Optimizing The Addition of TiB to Improve Mechanical Properties of the ADC 12/SiC Composite Through Stir Casting Process

Cindy Retno Putri[1], *Anne* Zulfia Syahrial[1,*], *Salahuddin* Yunus[2], and *Budi* Wahyu Utomo[3]

[1]Departement of Metallurgy and Materials Engineering, University of Indonesia, Jl. Margonda Raya, Pondok Cina, Depok, 16424, Indonesia
[2]Department of Mechanical Engineering, University of Jember, Jl. Kalimantan No.37, Jember, East Java, 68121, Indonesia
[3]Astra Honda Motor, Cikarang Barat, 17530, Indonesia

Abstract. The goal of this research is to improve the mechanical properties such as strength, hardness and wear resistance for automotive application such as brake shoe and bearings due to high cycle, load and impact during their usage. Therefore, another alloying element or reinforcement addition is necessary. In this work, the composites are made by ADC 12 (Al-Si aluminum alloy) as the matrix and reinforced with micro SiC through stir casting process and TiB is added various from (0.04, 0.06, 0.15, 0.3 and 0.5) wt.% that act as grain refiners and 5 wt.% of Mg is added to improve the wettability of the composites. The addition of TiB improves the mechanical properties because the grain becomes finer and uniform, and the addition of Mg makes the matrix and reinforce have better adhesion. The results obtained that the optimum composition was found by adding 0.15 wt.% of TiB with tensile strength improve from 98 MPa to 136.3 MPa, hardness from 35 to 53 HRB and wear rate reduced from 0.006 2 $mm^3 s^{-1}$ to 0.002 3 $mm^3 s^{-1}$ respectively.

Keywords: Composite aluminum, grain refiner TiB, micro SiC.

1 Introduction

Aluminum has been widely used in manufacture industries due to its mechanical properties such as an excellence corrosion resistant, good thermal and electrical conductivity, and also light weighted [1]. But, because of its softness and ductility, aluminum needs to be combined with other materials to fulfil the higher demand of high strength, wear resistance and toughness for further application like on automotive industry. For example, the need of a lightweight and high strength material for the brake pads in automotive industry can be fulfilled by the use of a lightweight metals reinforced with a high strength ceramics instead of the conventional cast iron that is heavy and more expensive.

ADC12 according to the Japanese standard is an aluminum which mainly alloyed with silicone and copper to increase its flow ability and hardness acts as the base material of this study which has 98.3 MPa in UTS, 35.03 HRB in hardness and 0.0062 $mm^3\ s^{-1}$ as wear rate [2]. Reinforcement was added to improve the yield, tensile, and hardness while maintaining its lightweight and ductility due to the addition of reinforcing [1]. Micro-sized particles of silicon carbide were chosen to be the reinforce due to its high strength, high stiffness modulus and high temperature resistance [3]. The size of the particles results in strong interphase and great distribution compared to macro-sized silicon carbide particles due to its large surface area contact. With the addition of reinforce, a wetting agent such as magnesium is needed to strengthen the interface between the matrix and reinforce [4]. Titanium boron also added to this study which acts as grain refiner that can enlarge the surface area of grain boundaries and lead a strengthening mechanism to happen [5]. Fabrication of this composite is through stir casting method which 3 volume fraction of silicon carbide particle, variation [(0.04, 0.06, 0.15, 0.3, and 0.5) wt.%] of titanium boron and 5 wt.% of magnesium is mixed with molten ADC 12 by mechanical stirring [6].

In this study, the effect of the TiB addition to the composite material was carried out, the composites were investigated by optical microscope (OM) and X-Ray diffraction (XRD) to analyze the chemical properties and several destructive tests as tensile testing, hardness testing, and wear testing also density testing to analyze the mechanical properties.

2 Experiments

2.1 Materials and methods

2.1.1 Materials

Aluminum alloy ADC 12 (Si 10.5 %; Fe 0.8 %; Cu 2.33 %; Mn 0.22 %; Mg 0.22 %; Zn 0.64 % and Cr 0.04 %) was used as the base material, three volume fraction of silicon carbide was used as the reinforcing with 5 wt.% of magnesium as the wetting agent, and (0.04, 0.06, 0.15, 0.3, and 0.5) wt.% of titanium boron was used as the grain refiner.

2.1.2 Making of ADC12/SiC composite

ADC 12 was melted in a crucible inside an electrically heated pot furnace at 800 ºC. The SiC particles were preheated in a crucible by heating it in another furnace at 900 ºC for 1 h. After ADC 12 was reaching the molten state, degassing process was performed to eliminate hydrogen trapped in the molten aluminum for 2 min using argon gas. Slag formed on the surface of the molten aluminum then removed to clean up the surface. Afterwards, the preheated SiC particles were added manually to the molten aluminum before the liquid aluminum was then mechanically stirred with a speed of 519 rpm (1rpm=1/60 Hz). Second degassing and slag removal process was performed in preparation for TiB and Mg addition to the molten ADC 12. After a while of TiB and Mg addition, the second mechanical stirring process was performed at the speed of 519 rpm for 5 min to ensure the composite has mixed well. Casting die was prepared by applying zirconia coating then heating it in the furnace at 350 ºC for 3 min before pouring the composite to the die.

2.2 Characterization

To investigate the microstructural features, optical microscope (OM) observation was carried out with composite samples that have been ground, polished by TiO_2, and etched by 0.5 % Hydrofluoric Acid for 10 s. X-ray diffraction (XRD) patterns were also taken to gain the information about different phases present in the microstructure. The chemical properties were observed using optical emission spectroscopy (OES). Mechanical properties were investigated by carrying out a tensile test based on ASTM E8 (GOTECH AI-7000 LA 10), hardness test (Rockwell B) based on ASTM E18, wear rate test with pin on disk (Ogoshi) method based on ASTM G99, and density testing based on Archimedes Theory.

3 Results and discussion

3.1 Microstructural analysis of ADC 12/SiC composite

The microstructure of the composite mainly contains α-Al, Al_2Cu, and Mg_2Si intermetallic. Generally, the titanium composition was gradually increased, but some of the amounts did not reach the number targeted. This phenomenon can be caused by the fading mechanism that happens because of the long period of holding time in the casting process and lack of stirring. So, with the presence of gravitation, TiB particles settled and deposited at the bottom of crucible [7, 8]. The composite also shows a higher amount of Mg that happened because of the addition of magnesium as a wetting agent, formed by reaction:

$$L \rightarrow Al + Si + Mg_2Si$$

Table 1. The chemical composition of ADC 12 and the composites.

Element	The composition of TiB addition (wt.%)					
	ADC 12	0.04	0.06	0.15	0.3	0.5
Al	84.8	79.667	74.433	73.0	74.05	77.933
Si	10.5	10.23	9.763	13.763	9.715	9.547
Fe	0.864	0.52	0.913	0.870	0.895	1.0
Cu	2.33	3.01	3.103	2.687	2.835	2.873
Mg	0.221	5.293	4.883	4.487	5.095	4.163
Cr	0.039	0.025	0.038	0.042	0.05	0.234
Ni	0.076	0.035	0.131	0.089	0.137	0.094
Ti	0.046	0.072	0.08	0.083	0.089	0.094
B	< 0.000 5	0.001	0.003	0.002	0.003	0.006

The phase identification of the ADC 12 and the composites are compiled in Figure 1 and predicted by the solidification path on ternary phase diagram. The lightest color known as base metal (α-Al) and what pictured by the slightly grey color known as Al_2Cu which has a porous morphology and can be formed with the reaction:

$$L \rightarrow Al + Si + Al_2Cu$$

The addition of Mg as wetting agent forms $MgAl_2O_4$ known as Spinel phase as seen on Figure 2. $MgAl_2O_4$ can increase the bond of the interphase. The black Chinese script microstructure can also be seen on the Figure 1 known as binary Mg_2Si, whereas the blocky microstructure known as primary Mg_2Si that also can be formed by the addition of magnesium as wetting agent [9]. All of the phase identified in optical microscope observation confirmed in XRD patterns shown in Figure 2.

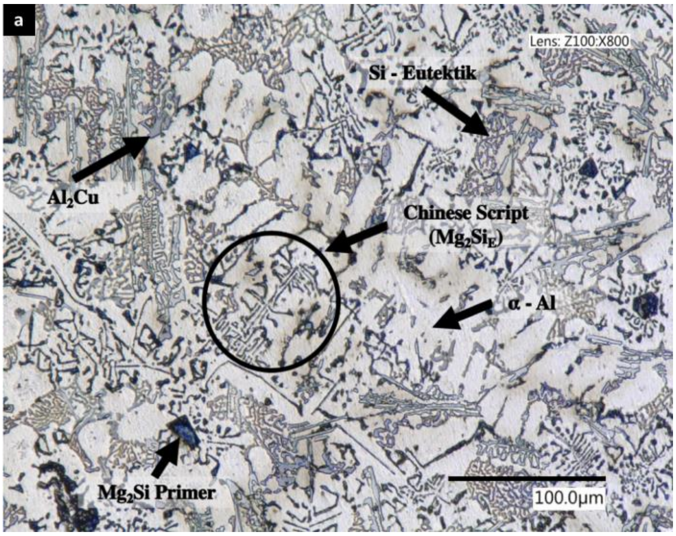

Fig. 1. Phase identification in composite microstructure using optical microscope with 500× magnification.

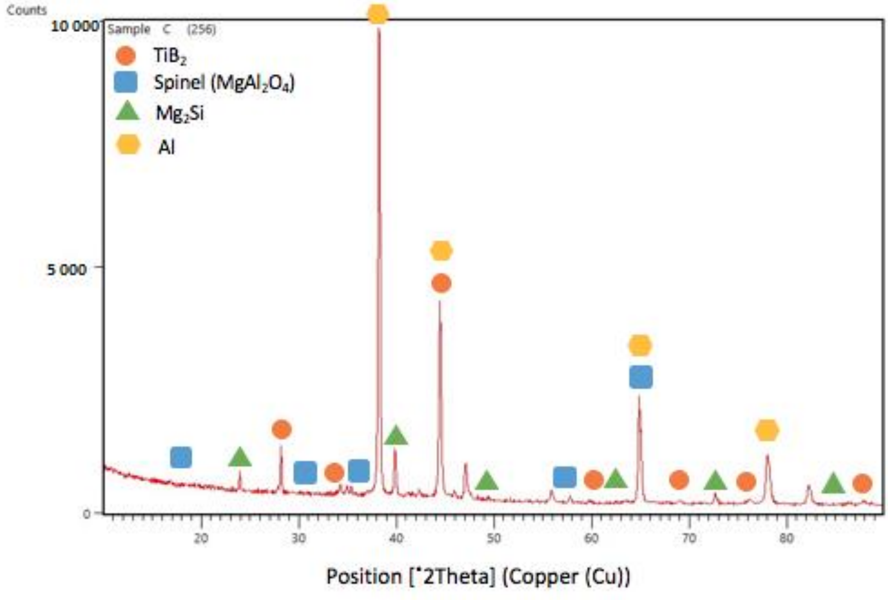

Fig. 2. XRD patterns of ADC 12/SiC Composite.

From Figure 3 It can be seen that the base material ADC 12 created a needle-like microstructure. In contrast, the composites with TiB addition exhibits a more equiaxial morphology resembles columnar grains as a result of directional solidification [5]. With more addition of Ti, the grain size supposed to be smaller [10]. The size of grain proved by single dendrite arm spacing (SDAS) calculation.

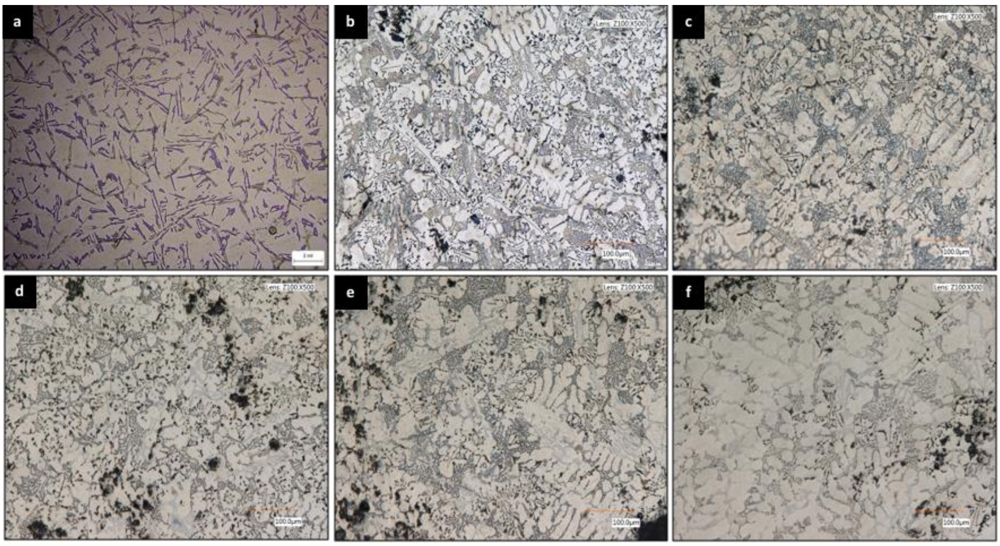

Fig. 3. Optical microscope observation, microstructure of a) Base material ADC 12 with 200× magnification, ADC 12/SiC Composite with TiB variation of b) 0.04 wt.% c) 0.06 wt.%, d) 0.15 wt.%, e) 0.06 wt.%, f) 0.5 wt.% with 500× magnification.

The result shown in Figure 4 prove a remarkable refinement with a reduction in the SDAS as TiB content adds up to 0.15 wt.%. Furthermore, at the TiB addition greater than 0.3 wt.% SDAS increases which indicate the coarser grain that happens because of the clustering phenomenon of Ti intermetallic that makes inoculation weakened [11].

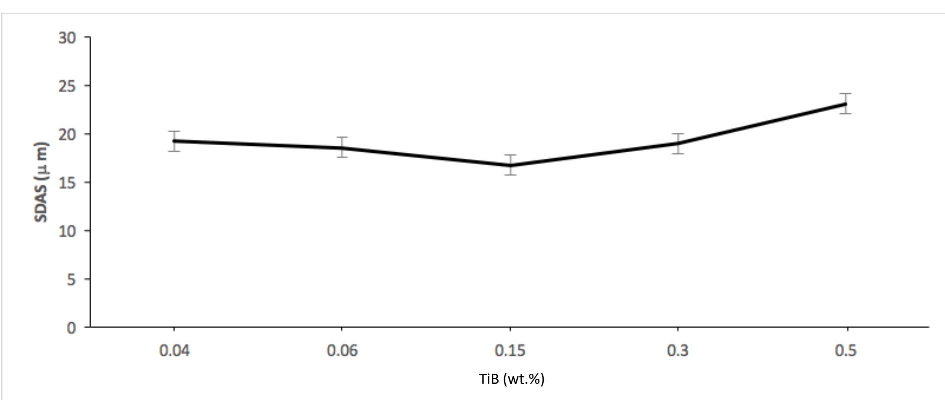

Fig. 4. Secondary dendrite arm spacing calculation.

3.2 Mechanical properties

3.2.1 Density and porosity

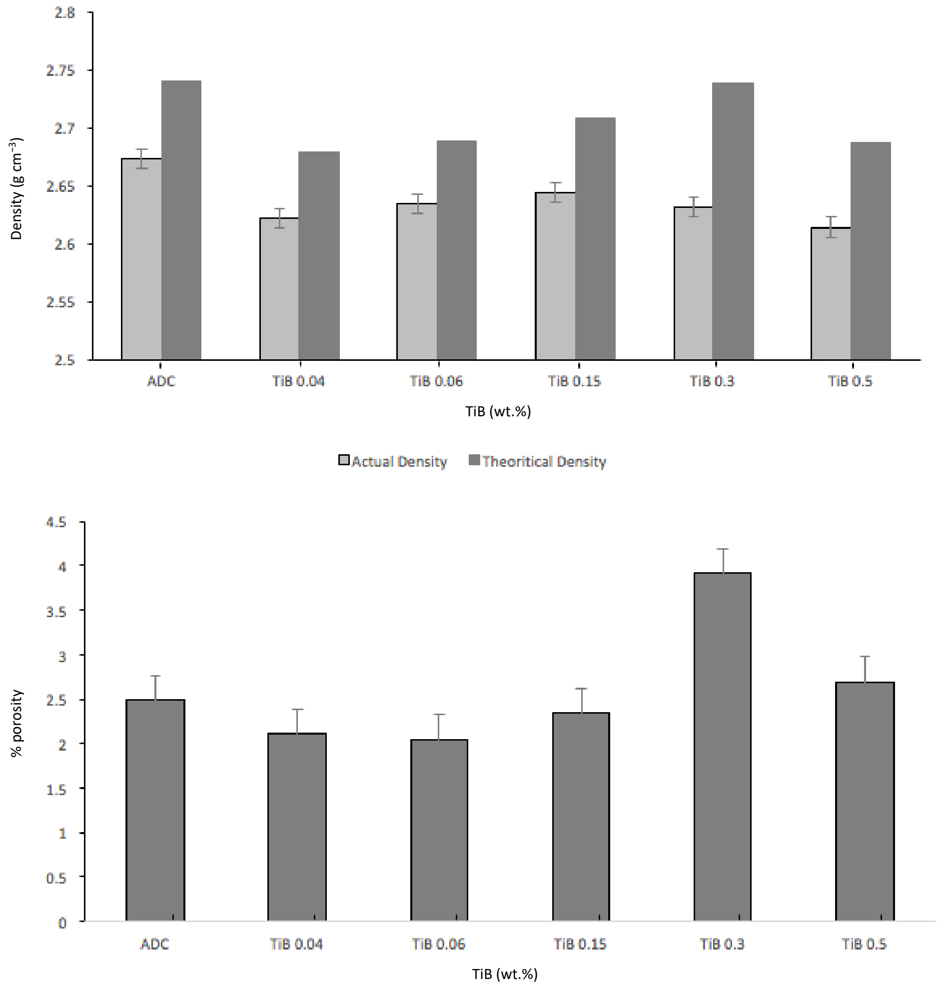

Fig. 5. Density (above) and porosity (below) calculation of composites.

Composite density stated in actual and theoretical number which has a difference in density value. Based on Figure 5. the actual density value is lower than the theoretical density value due to the presence of H_2 gases during stir casting process at the temperature greater than 600 ºC because of the higher solubility limits of H_2 as increased temperature as shown in Figure 6 [12]. That entrapped air caused porosity in the molten aluminum that affects the mechanical properties of the composites.

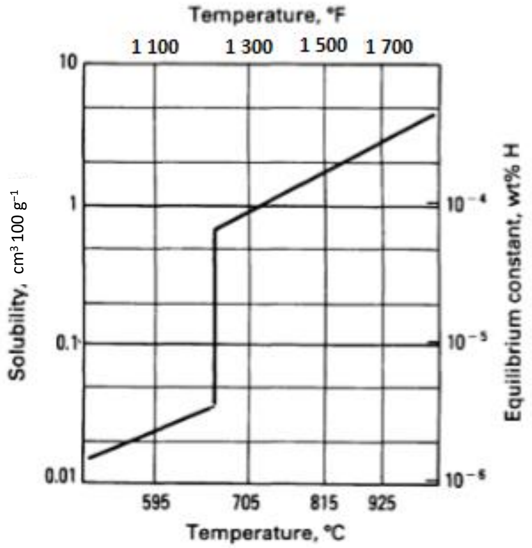

Fig. 6 Effect of temperature to H_2 solubility in molten aluminum [12].

3.2.1 Tensile and elongation

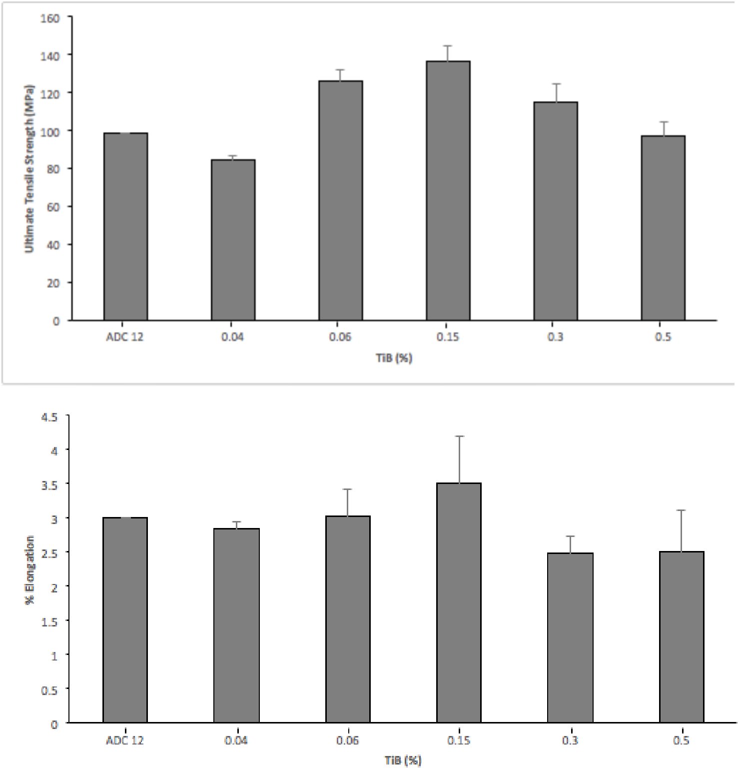

Fig. 7. UTS (above) and elongation (below) calculation of composites.

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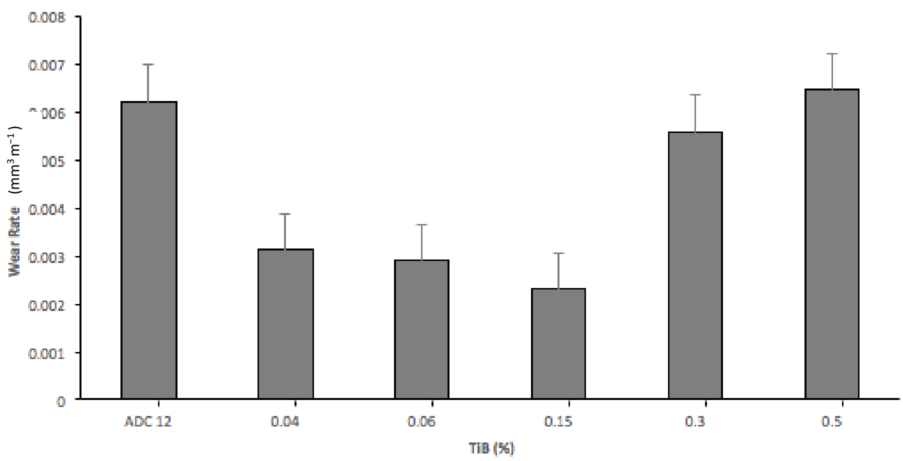
The variation in tensile properties due to Ti addition from 0.04 wt.% until 0.5 wt.% shown in Figure 7 respectively are (94, 125, 136, 115, and 96) MPa, mainly improved from the original ADC 12 which has 98 MPa tensile strength. As the Ti content increased from 0.04 wt.% to 0.15 wt.% the ultimate tensile strength (UTS) and elongation increased. This phenomenon caused by grain boundary strengthening mechanism that happens in the material with TiB addition. TiB acts as a grain refiner which starts the inoculation to produce finer grain with the intention to enlarge the grain boundary [13]. Grain boundary has the power to stop dislocation movement and improve the mechanical properties of the material. As shown in the picture, the tensile properties of the composite showed maximum value at Ti contents of 0.15 wt.%. Addition of Ti greater than 0.15 wt.% reduces the tensile strength that can be caused by weakening inoculation results of Ti intermetallic clustering [5].

3.2.1 Hardness and wear rate



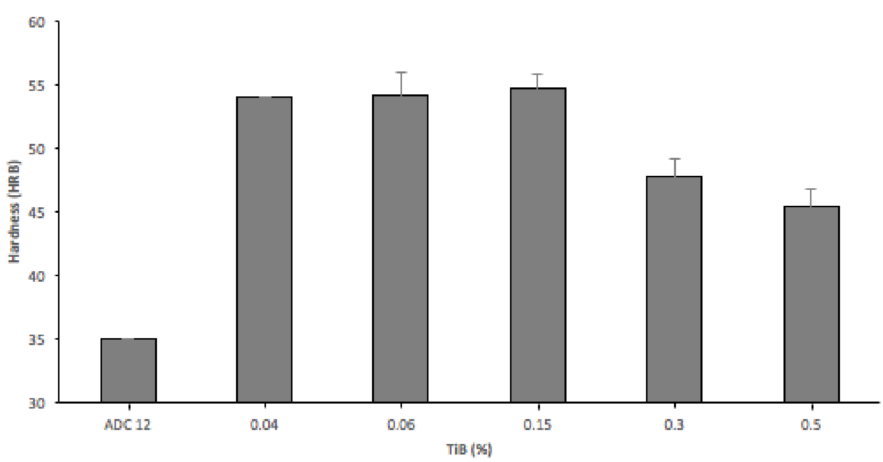


Fig. 8 Hardness (left) and Wear Rate (right) measurements of composites.

The variations of hardness and wear rate with the addition of Ti from 0.04 wt.% to 0.5 wt.% shown in Figure 8 possessed hardness values of (53.97, 54.17, 54.6, 47.7 and

45.4) HRB respectively. This hardness value is way higher than the base material because of the addition of SiC particles as a reinforce and TiB as a grain refiner. SiC blocks the dislocation movement by a mechanism called orowan looping and TiB by grain boundary strengthening mechanism [13]. Figure 8 also concluded that wear rate inversely proportional to hardness. This two related because wear rate was calculated from how many particles removed from materials on a certain velocity, load and sliding distance. The higher number of particles removed, it lowers the rate of abrasion.

4 Conclusion

Based on the research that has been done, obtained that the addition of the grain refiners aim to refine the grain to improve its mechanical properties and reach the optimum value of 0.15 wt.% TiB addition. The effect of the addition of 0.15 wt.% TiB on an ADC12/SiC composite resulting ultimate tensile strength of 136 MPa, hardness value of 54.66 HRB, wear rate of 0.002 3 $mm^3\ s^{-1}$. Phases identified from the research are Mg_2Si, spinel $MgAl_2O_4$, TiB_2, and Al_3Ti which function as α-Aluminum nuclei.

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