Characteristics Of Aluminium ADC 12/SiC Composite with the Addition of TiB and Sr Modifier

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Abstract. The addition of silicon carbide (SiC) as a reinforce in a composite can improve mechanical properties. In this study aluminium ADC 12 (Al-Si-Aluminium Alloy) is treated with an addition of SiC varied from (1; 1.5; 2; 2.5 to 3) vf% and mixed with 0.18 wt% Sr to change the morphology of the silicone eutectic phase and 0.15 wt% titanium boron (TiB) was added as a grain refiner as well as the addition of 5 wt% magnesium (Mg) to increase the wettability. All materials were fabricated by stir cast method. This research is conducted to obtain the candidate material for application in train's brake shoe and bearing. This kind of usage requires high mechanical properties such as wear resistance, thermal resistance, good elastic modulus and lightweight. The composites were characterised by both mechanical properties and microstructure. The result shows that there is an increase in the mechanical properties of aluminium ADC 12 /SiC composite compared to unreinforced with the value of 144 MPa of strength, 53 HRB of hardness, and 0.0049 mm^3 m^{-1} of wear rate. As a result, the higher addition of the SiC results in the better mechanical properties for the composite.

Keywords: ADC12, composite aluminium, grain refiner TiB, micro-SiC, modifying agent Sr

1 Introduction

The composites are different from the metal alloys, wherein the compound of the materials used has different chemical, physical, and mechanical properties. The main components of the composite are the matrix and reinforce [1]. Composite has been used to manufacture industry, especially for the automotive industry. ADC 12 is used as a composite matrix which is an aluminum alloy with a composition of Silicon < 12 %, ADC 12 have a relatively lightweight, corrosion resistance, high thermal conductivity, and ductile [2]. The fabrication of this Aluminum composite consists of SiC particles as a reinforcement, TiB as

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a grain refiner, and Sr modifier, manufactured by stir casting method. This research is conducted obtain homogeneous particle distribution, and the escalation of various mechanical properties, so that it exceeds the aluminium ADC 12 tensile strength, 98.36 MPa and hardness value 35.03 HRB [3].

Silicon carbide used as a reinforce in the ADC 12 matrix because silicon carbide has a high strength, high stiffness modulus, and resistance to high temperature [4]. Size particle of SiC can improve the mechanical properties of bending strength on aluminium composites. In this study using microparticles of (10^{-6}) so that SiC is more easily dispersed and improves the mechanical properties [5]. The addition of strontium must be at the optimum composition because if the levels of strontium added to exceed the optimal level, it will tend to occur porosity and the formation of intermetallic compounds in the composite matrix and will reduce the resulting mechanical properties [6]. The addition of Sr can change the Al dendritic into equiaxed and reduced secondary dendrite arm spacing (SDAS) in primary Al, and the Al-Si eutectic phase becomes more fibrous [7]. The influence of the addition of TiB is that can reduce the porosity because it minimises the occurrence of hot tearing resulting in uniform structure [8]. Based on the research with the addition of 0.015 % Sr to Al-11.6 % Si resulted in the morphology of α-Al phase changed to be more columnar, and with the increased Sr dendrite arm spacing is decreased [9]. The wettability between the matrix and reinforce affect the quality of the composite. An addition Magnesium into the composite as a wetting agent to increase the wettability at a temperature range of 750 °C to 1 100 °C and reduced contact angle by eliminating the oxide-forming reaction occurring at high temperatures, so that the wettability of the reinforcing particles can be increased [10]. The above explanation shows that the study of aluminium composite ADC 12 with SiC particle with TiB as a grain refiner and Sr as a modifier manufactured by stir casting method can increase the mechanical properties, such as high wear resistance, hardness and toughness, resistant to high temperature and low density.

2 Experiments

2.1 Material analysis of ADC 12/SiC compound

Aluminium ADC 12 ingot 568 g was melted in the tilting furnace at temperature 800 °C. In addition of the variation of SiC particle (1; 1.5; 2; 2.5; 3) vf% were heated at 900 °C for 1 h. After ADC 12 was melted, a degassing process is performed in a circular motion using Argon (Ar) gas for 2 min to reduce hydrogen solubility (H_2) and proceed with the removal of slag formed on the surface of the molten metal. 5 wt% of Mg, 0.03 wt% of Al-Sr and 0.15 wt% of Al-5Ti-B were added into the crucible followed by stirring for 5 min. Afterwards, the reinforce was poured into melted alloy then stirred with a speed of 519 rpm and degassing process with argon. The metal mold was inserted into the furnace for 2 min at a temperature of 300 °C to avoid any thermal shock. While the casting die was heated, the molten aluminium stirred for 2 min. Then tilt the molten composite into a metal casting die and cooled at room temperature.

2.2 Characterization

For the microstructural observation all specimen characterised by Optical Microscope (OM), for the preparation, the sample were grinded, then plosihed by TiO_2, and followed by etchic using 0.5 % Hydrofluoric Acid for 10 s. The chemical composition was observed using Optical emmission Specstroscopy (OES) test, the highest Ultimate tensile strength

(UTS) specimen was tested by X-Ray Diffraction (XRD) to know the phase present in the composite material.

All samples were consist of tensile tested based on ASTM E8, then hardness test with Rockwell B according to ASTM E18, also followed by wear testing with Ogoshi based on ASTM G99, and the density invesigation using Archimedes method.

3 Results and discussion

3.1 Material and microstructures

In Figure 1(a) is a microstructure of the matrix used in the composite of Base Aluminum ADC 12. The phase contained in the ADC 12 matrix material is composed of α-Al which is the main phase in the alloy, grey acicular eutectic, Al_2Cu phase, and β phase (Al_5FeSi) in the form of needle like. In Figure 1(b), 1(c), 1(d), 1(e) and 1(f) are composites with matrix ADC12 were added by Sr, TiB, Mg and variaty of SiC particles. When seen in Figure 3, the phases formed in the ADC 12/SiC composite with the addition of Sr and TiB are α-Al phase, the blocky Mg_2Si primary phase, Mg_2Si binary eutectic in the form of chinese script, β phase (AlFeSi) in needle like shape, Al_2Cu phase which is gray and acicular.
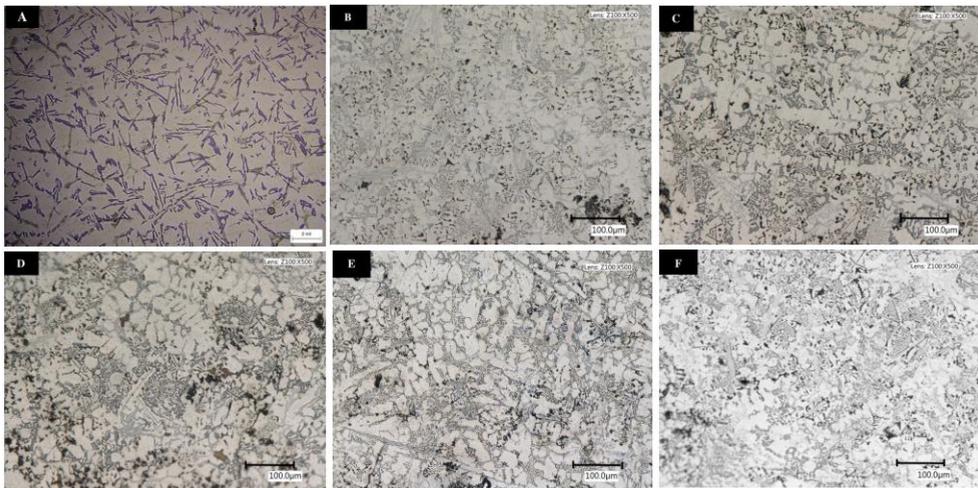

Fig. 1. Observation by using Optical Microscope, Microstructure (a)Base Material ADC12 with 200X magnification, Material with SiC Variation with magnification 500× (b) 1 vf.% (C) 1.5 vf.% (D) 2 vf.% (E) 2.5 vf.% (f) 3 vf.% and the addition of Sr and TiB

In Figure 2 shows the value of Secondary Dendrite Arm Spacing (SDAS) which decreases on the variation of SiC addition from (1; 1.5; 2; 2.5; 3) vf% with SDAS length was 24.38 μm; 21.85 μm; 20.78 μm; 18.11 μm; 18.02 μm respectively. This is also proven that the addition of wt% SiC of 5 to 15 wt% the value of SDAS is reduced but not very significant [11]. In addition of 0.15 wt% TiB and 0.03 wt% Sr on the composite ADC 12/SiC also affects the decreases of SDAS, with an addition of the wt% TiB will bw decrease grain size significantly on the A356/SiC [12]. And also the addition of strontium affects the growth of dendritic columnar in Al-Si alloys. As the growth of strontium, grain morphology becomes more columnar [11].
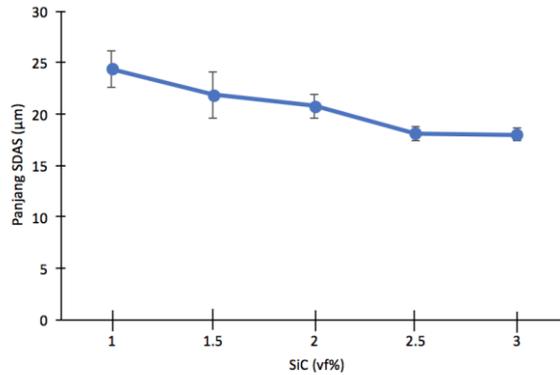
Fig. 2. The effect of addition SiC to Secondary Dendrite Arm Spacing (SDAS).

Table 1. The chemical composition of composites.

Element	The Composition (wt%)					
	ADC 12	SiC 1%vf	SiC 1.5%vf	SiC 2%vf	SiC 2.5%vf	SiC 3%vf
Al	84.8	63.4	66.7	69.1	67	71.9
Si	10.5	11.03	11.14	11.13	11.59	12.61
Fe	0.864	1.13	1.05	1.02	1.92	1.55
Cu	2.33	3.22	3.82	3.00	2.94	2.92
Mg	0.221	5.35	6.04	5.96	4.31	5.19
Cr	0.038 9	0.039 5	0.16	0.043	0.112	0.042
Ni	0.075 9	0.051 9	0.142	0.055	0.046	0.060
Ti	0.046 2	0.065	0.075	0.082	0.08	0.084
Sr	< 0.000 1	0.003 7	0.003 9	0.004 0	0.003 9	0.003 9

As seen in Table 1. from OES test there is an increase in the amount of Si content in the addition of SiC (1; 1.5; 2; 2.5; 3) vf% these match with the mass balance. The suitability between the mass balance and the composite ADC 12, where the Si in base ADC 12 is 10.5 wt% and increased in the composite ADC 12 into 12.61 wt% due to the addition of SiC to the composite ADC 12.
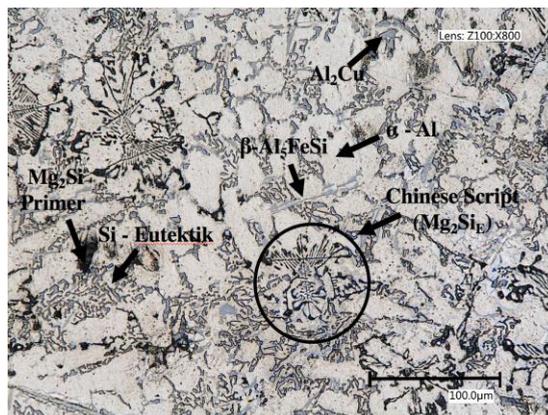

Fig 3. Intermetallic phase with Optical Microscope (OM) with Magnification 800×.

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Micrographs of composites ADC 12 are shown in Figure 3 shows indicate intermetallic phases. From Figure 3 the arrows show the different phases present in the microstructure. α-Al phase has the lightest colour, the slightly grey colour known as Al_2Cu, also Mg_2Si eutectic phase known as chinese script whreas the blocky phase that was Mg_2Si Primary, and βAl_5FeSi has a needle like forms were also present in the microstructure. The phases were predicted by creating solidification path on ternary phase diagram [13]. The β-Al5FeSi phase is easily formed in the normal melting and casting conditions, and the β-Al5FeSi phase can also trigger shrinkage voids in order to decrease the mechanical properties of a material [14]. The reaction forms β-Al5FeSi:

$$L + \beta(AlFeSi) \rightarrow FeSiAl_5 \qquad (1)$$
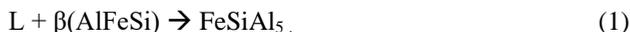
This reaction occurs at temperature 595 ºC [13]. Mg_2Si is a stable intermetallic phase in Mg-Si binary. The phase has a high melting temperature, low density, high hardness, low thermal expansion coefficient and high elastic modulus [15]. The reaction forms Mg_2Si:

$$L \rightarrow Al + Si + Mg_2Si \qquad (2)$$

Al_2Cu phase is formed during solidification on the composite [13]. The Al_2Cu phase is an intermetallic phase which has a porous morphology, and the Al_2Cu phase is an intermetallic phase that affects decreased the mechanical properties of composite materials [16]. The reaction forms Al_2Cu [13]:

$$L \rightarrow Al + Si + Al_2Cu \qquad (3)$$
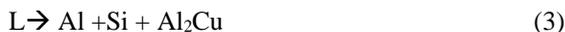
XRD also confirmed the existence of Mg_2Si and Al_2Cu compounds on Figure 4. The Spinel ($MgAl_2O_4$) and MgO phases were seen in the XRD test. The presence of the MgO compound can increase the bond between the matrix with SiC particles, thereby increasing the mechanical properties [17].
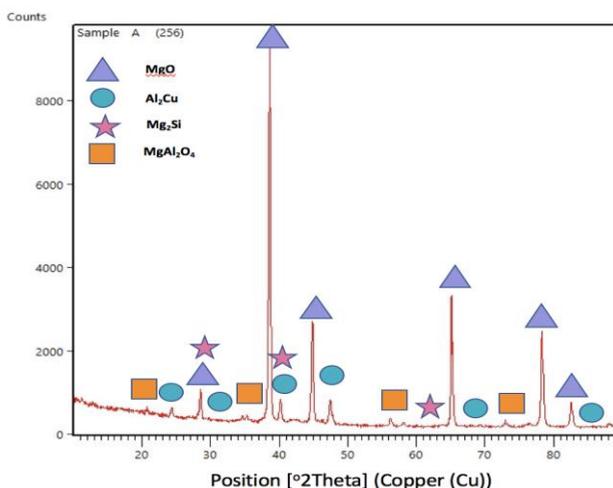

Fig 4. XRD pattern of ADC12 reinforced with 3 vf% SiC with addition of Sr modifier and grain refiner TiB.

3.1 Mechanical properties ADC12/ SiC composite

3.1.1 Density and porosity

Based on Figure 5. There is the difference between the theoretical density value and the actual density value of the composite material see in Figure 5, this is due to the formation of porosity due to the presence of H_2 gas during the casting process, at a temperature of over 600 °C will increase the solubility of H_2 gas and into the metal, this causes the difference in density value [18].

Figure 5 shows that there is an increase in the porosity value of the composition of the addition of vf% SiC The decrease of the porosity value in the fourth composition is 2.5 vf% the porosity value is fluctuated due to grain refiner TiB. Grain refiner TiB was effectively nucleating, whereas in the 2nd composition there may be clustering of TiB_2 particles and the gas entrapped in the molten composites so that can affect porosity nucleation [19].
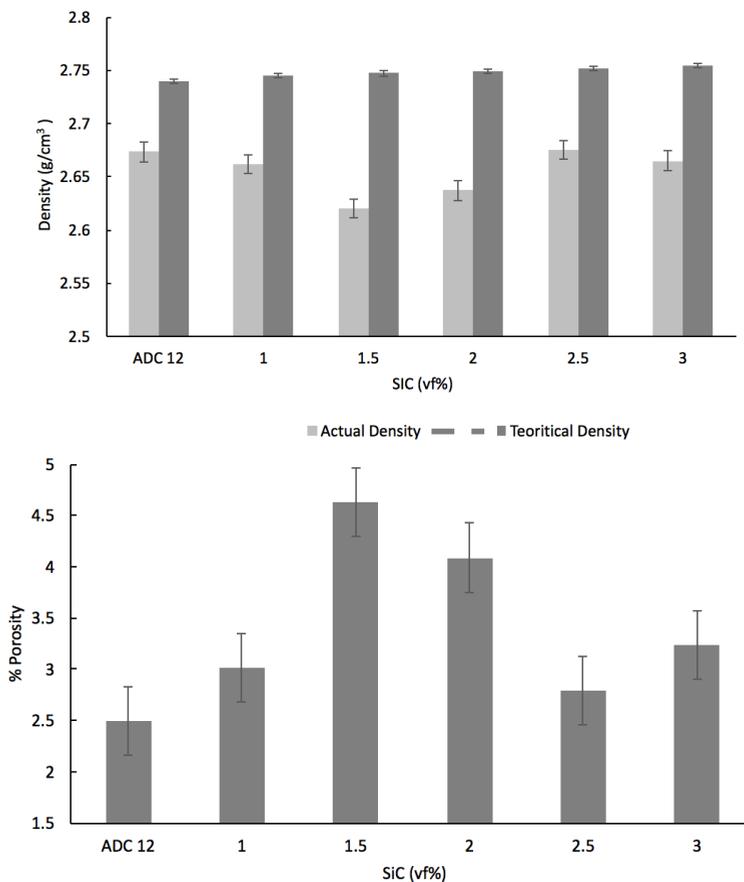
Fig 5. Effect of Adding SiC to Composite Density (left) and Porosity (right) of ADC 12 / SiC with the addition of Sr modifier and grain refiner TiB.

3.1.2 Tensile and elongation

Figure 6 show the elongation values in ADC12 materials of 3 %, and ADC 12 composites with SiC 1 variations; (1.5; 2; 2.5; 3) % vf has the value of elongation was 6.67 %, 3.02 %,

2.89 %, 1.83 %, and 3.44 % respectively, from result the tendency of elongation value on composite ADC12 decreased. Based on the literature, in general, the increase of SiC% vf will lead to a significant decrease in elongation [20]. This theory is supported with increased SiC particles, can increase tensile strength, but decrease the value of plastic deformation, this is due to the decrease of dislocation slip distance with increasing vf% SiC particles and the presence of SiC can form β-Al5FeSi phase which can be a crack initiation [21].

Figure 6 shows the tensile strength on composites with SiC variations of (1; 1.5; 2; 2.5; 3) % vf are respectively; (132, 118; 133; 138; 144) MPa. The value of composite tensile strength tends to increase, this is proved by the addition of SiC will increase the tensile strength of a material, this becase of the mechanism of load transfer effect, Hall-Petch Strengthening and Orowan Strengthening [22]. Orowan Strengthening Mechanism, SiC particles will block the movement of dislocations around the particles within the matrix [23].
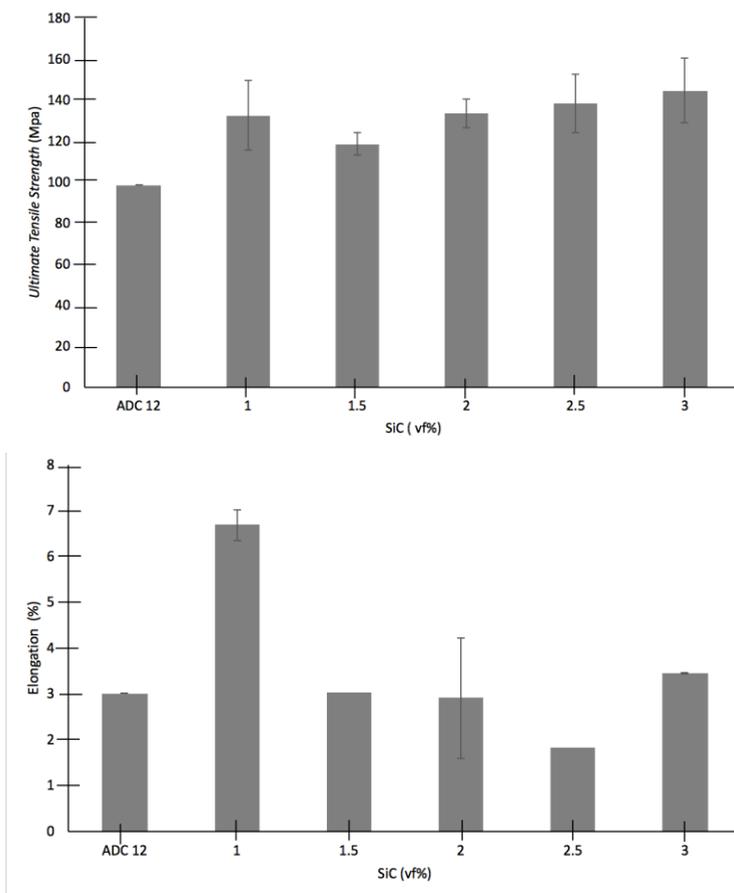

Fig 6. Effect of Adding SiC to Composite Tensile Strength (left) and Elongation (right) of ADC 12/SiC with the addition of Sr modifier and grain refiner TiB.

3.1.3 Hardness and wear rate

Figure 7 shows The hardness value of ADC 12 material is 35.03 HRB, whereas in g ADC 12/SiC composite material with the addition of Sr and TiB obtained the optimum hardness at 3 vf% SiC composition of 53.4 HRB. This is in line with the theory, whereas with

increasing vf% SiC can increase the hardness value because, with the increasing number of reinforcing particles, the possibility of clustering and distribution of particles in heterogeneous matrices can increase the hardness value of the material [3]. In addition to increasing the SiC% vf, modifying the aluminium matrix grain size can also increase the hardness of the material, such as by adding the Ti element as a grain refiner and shrinking the grain size, so that grain boundaries are formed increasing and can inhibit dislocation movements [19].
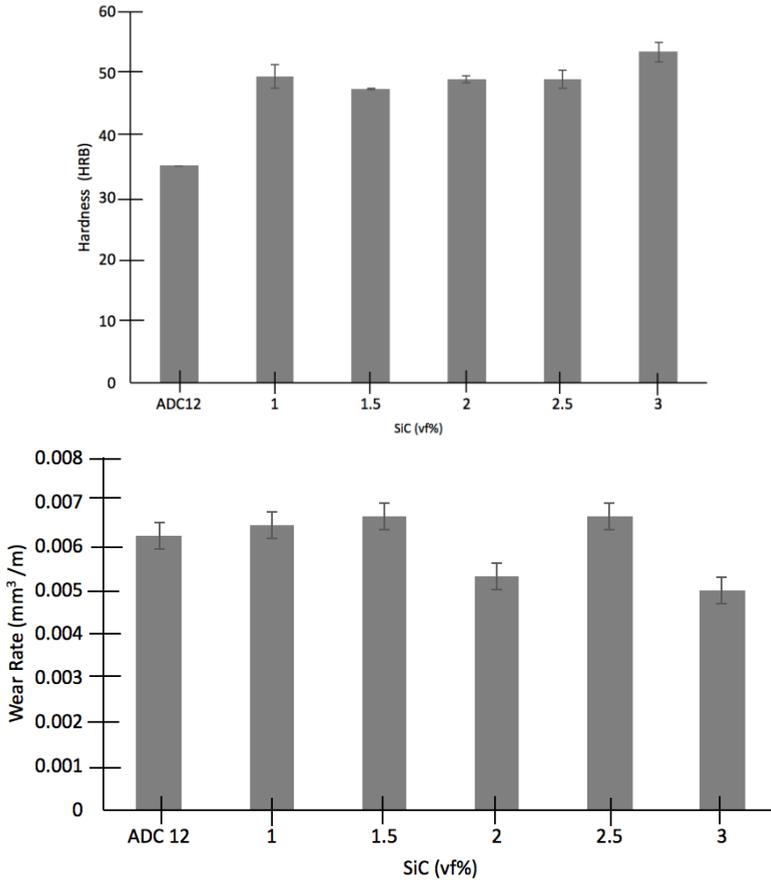

Fig 7. Effect of Adding SiC to Composite Hardness (left) and Wear Rate (right) of ADC 12 / SiC with the addition of Sr modifier and grain refiner TiB.

Figure 7 can be seen, that the value of the wear rate tends to decrease. The lowest wear rate is on the composite ADC 12/SiC with composition fifth with SiC 3 vf% which is 0.004 9 mm^3 m^{-1}, which has a lower wear rate than the composite base rate of ADC 12 composite material. This is due to the addition of SiC increases hardness in composite materials. The graph of wear rate is following the previous author revealed that increasing the hardness value will decrease the wear rate [24].

4 Conclusion

The results show that there is an increase in the mechanical properties of aluminium ADC 12 /SiC composite compared to unreinforced with the value of 144 MPa of strength and 53 HRB of hardness. As a result, the higher addition of the SiC results in the better mechanical properties for the composite. The addition of SiC particles can improve the mechanical

properties of composite materials by the mechanism of load transfer effect, hall-petch strengthening and orowan strenthening. With the addition of‰, SiC vf % decreased the SDAS value. The addition of the TiB as grain refiner produces the Al_3Ti phase which will perform the α-Aluminum nucleation of the composite material and leads the uniform distribution of SiC particles. Phases formed on ADC 12 / SiC composites with the addition of Sr and Grain Refiner TiB that were α-Al, Mg_2Si primer, Mg_2Si binary eutectic, β (AlFeSi) and Al_2Cu, which are known from the XRD resluts.

References

1. F.C. Campbell, *Manufacturing process for advance composite*. Oxford: Elsevier Advance Technology (2004). p. 3−37. https://the-eye.eu/public/Books/Materials%20science%20and%20engineering/M321%20Composites%20manufacturing/Flake%20C%20Campbell%20Jr%20Manufacturing%20Processes%20for%20Advanced%20Composites.pdf
2. A.P. Bayuseno, N.A. Chamdani. Rotasi **13**,1:17–23(2013). https://ejournal.undip.ac.id/index.php/rotasi/article/view/4419
3. G.H. Majzoobi, H. Bakhtiari, A. Atrian, M.K. Pipelzadeh, S.J. Hardy, Proc. IMechE Part L: J. Materials: Design and Applications, **0**,0:1–13(2015). https://www.academia.edu/26479215/Warm_dynamic_compaction_of_Al6061_SiC_nanocomposite_powders
4. Association Aluminium, *Technical committee on product standards technical procedures manual*, Arlington: Association Alluminium, Inc (2015). p. 42. https://www.aluminum.org/sites/default/files/TCPS_Technical_Procedure_Manual_April_2015.pdf
5. Z. Tan, Z. Cheng, G. Fan, G. Ji, J. Zhang, R. Xu, et al., Mater. Des., **90**:845–851(2016). https://www.researchgate.net/publication/284103206_Effect_of_particle_size_on_the_thermal_and_mechanical_properties_of_aluminum_composites_reinforced_with_SiC_and_diamond
6. H.R. Lashgari, A.R. Sufizadeh, M. Emamy, Mater. Des., **31**,4:2187–2195(2010). https://www.researchgate.net/publication/248465379_The_effect_of_strontium_on_the_microstructure_and_wear_properties_of_A356-10B_4C_cast_composites
7. S. Farahany, A. Ourdjini, M.H. Idrsi, S.G. Shabestari, Thermochim. Acta, **559**:59–68(2013). https://www.researchgate.net/publication/235997987_Evaluation_of_the_Effect_of_Bi_Sb_Sr_and_Cooling_Condition_on_Eutectic_Phases_in_an_Al-Si-Cu_Alloy_ADC12_by_In-situ_Thermal_Analysis
8. M. Emamy, A. Razaghian, H.R. Lashgari, R. Abbasi, Mater. Sci. Eng. A, **485**,1–2:210–217(2008). https://www.researchgate.net/publication/223271663_The_effect_of_Al-5Ti-1B_on_the_microstructure_hardness_and_tensile_properties_of_Al2O3_and_SiC-containing_metal-matrix_composites
9. H. Liao, Y. Sun, G. Sun, Mater. Sci. Eng. A, **335**,1–2:62–66(2002). https://www.researchgate.net/publication/222868130_Correlation_between_mechanical_properties_and_amount_of_dendritic_a-Al_phase_in_as-cast_near-eutectic_Al-

116_Si_alloys_modified_with_strontium
10. A. Sangghaleh, M. Halali, Appl. Surf. Sci., **255**,19:8202–8206(2009).
https://www.sciencedirect.com/science/article/pii/S0169433209006394
11. Y. Zhao, X. Liu, Y. Yang, T. Bian, China Foundry, **11**,2,:91–97(2014).
https://www.researchgate.net/publication/248195603_Effect_of_magnesium_addition_
on_the_wetting_of_alumina_by_aluminium
12. C. Lee, Mater. Sci. Eng. A, **668**:152–159(2016).
https://www.sciencedirect.com/science/article/abs/pii/S0921509316305664
13. L.F Mondolfo. *Aluminum alloys: Structure and properties*. London;Boston
Butterworths (1976). p. 973.
https://www.sciencedirect.com/book/9780408709323/aluminum-alloys
14. B. Suárez-Peña, J. Asensio-Lozano, Scripta Materialia, **54**,9:1543–1548(2006).
https://www.sciencedirect.com/science/article/pii/S1359646206000923
15. Y.X. Gao, J.Z. Yi, P.D. Lee, T.C. Lindley, Acta Mater., **52**,19:5435–5449(2004).
https://www.sciencedirect.com/science/article/abs/pii/S1359645404004446
16. H. Nagaumi, S. Suzuki, T. Okane, T. Umeda, Mater. Trans., **47**,11:2821–2827(2006).
https://www.jstage.jst.go.jp/article/matertrans/47/11/47_11_2821/_article
17. F. Delannay, L. Froyen, A. Deruyttere, Journal of Material Science, **22**,1:1–16(1987).
https://link.springer.com/article/10.1007/BF01160545
18. R.S. Rana, R. Purohit, S. Das, Int. J. Sci. Res. Publ., **2**,6:1–7(2012).
http://www.ijsrp.org/research_paper_jun2012/ijsrp-June-2012-10.pdf
19. M. Easton, D. StJohn, Metall. Mater. Trans. A, **30**,6:1613–1623(1999).
https://www.academia.edu/13901359/Grain_refinement_of_aluminum_alloys_Part_I_
the_nucleant_and_solute_paradigms_a_review_of_the_literature
20. A. Mazahery and M. O. Shabani, Powder Technol., **217**:558–565(2012).
https://www.researchgate.net/publication/256831875_Nano-
sized_silicon_carbide_reinforced_commercial_casting_aluminum_alloy_matrix_Exper
imental_and_novel_modeling_evaluation
21. M. SONG, Trans. Nonferrous Met. Soc. China (English Ed.), **19**,6:1400–1404(2009).
https://www.researchgate.net/publication/240440431_Effects_of_volume_fraction_of_
SiC_particles_on_mechanical_properties_of_SiCAl_composites
22. R. Casati, M. Vedani, Metals (Basel)., **4**,1:65–83(2014). https://www.mdpi.com/2075-
4701/4/1/65/pdf
23. A. Mazahery, M.O. Shabani, Trans. Nonferrous Met. Soc. China (English Ed.),
22,2:275–280(2012).
https://www.researchgate.net/publication/257443682_Characterization_of_cast_A356_
alloy_reinforced_with_nano_SiC_composites
24. P.L. Menezes, S.P. Ingole, M. Nosonovsky, S.V. Kailas, M.R. Lovell, *Tribology for
Scientists and Engineers*. New York: Springer (2013). p. 921.
https://www.researchgate.net/publication/280566932_Tribology_for_Scientists_and_E
ngineers