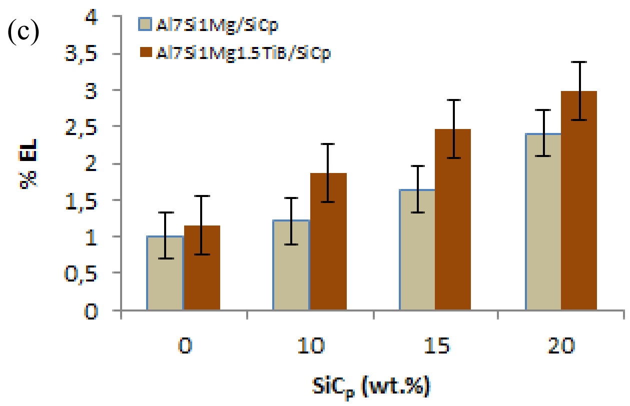


Figure 4. Graph (a) Tensile strength, (b) Yield strength, (c) Elongation of Al7Si1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ Composites

Figure 4a The graphic of tensile strength of Al_7Si_1Mg/SiC_p composite was bigger than $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite with the difference of average of 16.18 %. The strength of $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite increased on the variation of SiC_p of 10 wt.% of as much as 120 MPa and on variation of SiC_p of 20 wt.% became 143 MPa, or improved of as much as 22.16 %. For the Al_7SiMg/SiC_p composite, the tensile strength was increasing on the variation of SiC_p of 10 wt.% of as much as 106.84 MPa, and on the variation of SiC_p of 20 wt.% became 125 MPa, or as much as 19.01%. The addition of 1.5% TiB could increase the tensile strength. Figure 4b indicates that the biggest yield strength was on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite, which was as much as 106 MPa. The difference on the yield strength of the Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites was of as much as 14 MPa. The yield strength of the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite was bigger than that of the composite with Al_7Si_1Mg/SiC_p matrix. It could be concluded from Figure 4c that the strain between the Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites increased with the difference of as much as 0.55%EL. The strain on the Al_7Si_1Mg/SiC_p composite was averagely 1.56%EL. whereas the strain of the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite was averagely 2.11%EL. The force on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite was bigger than that on the Al_7Si_1Mg/SiC_p composite. It was based on the discovery of the previous researchers that the extra level of TiB with certain percentage would repair the grain structure of the composites [10,19].

3.3. Impact Test

The impact test was conducted according the standard of ASTM E-23 02a [20]. The test results could be seen on Table 5.

Table 5. Results of impact test

Composites (wt.%)	Load of hitter (Kg)	Impact value (J/mm^2)
Al_7Si_1Mg/SiC_p 0%	1	4.43
Al_7Si_1Mg/SiC_p 10%	1	3.93
Al_7Si_1Mg/SiC_p 15%	1	4.93
Al_7Si_1Mg/SiC_p 20%	1	5.46
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 0%	1	4.56
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 10%	1	6.06
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 15%	1	4.73
$Al_7Si_1Mg_{1.5}TiB/SiC_p$ 20%	1	5.63

The graphic of relationship between the impact value and the percentage variation of SiC_p is shown in Figure 5.

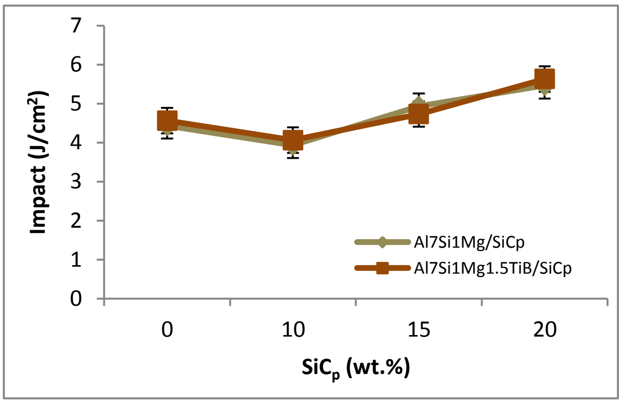


Figure 5. The impact price changes on the Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites

The impact value of $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite was higher than that of Al_7Si_1Mg/SiC_p composite. On the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite, the impact value for the variations of SiC_p of 10, 15, and 20 wt.% increased averagely of 4.74 J/cm^2. On the Al_7Si_1Mg/SiC_p composite with 10, 15, 20 wt.% variations of SiC_p, the impact price increased averagely of 4.68 J/cm^2. The difference between Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites was of as much as 0.06 J/cm^2. The highest impact value was on found on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite. The extra level of TiB could bear a bigger impact load.

3.4. Micro Structure

The micro structure test was conducted by employing an Olympus optical microscope. The results of micro-photos of Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites are shown on Figure 6.

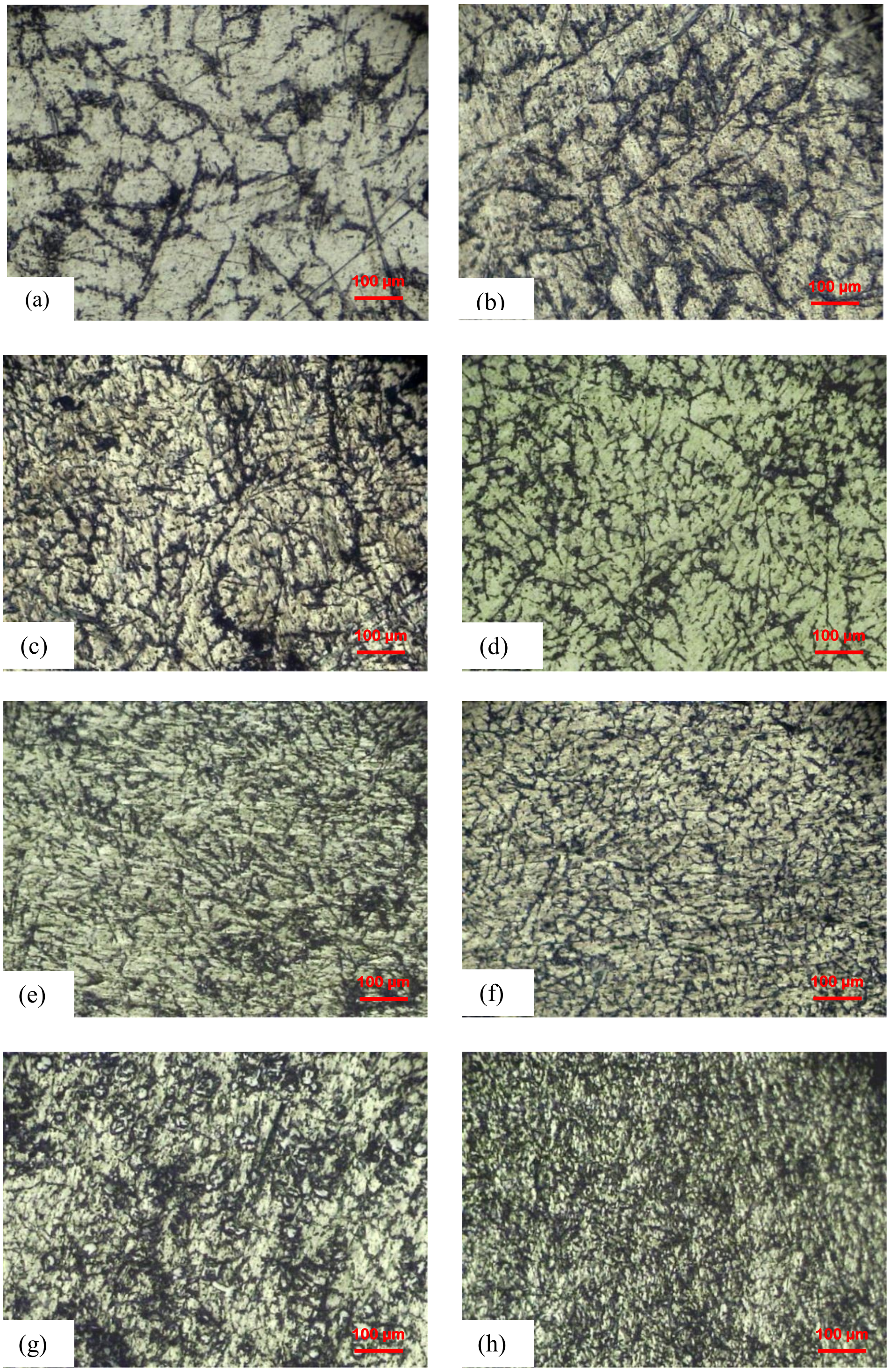


Figure 6. Micro photos of: (a) 0% Al_7Si_1Mg/SiC_p, (b) 0% $Al_7Si_1Mg_{1.5}TiB/SiC_p$, (c)10% Al_7Si_1Mg/SiC_p (d)10% $Al_7Si_1Mg_{1.5}TiB/SiC_p$ (e)15% Al_7Si_1Mg/SiC_p (f) 15% $Al_7Si_1Mg_{1.5}TiB/SiC_p$, (g) 20% Al_7Si_1Mg/SiC_p (h) 20% $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites

It could be seen in Figure 6 that the higher the level of SiC_p in the composite, the more SiC_p was bound in the matrix. On the Al_7Si_1Mg/SiC_p composite, the Si was the grey substance with irregular round grains. Figure 8 b, d, f, and h show the $AlSi_1Mg_{1.5}TiB/SiC_p$ composite in the form of black-colored fine grain boundaries. Finer grains on that composite were also noticed. The SiC_p particle was dispersed randomly and evenly in the Al_7Si_1Mg/SiC_p matrix as well as $Al_7Si_1Mg_{1.5}TiB/SiC_p$ matrix. The more SiC_p was dispersed, the harder the composite could be. It was based on the previous study by Hashim et al. (2001) and Lin et al. (2010) that indicated that the employment of semi solid stir casting may help increasing the wettability and dispersing the reinforcing particle homogenously [7].

3.5. Morphology

The test of Scanning Electron Microscopy (SEM) is known to be able to measure the spread of SiC_p particle in the Al7Si matrix. The SEM observation result was on the form of morphology with 10.000x magnification in which it produced SEM photos of $AlSi_1Mg/SiC_p$ and $AlSi_1Mg_{1.5}TiB/SiC_p$ which are shown on Figure 7 below.

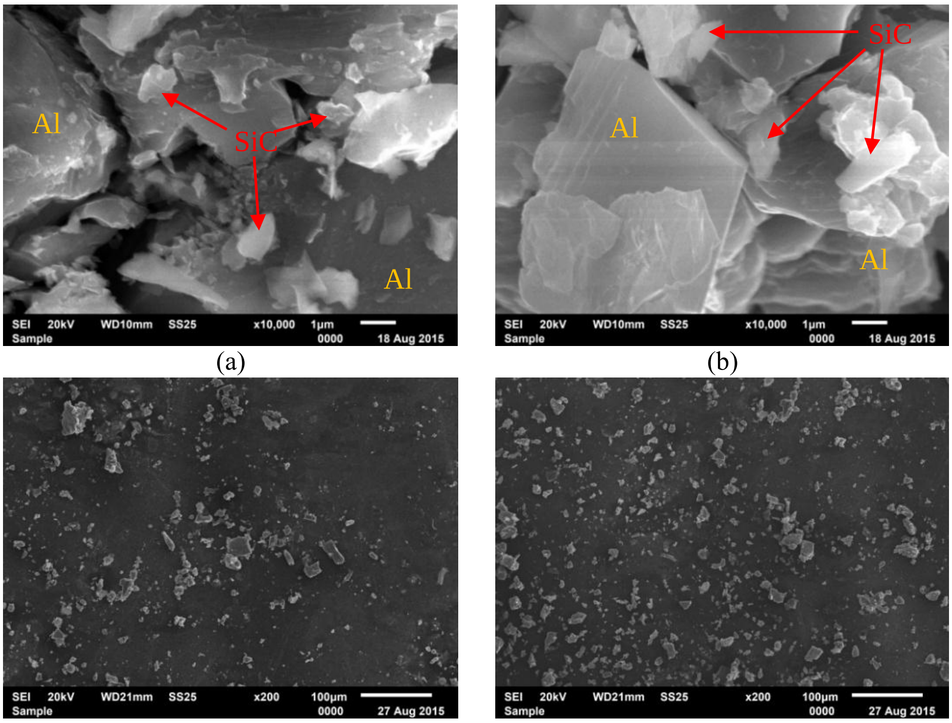


Figure 7. SEM Composite: The morphology (a) 20 wt.% $Al7Si1Mg/SiC_p$ (b) 20 wt.% $Al_7Si_1Mg_{1.5}TiB/SiC_p$, the spread of SiC_p particle (c) 20 wt.% Al_7Si_1Mg $/SiC_p$ (d) 20 wt.% $Al_7Si_1Mg_{1.5}TiB/SiC_p$

Figure 7a shows the morphology of Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites between the reinforcing particle and matrix that could be united. On the Al_7Si_1Mg/SiC_p composite, the SiC_p particle was found around the interlocking Al_7Si matrix. Figure 7b demonstrates the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite noticed between the SiC_p and Al_7Si matrix which was mixed thoroughly. The extra level of TiB changed the particle forms to be finer.

4. Conclusion

In the present study, the researchers derived several conclusions as follow: The morphology of the Al_7Si_1Mg/SiC_p and $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composites between the reinforcing particle and matrix could be united and dispersed evenly. The effect of SiC_p wt.% was noticed from the value of tensile strength from two kinds of composites. The $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite went through an increase on the variation of SiC_p of 20 wt.% became 143 MPa or increased of as much as 22.16 %. The biggest yield strength was found on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite that was averagely amounted to 106 MPa. The difference in the yield strength between those two composites was 14 MPa.%EL in which the highest one was found on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite with the average value of 2.11%EL. The $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite had a higher impact value compared to the Al_7Si_1Mg/SiC_p composite. The highest impact toughness was averagely amounted to 4.74 J/mm^2. The porosity value of the Al_7Si_1Mg/SiC_p composite was averagely 2.38%. On the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite, the porosity value was averagely 2.10%. The smallest porosity was found on the $Al_7Si_1Mg_{1.5}TiB/SiC_p$ composite. The difference in the increase of porosity percentage on those two composites was 0.13 %. The extra level of 1.5 wt.% TiB could make the grain refinement to be smoother. The extra level of TiB could result in an increase on the tensile strength value and impact value, and from the different morphology from micro structure and SEM.

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