Analysis of the Impact of Silicone Carbide (SiC) as a Reinforcement on Composite Properties

Ramlan[1], Endah Puspita[2], Akhmad Aminuddin Bama[3], Melenia Tambunan[4]

{ramlan@unsri.ac.id[1], endahpuspita1908@gmail.com[2], akhmadbama@yahoo.com[3], milen17022000@yahoo.com[4]}

Physics Department, Faculty of Mathematics and Natural Sciences, Universitas Sriwijaya, South Sumatera 30662 Indonesia[1,2,3,4]

Corresponding author: milen17022000@yahoo.com

Abstract. Al-SiC composites were prepared with variations of SiC addition of 0%, 10%, 15%, and 20% using the powder metallurgy method. The purpose of this study was to determine the effect of SiC addition on Al matrix composites. The materials were characterized in terms of density, porosity, hardness, X-Ray Diffraction (XRD), and Scanning Electron Microscope (SEM). Based on the results of density, porosity, hardness, it shows that the Al-SiC composite samples with SiC variations of 0%, 10%, 15% and 20% have densities of 2.98 g/cm^3, 3.16 g/cm^3, 3.74 g/cm^3 and 3.23 g/cm^3, while the porosity is 4.30%, 0%, 0% and 5.07%, and the hardness is 513 Hv, 528 Hv, 560 Hv, and 560 Hv, respectively. XRD results show that the samples produced multiphase of Al, SiC and SiO_2. SEM results show that the Al-SiC composite has a grain size of 1 - 8.50 μm.

Keywords: Composite, Al-SiC, powder metallurgy, XRD, SEM.

1 Introduction

The development of materials technology in various industries continues to increase [1]. Many researchers have continued to innovate to continuously improve material quality, where material quality has important components such as strength, corrosion resistance, specific gravity, and high-temperature resistance. An example of a good quality material is a composite [2]. Composites are materials formed from two or more materials that are heterogeneous on a macroscopic scale [3-5]. Composite materials are valued for their flexible design capabilities, lightweight, corrosion resistant, and durable [6,7]. Composite materials have been widely applied and used in various fields such as the automotive industry, sports, transportation and infrastructure, environmental engineering, electricity distribution, and others [8].

The classification of composite materials consists of matrix and reinforcement. The reinforcement matrix can be classified into three types namely polymer matrix composites (PMCs), ceramic matrix composites and metal matrix composites [4]. MMCs are a combination of a metal matrix reinforced by another metal. MMCs have properties such as specific stiffness,

SICBAS 2025, November 06, Palembang, Indonesia

DOI 10.4108/eai.6-11-2025.2364331

specific strength, excellent corrosion resistance, wear resistance, and high modulus of elasticity [9]. Some examples of metals that can be used as a matrix include Al, Mg, Cu, Fe, Ti, and others. Al metal is one of the metals that can be used as a composite matrix, where Al has properties and characteristics such as corrosion resistance and high thermal conductivity, making it very suitable for various applications. Therefore, Al matrix in composites can be referred to as aluminum matrix composites (AMCs) [10-12].

Aluminum matrix composites (AMCs) are an advanced class of composite materials. AMCs have several advantages such as combine lightweight performance with high strength, stiffness, and ductility, while also offering low thermal expansion, strong resistance to wear and creep at elevated temperatures, and excellent corrosion resistance [13-15]. AMCs are widely used in some industries, such as automotive, military, power and others. At present, many scientists have paid more attention to the development of AMCs. In addition, the use of the type and proportion of reinforcements also affects the properties and characteristics of Al composites [16]. Reinforcement materials that can be used in AMCs can come from ceramics, carbon fibers, glass fibers, and others. The incorporation of reinforcement enhances the physical and mechanical properties of AMCs. Common ceramic particulate reinforcements include silicon carbide (SiC), boron carbide (B_4C), titanium carbide (TiC), Al_2O_3, and silica particles (SiO2)[17]. This is evidenced by the research conducted by Liu et al. (2019) on the fabrication of MMC composites using Al as the matrix and Al2O3 as the reinforcement. The results show that composites with Al2O3 reinforcement produce higher strength than pure Al composites, namely yield strength and ultimate strength of 610 MPa and 784 MPa under quasi-static compression [18]. The fabrication of MMCs can be done by several methods, namely stir casting, in situ fabrication, powder metallurgy, squeeze casting, investment casting, and squeeze casting [19-22].

Furthermore, the fabrication of AMCs using SiC matrix reinforcement for various applications has been widely carried out. However, no specific research has been conducted to see the effect and comparison regarding the properties and characteristics of AMCs when done before and after the addition of SiC material as reinforcement. Therefore, we will conduct research on the production of Al-SiC composites by powder metallurgy.

2 Research methodology

Al-SiC composites are manufactured by powder metallurgy. The raw materials used in this research are aluminum (Al) and silicon carbide (SiC). The variations in sample composition based on weight percent (%wt) are 95% Al and 0% SiC, 90% Al and 10% SiC, 85% Al and 15% SiC, 80% Al and 20% SiC. A total of 11.59 g, 13.5 g, 12.75 g, and 12 g of Al powder were mixed with 0 g, 1.5 g, 2.25 g, and 3 g of SiC, respectively. Milling with HEM for 30 minutes. The sample was formed using a hydraulic press with a weight of 8 tons and held for 1 minute. The samples were then sintered at 650 °C for 1 hour.

Al-SiC composite samples were characterized by density, porosity, hardness, X-ray diffraction (XRD) (XRD; PANalytical AERIS), and scanning electron microscope (SEM) (SEM-EDX; PhenomProX Desktop). For density, it is done manually, namely using a caliper to measure the diameter and height of the pellets, then recording the results of each 5 repetitions of each measurement of diameter and height of the pellets, averaging each measurement of the diameter and height of the pellets. Weigh the dry mass of the pellets and calculate the density by dividing the pellet mass and volume. For porosity, weigh the mass of oven-dried pellets. Soak the pellets in water for 24 hours. After soaking, weigh the pellets to find the wet mass value and calculate the porosity value by subtracting the wet mass value from the dry mass value. then divided by the dry mass value and multiplied by 100%. To measure the hardness of the pellets use a Durometer type Shore D tool, do five repetitions then take the average of the repeated measurements, then convert the hardness value into Vickers hardness (HV).

3 Result and discussion

3.1 Density and porosity

The characterization to find the value of density and porosity in the CAl-SiC composite sample can be shown in **Figure 1**.

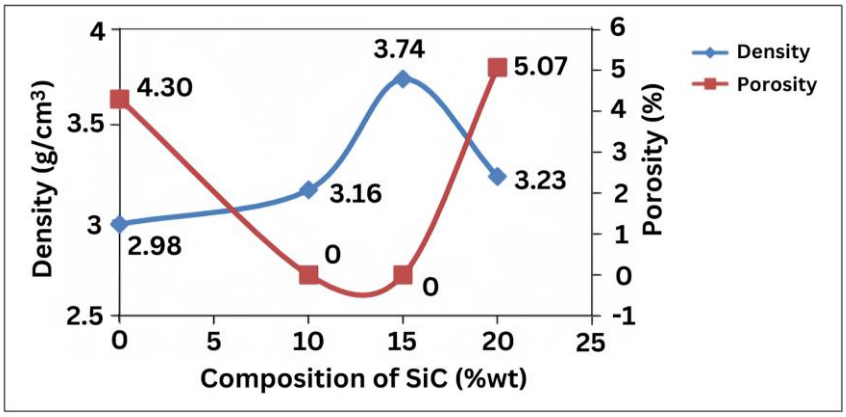

Fig. 1. Correlation between density and porosity in Al-SiC composite samples.

The results of the density and porosity values in the Al-SiC sample shown in **Figure 1**. The addition of 0% SiC to the Al composite results in density and porosity values of 2.98 g/cm^3 and 4.30%, respectively. The large porosity value indicates that the sample still has voids in the material or the density of the material is not maximized. In the addition of 10% and 15% SiC, it shows an increase in the size of the density value, which is 3.16 g/cm^3 and 3.74 g/cm^3, respectively, and the porosity produced is 0%. The increase in the density value indicates that the density of the Al-SiC composite has increased to the point where there are no empty voids. Thus, it can be said that the addition of SiC can increase the density value of the material and reduce the porosity. However, the addition of 20% SiC to the Al composite shows a decrease in density and an increase in porosity, which are 3.23 g/cm^3 and 5.07%, respectively. This decrease in density and increase in porosity can be caused by the sintering temperature used not being suitable for the addition of higher SiC, resulting in the resulting Al-SiC composite sample cracking and compaction not being optimal.

3.2 Hardness

The hardness value of the Al-SiC composite sample is shown in **Figure 2**. **Figure 2** shows the hardness level of the Al-SiC sample. In pure Al (0% SiC) shows the hardness level of the Al-SiC composite of 513 Hv, then in the addition of the composition of 10% SiC and 15% SiC respectively there has been an increase in the hardness curve in the sample which is 528 Hv and 560 Hv. The increase in hardness value by the addition of SiC in the Al-SiC sample can be caused by Al having a weak or soft hardness value so that a filler is needed as a reinforcement, namely SiC, this is what makes the addition of SiC, the hardness value increases. SiC was chosen as the filler because it has a good hardness value.

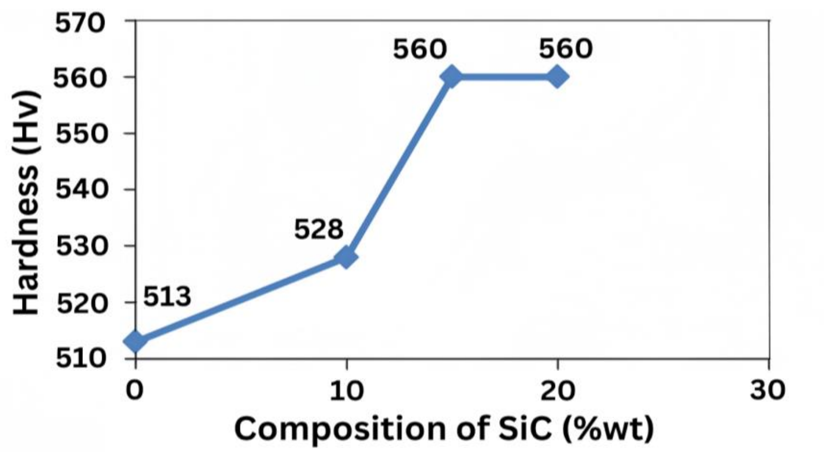

Fig. 2. Hardness of the Al-SiC composite

In addition, SiC binds easily to Al and does not cause oxidation. However, at 20% SiC composition there was no increase in hardness. This could be because the SiC is agglomerated or unevenly distributed, so this could reduce the effectiveness of the reinforcement and the hardness does not increase [23,24].

3.3 X-Ray diffraction (XRD)

The crystal structure and phase formed in the Al-SiC composite sample can be shown in **Figure 3**. **Figure 3** shows the results of the diffraction pattern peaks in Al-SiC composites with variations in SiC addition of 0%, 10%, 15% and 20% with 2θ angles of 38.50^o, 39.00^o, 38.15^o and 38.15^o. At 0% SiC composition, a single phase of Al is identified with no foreign phases detected, indicating that Al is not oxidized by oxygen or combined with other compounds during the sintering process.

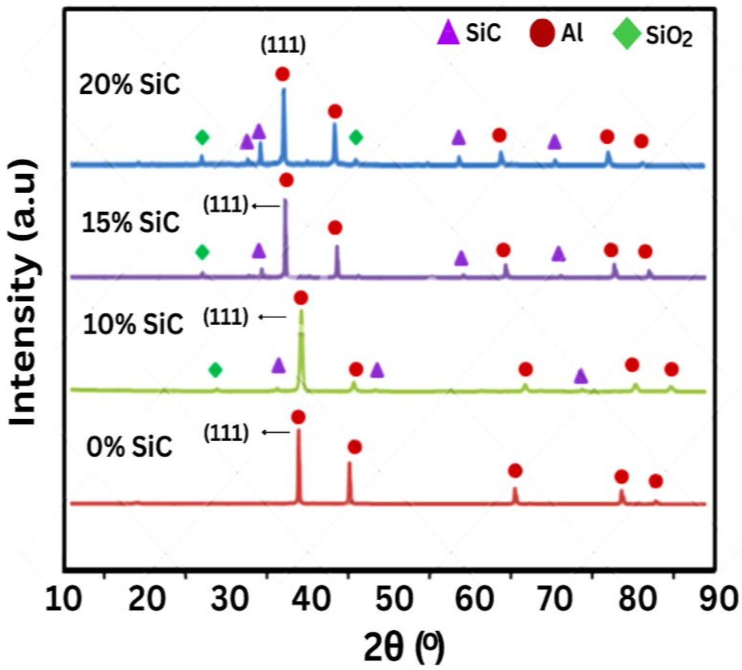

Fig. 3. Diffraction pattern peaks in Al-SiC composites.

As for the composition of 10%, 15%, and 20% in SiC, it shows the presence of other phases besides Al, namely SiC and SiO_2. The appearance of the SiC phase in the sample is due to the presence of SiC content in the composite while SiO_2 can be caused by oxidation during the sintering process. The crystal size in the pure composite is calculated to be 85.88 nm in the hkl (111). At 10%, 15% and 20% composition, crystals with sizes of 26.75 nm, 103.92 nm and 67.98 nm were obtained. The crystal size decreases with the addition of 10% SiC, then the crystal size at 15% composition is larger than the previous two compositions. A decrease in crystal size occurs at 20% SiC composition. It can be seen that the reduction in crystal size does not occur in powders with 15% SiC added. The resulting crystal size is larger than that of powders with 10% SiC. The increase in crystal size may be caused by agglomeration [24].

3.4 Scanning electron microscope (SEM)

The morphological state of the Al-SiC composite is shown in **Figure 4**, where the addition of 10% SiC is the best composition for the Al matrix. **Figure 4** shows the morphology of the Al-SiC composite sample with 10% SiC addition variation. From the test results, it can be observed that the shape of the grains in the composite is irregular in terms of size and shape, which is not the same from one grain to another.

At 500X magnification, there are boundaries in the morphology of the Al-SiC composite with white lines in the form of SiC grains on the surface. In addition, there is agglomeration (clumping) of grains on the surface of the composite, which can be seen at magnifications of 500x, 1000x, 5000x and 10000x, where the agglomeration size is 1-8.50 µm.

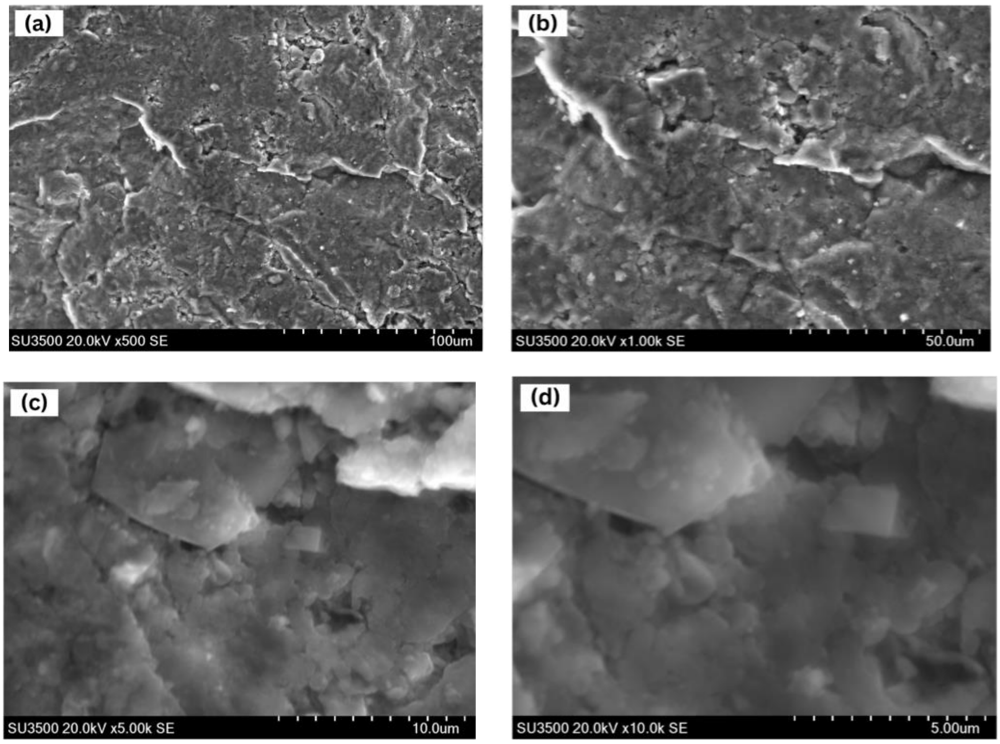

Fig. 4. Morphological state of the Al-Sic composite at (a) 500x, (b) 1,000x, (c) 5,000x, and (d) 10,000x magnifications.

4 Conclusion

In this research, Al-SiC composites were successfully prepared by powder metallurgy method. Based on the XRD results, it is shown that the Al-SiC composite produces multi-phase Al, SiC and SiO_2. For the density results in the sample increased as SiC (0%, 10% and 15%) was added to Al to 2.98 g/cm^3, 3.16 g/cm^3, 3.74 g/cm^3 respectively, but in the 20% SiC variation the density decreased to 3.23 g/cm^3 due to Al-SiC composite cracking. The hardness level of the composite increases when given additional SiC as in the composition of 10% SiC which is 528 Hv greater than the 0% SiC sample which is 513 Hv. SEM results show that the Al-SiC composite has a particle size of 1 - 8.50 µm which is due to the agglomeration of the sample.

References

[1] Xu, Q.: Thoughts on the development of new material technology. IOP Conference Series: Materials Science and Engineering. Vol. 493, no. 1, pp. 1-4 (2019)

[2] Pramono, A., Jumiadi.: Analisis SEM dan XRD komposit logam (Al-SiC) hasil proses metalurgi serbuk. Transmisi. Vol. 2, no. 2, pp. 939-946 (2013)

[3] Magibalan, S., Kumar, P.S., Vignesh, P., Prabu, M., Balan, A.V., Shivasankaran, N.: Aluminium metal matrix composites - A review. Transactions on Advancements in Science and Technology. Vol. 2, no. 1, pp. 1-6 (2017)

[4] Raju, A., Shanmugaraja, M.: Recent researches in fiber reinforced composite materials: A review. Materials Today: Proceedings. Vol. 46, pp. 9291-9296 (2019)

[5] Salernitano, E., Migliaresi, C.: Composite materials for biomedical applications: A review. Journal of Applied Biomaterials and Biomechanics. Vol. 1, no. 1, pp. 3-18 (2003)

[6] Agrawal, P., Kundu, A.K., Purohit, D., Gautam, N., Sharma, A., Patil, V.: A review paper of composite materials: Advantages and applications. International Journal of Advances in Engineering and Management (IJAEM). Vol. 4, no. 11, pp. 369-370 (2022)

[7] Thori, P., Sharma, P., Bhargava, M.: An approach of composite materials in industrial machinery: Advantages, disadvantages and applications. IJRET: International Journal of Research in Engineering and Technology. Vol. 2, no. 12, pp. 350-355 (2013)

[8] Ngo, T.-D.: Composite and nanocomposite materials. IntechOpen (2020)

[9] Kok, M.: Production and mechanical properties of Al_2O_3 particle-reinforced 2024 aluminium alloy composites. Journal of Materials Processing Technology. Vol. 161, no. 3, pp. 381-387 (2005)

[10] Ekka, K.K., Chauhan, S.R., Varun.: Dry sliding wear characteristics of SiC and Al_2O_3 nanoparticulate aluminium matrix composite using Taguchi technique. Arabian Journal for Science and Engineering. Vol. 40, no. 2, pp. 571-581 (2015)

[11] Gupta, M.: Metal matrix composites. Metals. Vol. 8, no. 6 (2018)

[12] Ramanathan, A., Krishnan, P.K., Muraliraja, R.: A review on the production of metal matrix composites through stir casting - Furnace design, properties, challenges, and research opportunities. Journal of Manufacturing Processes. Vol. 42, pp. 213-245 (2019)

[13] Mavhungu, S.T., Akinlabi, E.T., Onitiri, M.A., Varachia, F.M.: Aluminum matrix composites for industrial use: Advances and trends. Procedia Manufacturing. Vol. 7, pp. 178-182 (2016)

[14] Parveez, B., Maleque, M.A., Jamal, N.A.: Influence of agro-based reinforcements on the properties of aluminum matrix composites: A systematic review. Journal of Materials Science. Vol. 56, no. 29, pp. 16195-16222 (2021)

[15] Ujah, C.O., Kallon, D.V.V.: Trends in aluminium matrix composite development. Crystals. Vol. 12, no. 10, pp. 1-27 (2022)

[16] Edoziuno, F.O., Nwaeju, C.C., Adediran, A.A., Odoni, B.U., Arun Prakash, V.R.: Mechanical and microstructural characteristics of aluminium 6063 alloy/palm kernel shell composites for lightweight applications. Scientific African. Vol. 12, e00781 (2021)

[17] Garg, P., Jamwal, A., Kumar, D., Sadasivuni, K.K., Hussain, C.M., Gupta, P.: Advance research progresses in aluminium matrix composites: Manufacturing & applications. Journal of Materials Research and Technology. Vol. 8, no. 5, pp. 4924-4939 (2019)

[18] Liu, J., Huang, X., Zhao, K., Zhu, Z., Zhu, X., An, L.: Effect of reinforcement particle size on quasistatic and dynamic mechanical properties of Al-Al_2O_3 composites. Journal of Alloys and Compounds. Vol. 797, pp. 1367-1371 (2019)

[19] Anandaraj, T., Sethusundaram, P.P., Chanakyan, C., Sakthivelu, S., Meignanamoorthy, M.: Influence of different reinforcements on properties of metal matrix composites: A review. Materials Today: Proceedings. Vol. 37, Part 2, pp. 3480-3484 (2020)
[20] Kareem, A., Qudeiri, J.A., Abdudeen, A., Ahammed, T., Ziout, A.: A review on AA 6061 metal matrix composites produced by stir casting. Materials. Vol. 14, no. 1, pp. 1-22 (2021)
[21] Nanda, I.P., Ghandvar, H., Idris, M.H., Hanif, A., Arafat, A.: Role of Gd addition on machinability of Al-15%Mg_2Si in-situ composite during dry turning. Communications in Science and Technology. Vol. 5, no. 2, pp. 65-69 (2020)
[22] Rajan, R.T.K., Ramesh, S., Boppana, S.B., Krishnan, P.K.: Sustainable development on production and characterization of metal matrix composites using stir casting. Journal of Physics Communications. Vol. 7 (2023)
[23] Arrahim, M.G., Wicaksono, L.H., Fadly, M.S., Musyafiq, A.A.: Analisis kandungan silikon karbida (SiC) sebagai filler terhadap peningkatan kekerasan pada metal matrik komposit. Infotekmesin. Vol. 14, no. 02, pp. 176-180 (2023)
[24] Deore, H.A., Mishra, J., Rao, A.G., Mehtani, H., Hiwarkar, V.D.: Effect of filler material and post process ageing treatment on microstructure, mechanical properties and wear behaviour of friction stir processed AA 7075 surface composites. Surface and Coatings Technology. Vol. 374, pp. 52-64 (2019)