REKAYASA MESIN V12 N1
eISSN 2477-6041 artikel 18, pp. 159 – 169, 2021

CHARACTERIZATION OF ALUMINUM MATRIX METAL COMPOSITE HYBRID REINFORCED WITH SICW/(AL_2O_3-MG) ON THERMAL CONDUCTIVITY AND HARDNESS

Ketut Suarsana
Lecturer
Udayana University
Department of Mechanical Engineering
ktsuarsana@yahoo.com

Rudy Soenoko
Lecturer
Brawijaya University
Department of Mechanical Engineering
rudysoen@yahoo.com

DNK Putra Negara
Lecturer
Udayana University
Department of Mechanical Engineering
devputranegara@gmail.com

P.W Sunu
Lecturer
Bali Polytechnic
Department of Mechanical Engineering
wijayasunu@pnb.ac.id

Characteristics of composite materials that are light, strong, heat resistant, and high hardness are needed in their application. This study aims to obtain a hard material and good heat conductivity, with the innovation of making aluminum matrix composites (AMC) from aluminum powder as a matrix, combined with silicon-carbon whisker (SiCw) and alumina particles (Al_2O_3p), and adding Magnesium through the powder process metallurgy. The method of making composites was carried out by means of powder metallurgy. The research variables composition I, II, and II with Al/(SiCw+Al_2O_3/Mg), were given temperature treatment: 500, 550, and 600^{o}C. The test results show that there is an increase in the mechanical properties of the composites both from variations in composition and also from variations in treatment temperature because the bond resulting from the addition of Al_2O_3 reinforcement has hard and fine grain properties. The physical and mechanical properties of the test results are in the form of the highest density at composition I, 600^{o}C (2,699 gr/cm^3) while the hardness at composition III is 600^{o}C (42,438 HV) and heat conductivity at composition III, 600^{o}C (185,183 Watt/m.^{o}C). Scanning with SEM showed that the pore size decreased from the treatment temperature of 500^{o}C to 600^{o}C due to phase changes and a stronger bond between the matrix and the reinforcement. So that the influence of composition and temperature will affect the thermal conductivity, hardness, and density of the composites.

Keywords : *Al_2O_3-Mg, Characterization, Hardness, SiCw Hybrid, Thermal Conductivity*

1. INTRODUCTION

Currently, the need for material manufacturing technology is also increasing, followed by a variety of material applications. Metal-based material development applications in the industrial world are very potential. Indonesia has a large enough potential for the aluminum bauxite mineral. Based on the latest data from the Indonesian ESDM Geological Agency in 2013, it shows that the amount of bauxite resources in Indonesia reaches 1.264 billion tons [1]. Aluminum is a material that has the potential to be developed to obtain material characteristics that suit your needs. The development of the aluminum material is an aluminum matrix composite with the addition of reinforcement. Composite is a material development that is widely applied in various fields. One type of composite is Metal Matrix Composite (MMC) [2].

Research on composites continues to be developed with various types of matrix materials combined with composite binders. Aluminum matrix composites reinforced with SiCw and Al_2O_3 made by powder metallurgy method with the compacting process have been studied to improve the mechanical properties of composites [3]. Composite strength increases along with increasing of temperature, but porosity decreases along with increasing of Al_2O_3 [2][3]. In previous studies, magnesium was added as a wetting agent which aims to increase the interface bond between the matrix and the reinforcement so that the composite becomes

Corresponding Author: ktsuarsana@yahoo.com Received on: August 2020 Accepted on: December 2020
DOI: https://doi.org/10.21776/ub.jrm.2021.012.01.18

stronger and more homogeneous [4].

In previous research, the manufacture of Al/(SiCw+Al_2O_3) hybrid composites using a mixture of fine aluminum powder as a matrix while silica carbide (SiCw) and alumina (Al_2O_3) as reinforcement with powder metallurgy method gave the result that the sintering process could affect the composite on its physical properties and mechanics. The addition of the weight percent composition of SiCw and alumina (Al_2O_3) has an effect on the physical and mechanical properties of the composite, where the density and wear increases with each addition of alumina itself [5].

Previous research explained that composites using aluminum powder added with SiCw and Mg powders gave the result of an increase in the value of thermal conductivity at each added pressure, while the value of the wear rate decreased with increasing pressure [6]. Based on research on the effect of whisker and alumina reinforcing aluminum matrix composites on the hardness properties of the material, increasing of hardness was obtained due to the increasing percentage of SiCw material composition among the composite reinforcing materials [7]. Research on the effect of holding time and sintering temperature of Al matrix composites with Al_2O_3 + SiCw reinforcement on density and hardness properties provides an increase in density and thus hardness [8]. The effect of the composition of the reinforcing fibers of SiC and particulate Al_2O_3 on the characteristics of the composites has a significant effect because the Al_2O_3 particles are smaller than the aluminum matrix, so they easily spread into the composite so that it gives the properties of the aluminum matrix with good SiCw and Al_2O_3 bonds. Meanwhile, SiCw in the form of fiber contributes to making it more porous. In this case, the addition of Al_2O_3 itself affects the hardness properties of the composite. In the sintering treatment with a longer holding time it causes an increase in hardness, at a temperature of 550ºC with a holding time of 6 hours, the highest increase in hardness occurs [9]. The effect of sintering time and temperature on Al_2O_3 + SiCw on the characteristics of aluminum matrix composites shows that the maximum elastic modulus occurs with a holding time of 3 hours at a temperature of 550ºC. SEM scanning shows that the structure of the composite is getting more homogeneous and denser because the distribution of particles and whiskers is more evenly distributed [10]. In a study on the effect of composition and sintering treatment on Al/(SiCw+Al_2O_3) composites on physical and mechanical properties, the results showed that increased wear and density occurred with each addition of Alumina for each composition [3].

Composite Material is a mixture of materials consisting of two or more materials, in which each material has different chemical and mechanical properties which then becomes a new material and has new characteristics [11]. By combining these materials, a new material is obtained which has better properties than the single constituent material [12]. Composites are divided into three types, one of which is Metal Matrix Composite (MMC). MMC is a combination of materials consisting of two or more materials, with their own properties and shapes, so that later it will produce a new material in the form of a composite with better properties and characteristics than the original material. The technology for making matrix metal composites depends on the chosen reinforcement, classified based on the type of matrix whether the matrix is in the liquid, solid or gas phase before adding the reinforcement [13] [14]. After the process is carried out, it will provide its own advantages and disadvantages, including economic calculations in production [15].

Non-ferrous aluminum metal has a light mass as well as good mechanical properties, corrosion resistance, and good electrical conductor. Aluminum is used very widely in various fields, and is also used as a composite matrix material [7] [16].Alumina is a raw material obtained in the electrolysis process and is used based on a stoichiometric balance, which is up to 1.89 kg in mass. Other uses are for the chemicals manufacture, abrasives and ceramic fibers. Alumina (Al_2O_3) is contained in an oxide compound from aluminum which is obtained through the refining process of bauxite (Al_2O_3 x H_2O). This process is known as the Buyer Process SiCw material is widely used for metal reinforcement [17]. SiCw material has high hardness, therefore the choice of SiCw material is very good in using lathe chisels because it is resistant to high temperatures. In addition, this material is widely used for reinforcing ceramic components which must have a very high operating temperature [18].

This research is focused on developing aluminum matrix with added SiCw and Al_2O_3/Mg as reinforcement and using powder metallurgy method in mixing matrix materials with reinforcement. The use of powder metallurgy and compacting techniques aims to combine two or more material properties into one so that the superior composite properties of the combined material are obtained. The study was carried out by experimenting in the laboratory to determine the new characteristics of composites which include: density, thermal conductivity, hardness, and composite structure.

2. MATERIAL AND METHODS

The process used in the formation of composites is the powder metallurgy method. The stage in this process begins with mixing and stirring of the powder particles in order to mix the powder perfectly from each of the composites to produce a homogeneous powder. The mechanism that occurs during the powder mixing process depends on the mixing method used [19]. The method in this research starts from the process of making aluminum matrix composites with SiCw+(Al_2O_3/Mg) reinforcement in the form of fine fibers and powder mixed using a magnetic stirrer. Furthermore, it will be characterized to determine its physical and mechanical properties. Composites with a percentage of the composition Al/SiCw + (Al_2O_3/Mg) are variables that will be observed for their effect on density, heat conductivity, hardness and wear and also the microstructure of the composite. The test material was made in a mold in the form of a cylinder with a diameter of 3 cm, a height of 2 cm, with the resulting composite volume of 14.130 cm^3. The material used are aluminum (ρm = 2,7 gr/cm^3), SiCw (ρ = 3,2 gr/cm^3), Al_2O_3 (ρ = 3,8 gr/cm^3), and Magnesium (ρ = 1,7 gr/cm^3) with a variety comparisons of Composition I : Al(65%) / SiCw(20%) + Al_2O_3(10%)/Mg(5%), Composition II: Al (65%)/ SiCw(15%) + Al_2O_3(15%)/Mg(5%), Composition III: Al (65%)/ SiCw(10%) + Al_2O_3(20%)/Mg(5%). This study aims to find the physical and mechanical characteristics of composites.

2.1 Hardness testing

Hardness is the resistance of an engineering material to penetration or deformation. This test uses the Vickers hardness method with the tool used by a micro hardness tester made of pyramid-shaped diamond as an indenter. Angle between the faces of the pyramid $\alpha = 136^o$

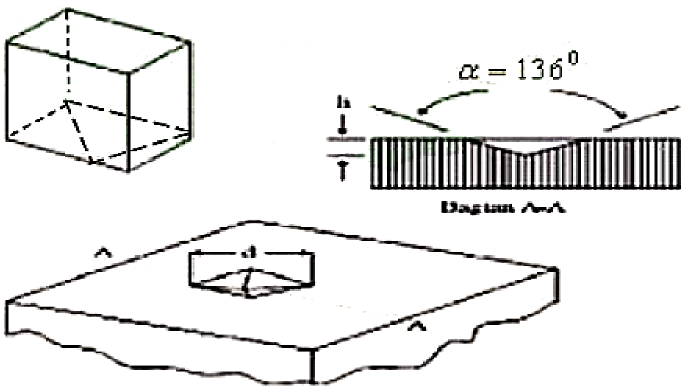


Figure 1. Hardness testing schematic

The strength range standard used in hardness testing is ASTM E-384 for the micro range (10-1000 gr), ASTM E-92 for the macro range (1-100 kg), and ISO 6507 for the micro and macro ranges.

The hardness value can be found by the equation (1):

$$VHN = 1{,}854 \frac{P}{(dmean)^2} \quad (1)$$

With:

d_{mean} = $(d_1 + d_2)/2$
VHN = *Vikers Hardness Number*
P = load (kgf)
d_1 = diagonal length 1
d_2 = diagonal length 2

2.2 Density Properties Testing

Density is a physical quantity, the ratio of the mass to the volume of the object [20]. Measurement of density in solid form using the Archimedes method can be calculated from equation (2) [21].

$$\rho = \frac{m_s}{(m_b - m_g)} x\rho H_2 0 \quad (2)$$

With:

ρ	= density (gr/cm^3)
ms	= dry mass (gr)
mg	= mass hung in water (gr)
mb	= mass after immersing in water (gr).
ρH2O	= density of water (1 gr/cm^3)

2.3 Heat Conductivity Testing

The thermal conductivity value of a material shows the rate of heat transfer flowing in a material [22]. The thermal conductivity of most materials is a function of temperature, and increases slightly as the temperature increases, but the variation is small and is often neglected [23]. If the value of the thermal conductivity of a material is greater, the more heat will flow through the object. Therefore, materials with high k values are good heat conductors, while materials with small k values are less conductive (insulators). The value of thermal conductivity can be seen in equation (3) [24]:

$$q = kA\,\frac{\partial T}{\partial x} \quad (3)$$

With:

q	= Heat transfer rate (W)
k	= Thermal conductivity (W/m. ^{o}C)
A	= Cross-sectional area (m^2)
∂T/∂x	= Temperature gradient, which is the rate of change in temperature T in the x direction flow (^{o}C/m)

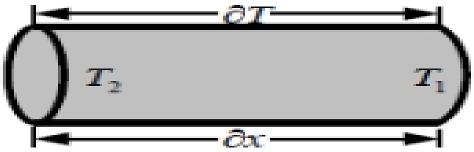


Figure 2. Temperature difference scheme

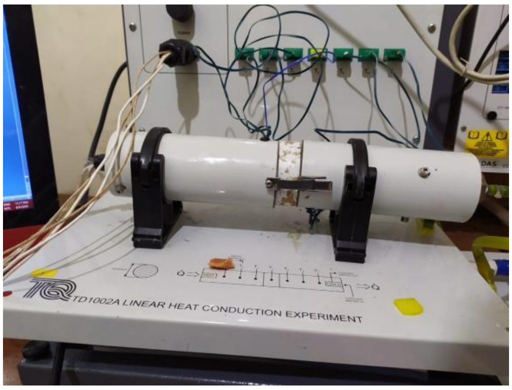
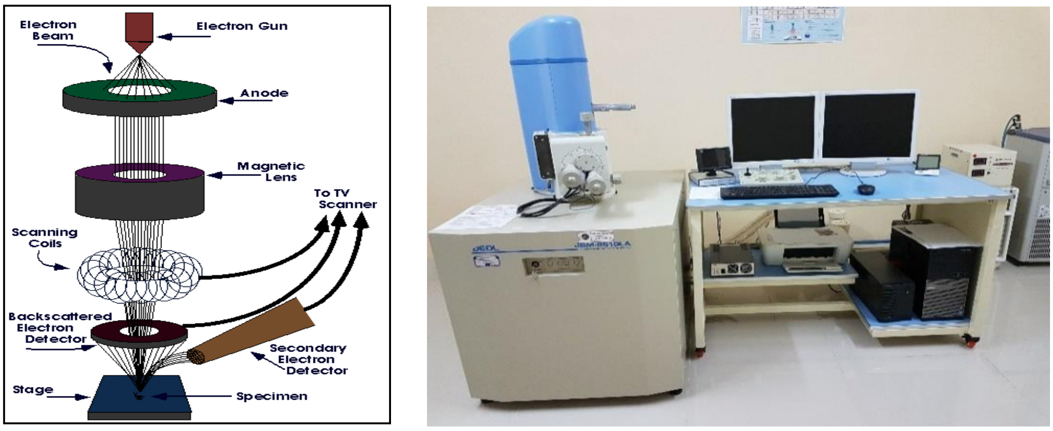


Figure 3. Thermal conductivity test equipment

2.4 Scanning Electron Microscope (SEM) Testing

Microstructure scanning was performed on the specimen surface using SEM [25]. The beam of an electron that is fired at the specimen will interact with the atoms or electrons from the specimen and produce an image object. SEM uses X-rays that have a wavelength of $4x10^{-3}$ nm, or about 100,000 times shorter than the wavelength of visible light. This is why SEM can be used to display objects that are so small that ordinary microscopes cannot separate them. The detector used in SEM is secondary electron. The purpose of this SEM scan is to determine the surface image of the specimen after the hardness test is carried out. The part to be observed is the surface of each specimen [26].



(a) (b)

Figure 4. a) SEM testing scheme; b) SEM test equipment

3. RESULT AND DISCUSSION

3.1 Density Test Result Data

With theoretical density testing performed on 3 composite compositions with 3 samples for each composition, then the average was sought. The theoretical density test is done by taking the density of each composite forming material to the total volume made. The calculation result data can be seen in Table 1.

Table 2: Density Test Result

	Sample Density test	Density composite
	2,8259	
Composition I	2,9059	**2,9059**
	2,9859	
Total	**8,7177**	
	2,825	
Composition II	2,8765	**2,8749**
	2,9232	
Total	**8,6247**	
	2,8152	
Composition III	2,8451	**2,839**
	2,8571	
Total	**8,517**	

Table 1 shows that for each composition I, II, and III there is a decrease in density. A decrease in the composition of the reinforcement also has an effect, there is a decrease in the theoretical density calculated by formula (1). This is because the fine fiber from SiCw decreases in the composition in the composite so that the density also decreases. SiCw is a fine fiber that has a high enough strength after being made into a composite as a reinforcing material. From Composition I to composition III in this study it can reduce density and strength because the less percentage of SiCw composition is 20%, 15% and 10%, respectively. This can also be seen in Figure 5 which shows a decrease in density due to a decrease in the SiCw reinforcement composition.

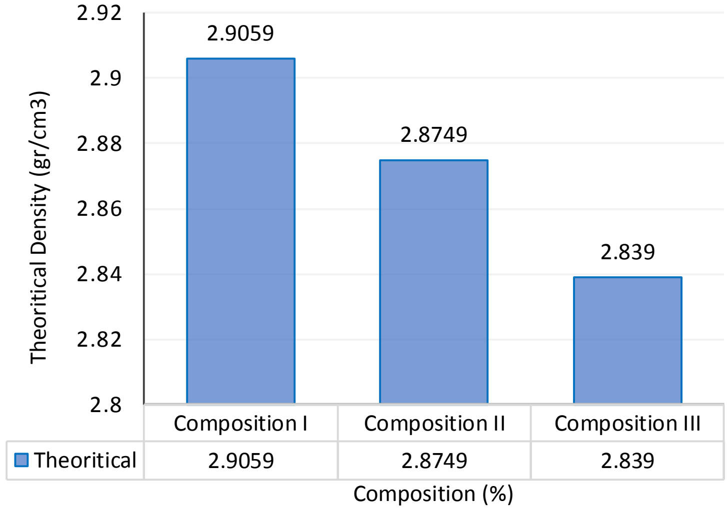


Figure 5. Graph of theoretical density results without temperature treatment

Figure 5 shows the relationship between the composition of the composites made in the study and the theoretical composite density results without treatment. The results obtained are a decrease in the value of density with the value of composition I (2.9059 gr/cm^3) and composition III (2.839 g/cm^3). The results of the composite density test without temperature treatment and temperature treatment can be seen in a graph in Figure 6.

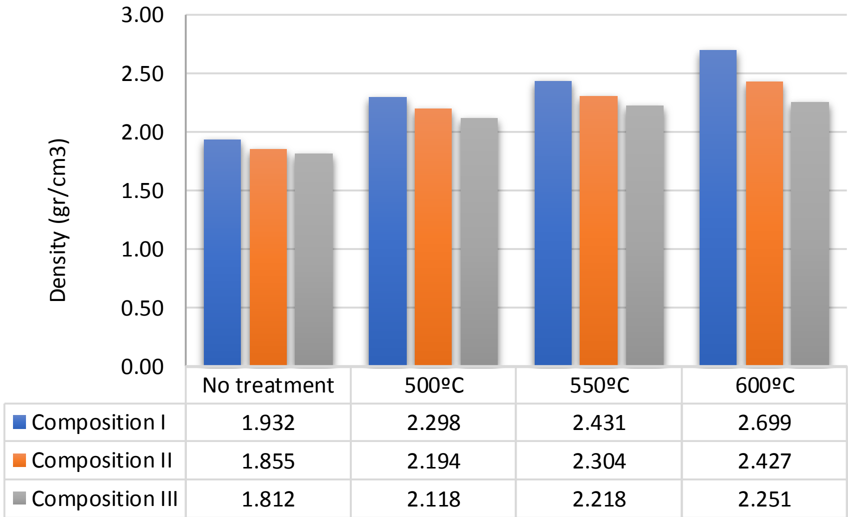
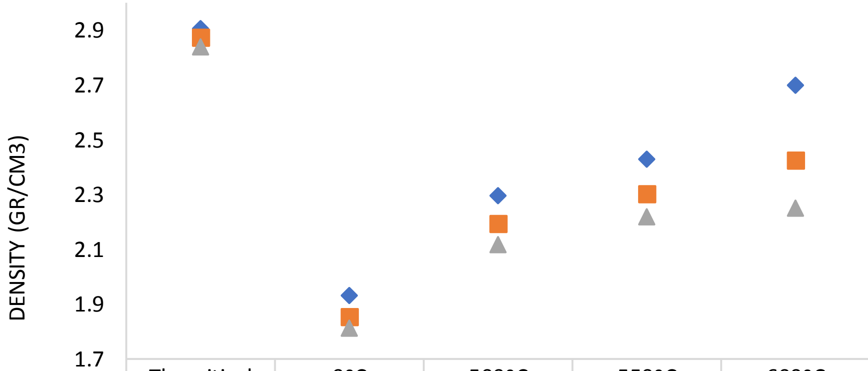


Figure 6. Graph of composite density results on the composition against temperature and without treatment

Figure 6 shows the results of the density test which are shown about the relationship without and with temperature treatment to the density of the composite. It can be seen that the composites without and with temperature treatment of 0°C and 500°C, 550°C and 600°C of each composition have an increase in density, but the variations of composition I, II and III show a decrease in density. So, the effect of the treatment temperature has an effect that causes a phase change so that the bond between the matrix and the reinforcement of each composition is getting stronger and can increase the density of the composite while the difference in composition does not have an increasing effect. Also, the relationship between theoretical density and composite density due to the effect of temperature treatment on each composition can be seen in Figure 7.



	Theoritical	0ºC	500ºC	550ºC	600ºC
Composition I	2.9059	1.932	2.298	2.431	2.699
Composition II	2.8749	1.855	2.194	2.304	2.427
Composition III	2.839	1.812	2.118	2.218	2.251

Figure 7. The theoretical density graph and the results of the composite density test with treatment.

Figure 7 shows the relationship between theoretical density and composite density due to the effect of temperature treatment on each composition. From this, it can be seen that the theoretical density results are above the density of the temperature treatment composites in each composition and each 500°C, 550°C and 600°C temperature. This is also due to the phase change that occurs due to the heat received by the composite in each composition which causes expansion of the SiCw fibers and so is the hard Al_2O_3 powder particles. So, it can be seen from the density results obtained that even though it is heated to 600°C, the theoretical density is still above the density test value of temperature treatment.

3.2 Hardness test Results

Hardness data obtained by the testing process carried out three times in each composition and temperature treatment on the test specimen. The test results are in the form of data, which are then processed in the form of a bar graph. Figure 8 shows the hardness value due to temperature changes in each composite composition.

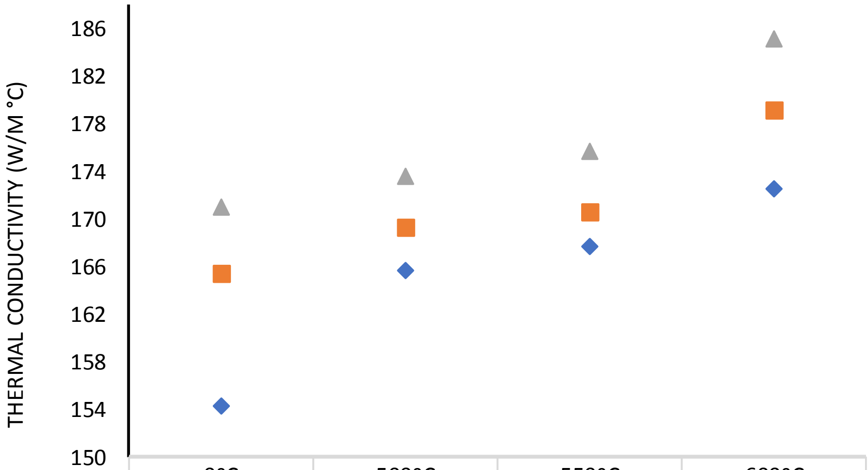
	0ºC	500ºC	550ºC	600ºC
Composition I	27.450	32.324	33.439	34.444
Composition II	30.125	36.440	37.529	38.479
Composition III	32.131	39.085	41.605	42.438

Figure 8. Graph of composite hardness test results against temperature treatment

The results on the graph show the relationship between temperature treatment and hardness, where at each increase in temperature there is an increase in hardness. Also, with each increase in the composite composition tested, the hardness also increased. The increase in hardness in this composite research was caused by the increase in the amount of Al_2O_3 composition in the form of hard and fine powder particles which functioned as reinforcement in the composite with the addition of magnesium as well. Al_2O_3 particles which have hard properties and can bond well will increased the hardness of composites matrix. Composition of composites I, II and III, in each composition showed an increase in hardness. So, hardness can be affected by the treatment temperature and also the percentage of Al_2O_3 particles as a binder or reinforcement for this composite. The lowest hardness was at composition I, 500ºC (32.324 HV) and the highest was at composition III, 600ºC (42.438 HV).

3.3 Thermal Conductivity Test Results

The results of the thermal conductivity test can be seen in Figure 9 which includes a description of the material and the T1 - T7 thermocouple with a sensor reader distance from each thermocouple. The test is carried out on each of the test materials with different composition variations. The test results then calculated the value of thermal conductivity. During the test, the ambient temperature was 19ºC and the heating power was 66 watts according to the test engine capability.



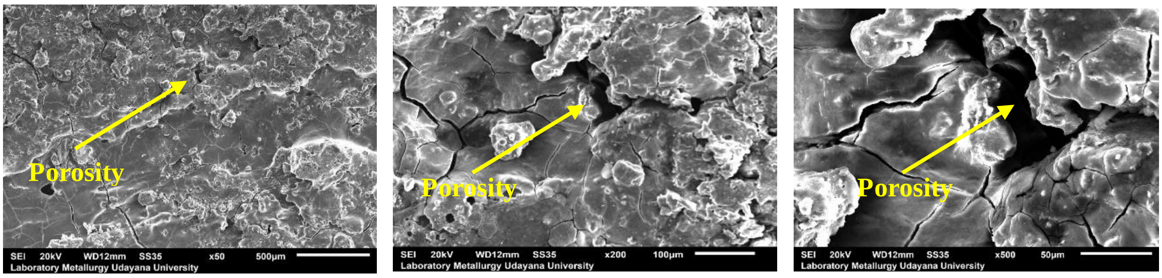
	0ºC	500ºC	550ºC	600ºC
Composition I	154.321	165.673	167.711	172.572
Composition II	165.453	169.357	170.627	179.225
Composition III	171.025	173.624	175.703	185.133

Figure 9. Graph of composite hardness test results against temperature treatment

Figure 9 shows the results of the thermal conductivity test on temperature treatment and composite composition in the form of a bar graph which provides data on the relationship between composition, temperature and thermal conductivity. The results showed that there was an increase in the heat conductivity of each temperature treatment and so did the different compositions. In composition I temperatures of 500ºC, 550ºC and 600ºC respectively produce thermal conductivity (165.673 Watt/m.ºC, 169.357 Watt/m.ºC and 173.624 Watt /m.ºC). In composition II temperatures of 500ºC, 550ºC and 600ºC respectively produce thermal conductivity (167.711 Watt/m.ºC, 170.62 Watt/m.ºC and 175.703 Watt/m.ºC). In composition III the temperature is 500ºC, 550ºC and 600ºC respectively resulting in thermal conductivity (172.572 Watt/m.ºC, 179.225 Watt/m.ºC and 185.133 Watt/m.ºC). So it can be seen that the effect of the composition of the composite and the temperature treatment on the heat conductivity results in each test increases. Each composition has the effect of increasing the ability of heat conductivity because it is influenced by the density and hardness increases with each treatment temperature. With the increase in the addition of Al_2O_3 particles as well as hard and fine grains of Magnesium can reduce pores and increased material density which can affect the conductivity of the composite material as a conductor of heat.

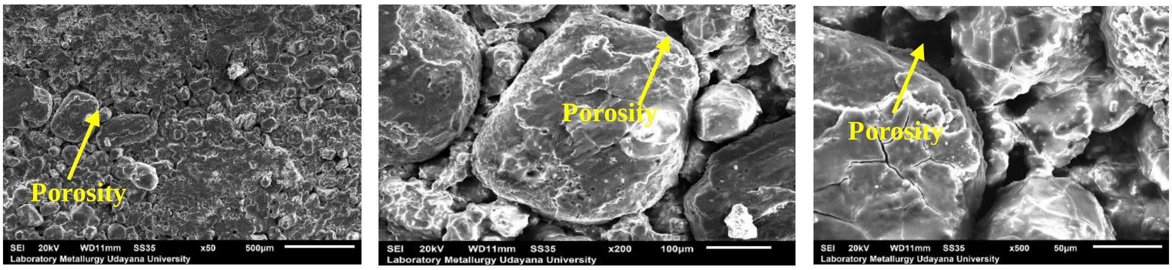
3.4 SEM Testing Results

SEM (Scanning Electron Microscope) tests are carried out on specimens that have been tested for density, hardness and thermal conductivity. The test was carried out three times of magnification for each composition I (500ºC), composition II (550ºC) and composition III (600ºC) with each magnification of 50x, 200x and 500x. The results of the SEM (Scanning Electron Microscope) test are shown in Figures 10 (a), (b) and (c); 11 (a), (b) and (c); 12 (a), (b) and (c).



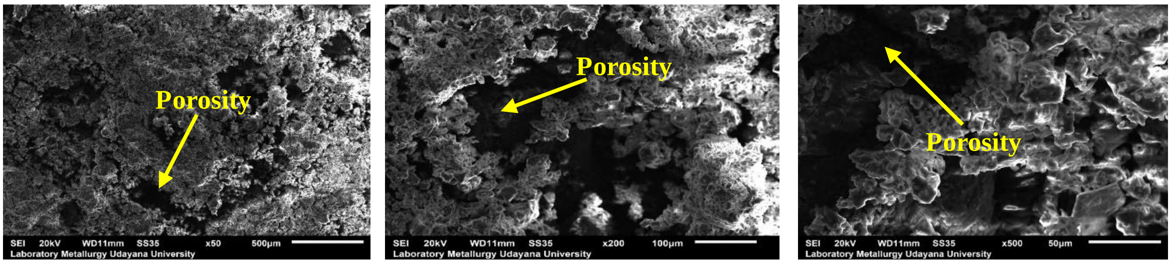
(a) (b) (c)

Figure 10. SEM photo of composition I at a temperature of 500ºC with (a) 50x; (b) 200x; (c) 500x magnification



(a) (b) (c)

Figure 11. SEM photo of composition II at a temperature of 550ºC with (a) 50x; (b) 200x; (c) 500x magnification



(a) (b) (c)

Figure 12. SEM photo of composition II at a temperature of 600ºC with (a) 50x; (b) 200x; (c) 500x magnification

Figures 10, 11 and 12 show SEM photos of the effect of composites composition I, II and III at treatment temperatures of 500ºC, 550ºC and 600ºC. The results show that the microstructure is getting tighter, the bonding occurs stronger and the pores are reduced, both from the composition with an increase in Al_2O_3 and due to temperature treatment of 500ºC, 550ºC and 600ºC. This is supported by previous research which states that the increase in temperature affects the size of the pore, where the pore size decreases from the increasing treatment temperature due to phase changes [5, 27]. In the SEM photos with different magnifications, their function is to clarify the surface morphology of the composites that are made. In general, direct observation to prove whether there is a numerical difference supported by visual differences. In the results of this study it is true that visually supports and proves the effect of composition and temperature treatment on the composite results of the study due to reduced pores, stronger bonds so that the strength of the composite increases. The enlargement made with 50x, 200x and 500x aims to clarify the pores that arise in composition I with a temperature of 500ºC, composition II with a temperature of 550ºC and composition III with a temperature of 600ºC.

4. CONCLUSION

Based on the research that has been carried out, the effect of variations in the composition of the SiCw and Al_20_3 / Mg reinforcement on the properties of the composites is the trend of increasing density test results with the effect of increasing temperature in each composition. In the test results, the hardness of the composite increases in temperature treatment from 500ºC, 550ºC and 600ºC in compositions I, II and III, respectively. For the test results, the heat conductivity increases in the composition and temperature treatment of 500ºC, 550ºC and 600ºC in each composition. Likewise, through observations using the Scanning Electron Microscope (SEM) it is concluded that the effect of adding the reinforcement composition and temperature treatment significantly reduces pores and increases the bond density between the matrix and the reinforcement which can be observed visually, so that the hardness and heat conductivity are increased and the observations show that the pores are reduced.

5. ACKNOWLEDGEMENTS

The author would like to thank the Udayana University Research and Community Service Institute for helping and facilitating this research, the Head of the Metallurgy Laboratory and the Production Process Laboratory, the Phenomena Laboratory of the Department of Mechanical Engineering, Udayana University, the Head of the Metallurgical Laboratory of the Institute of Technology (ITN) Malang and the Head of the Metallurgical Laboratory of the Department. Mechanical Engineering, Brawijaya University Malang for assistance in facilitating the test site and data collection.

6. REFERECES

[1] O. ABDURAHMAN, PRIATA, F. DAMAYANTI, N. DWI HAPSARI, and C. HANDOKO, *Laporan Akuntabilitas Kinerja Instansi Pemerintah LAKIP BADAN GEOLOGI Tahun 2013*. Badan Geologi Kementrian Energi dan Sumber Daya Mineral, 2013.

[2] S. CASTING, "Pengaruh Sic Terhadap Sifat Fisis Dan Mekanis Komposit Matrik Aluminium Yang Diperkuat Serbuk Sic," *J. Tek. Mesin Undip*, vol. 2, no. 3, pp. 211–218, 2014.

[3] I. W. L. SUPRAPTO, K. SUARSANA, and N. SANTHIARSA, "EFEK KOMPOSISI DAN PERLAKUAN SINTERING PADA KOMPOSIT Al/(SiCw+Al2O3) TERHADAP SIFAT FISIK DAN KEAUSAN," *J. Muara Sains, Teknol. Kedokt. dan Ilmu Kesehat.*, vol. 1, no. 1, pp. 124–131, 2017, doi: 10.24912/jmstkik.v1i1.423.

[4] L. GENG, L. HAO-ZE, H. ZHANG, and L. GUAN, "Effects of Mg content on microstructure and mechanical properties of SiC p/Al-Mg composites fabricated by semi-solid stirring technique," *Trans. Nonferrous Met. Soc. China*, pp. 1851–1855, 2010.

[5] K. SUARSANA, I. M. ASTIKA, and P. W. SUNU, "Properties of thermal conductivity, density and hardness of aluminium matrices with reinforcement of sicw / al2o3 hybrid after sintering process," in *IOP Conference Series: Materials Science and Engineering*, 2019, vol. 539, no. 1, doi: 10.1088/1757-899X/539/1/012016.

[6] R. PRASETYO, K. SUARSANA, and N. SANTHIARSA, "Pengaruh Variasi Gaya Tekan Pada Komposit Al /(SiC / Alumina / Magnesium) Terhadap Konduktivitas Termal dan Keausan," *J. Ilm. Tek. DESAIN Mek.*, vol. 7, no. 2, pp. 143–148, 2018.

[7] P. H. SETIAWAN, K. SUARSANA, and I. G. N. N. S, "Efek Komposisi Komposit Matrik Aluminium Dengan Penguat Silikon Carbida Whisker Dan Alumina Terhadap Sifat Kekerasan," *J. Ilm. Tek. DESAIN Mek.*, vol. 7, no. 2, pp. 126–129, 2018.

[8] G. TAWAN, K. SUARSANA, and I. SANTIHARSA, "Pengaruh Waktu Penahanan Dan Temperatur Sintering Komposit Al Matrik Dengan Penguat Al2O3 + SiCw Terhadap Sifat Densitas Dan Kekerasan," *J. Ilm. Tek. Desain Mek.*, vol. 8, no. 2, pp. 512–516, 2019.

[9] K. SUARSANA, R. SOENOKO, A. SUPRAPTO, and A. PURNOWIDODO, "The Effect Composition of Reinforcement SiC Whiskers and Al2O3 Particulates on Characteristics of Aluminum Matrix Composite," *Aust. J. Basic Appl. Sci.*, vol. 7, no. December 2013, pp. 246–256, 2013.

[10] K. SUARSANA, R. SOENOKO, A. SUPRAPTO, A. PURNOWIDODO, and E. FACULTY, "The Influence of Sintering Time and Temperature of Sicw + Al2O3P Reinforcement on Aluminum Matrix

Composite Characteristics," *Aust. J. Basic Appl. Sci.*, vol. 8, no. April, pp. 487–495, 2014.

[11] K. ANAM, A. PURNOWIDODO, and S. A. SETYABUDI, *Pengaruh Woven Angle dan Proses Penekanan terhadap Tegangan Tarik pada Natural Fiber Laminate Composite*, vol. 9, no. 3. 2018.

[12] SUNARDI, M. FAWAID, and F. R. N. M, "Variasi Campuran Fly Ash Batubara Untuk Material Komposit," *J. Tek. Mesin Untirta*, vol. I, no. April, pp. 90–102, 2015.

[13] A. RAMANATHAN, P. K. KRISHNAN, and R. MURALIRAJA, "A review on the production of metal matrix composites through stir casting – Furnace design, properties, challenges, and research opportunities," *J. Manuf. Process.*, vol. 42, no. September, pp. 213–245, 2019, doi: 10.1016/j.jmapro.2019.04.017.

[14] B. G. NARASIMHA, V. M. KRISHNA, and A. M. XAVIOR, "A review on processing of particulate metal matrix composites and its properties," *Int. J. Appl. Eng. Res.*, vol. 8, no. 6, pp. 647–666, 2013.

[15] T. CLYNE, "Metal Matrix Composites: Matrices and Processing," in *Encyclopaedia of Materials: Science and Technology*, 2001.

[16] A. K. SHARMA, R. BHANDARI, A. AHERWAR, and R. RIMAŠAUSKIENE, "Matrix materials used in composites: A comprehensive study," *Mater. Today Proc.*, vol. 21, pp. 1559–1562, 2020, doi: 10.1016/j.matpr.2019.11.086.

[17] S. T. MAVHUNGU, E. T. AKINLABI, M. A. ONITIRI, and F. M. VARACHIA, "Aluminum Matrix Composites for Industrial Use: Advances and Trends," *Procedia Manuf.*, vol. 7, pp. 178–182, 2017, doi: 10.1016/j.promfg.2016.12.045.

[18] A. WIBOWO, "Analisis Sifat Mekanis Komposit Barium Hexaferrit Dengan Penguat Silika," *J. Integr.*, vol. 8, no. 1, pp. 29–33, 2016.

[19] R. DEVESWARAN, S. BHARATH, B. V BASAVARAJ, S. ABRAHAM, S. FURTADO, and V. MADHAVAN, "Concepts and Techniques of Pharmaceutical Powder Mixing Process : A Current Update," *Res. J. Pharm. Technol.*, vol. 2, no. 2, pp. 245–249, 2009.

[20] S. M. OSKUI, H. C. BHAKTA, G. DIAMANTE, H. LIU, D. SCHLENK, and W. H. GROVER, "Measuring the mass, volume, and density of microgram-sized objects in fluid," *PLoS One*, vol. 12, no. 4, pp. 1–17, 2017, doi: 10.1371/journal.pone.0174068.

[21] C. SHEN, E. F. JULIUS, T. J. TYREE, R. DAN, D. W. MOREAU, and R. THORNE, "Measuring the densities of aqueous glasses at cryogenic temperatures," *J. Vis. Exp.*, vol. 2017, no. 124, pp. 1–7, 2017, doi: 10.3791/55761.

[22] I. AGUSTINA, "Penentuan Konduktivitas Termal Logam Tembaga, Kuningan, dan Besi dengan Metode Gandengan," in *Prosiding Seminar Nasional Fisika dan Pendidikan Fisika (SNFPF)*, 2015, vol. 6, pp. 30–34.

[23] W. N. DOS SANTOS, J. A. DE SOUSA, and R. GREGORIO, "Thermal conductivity behaviour of polymers around glass transition and crystalline melting temperatures," *Polym. Test.*, vol. 32, no. 5, pp. 987–994, 2013, doi: 10.1016/j.polymertesting.2013.05.007.

[24] B. J. GONÇALVES *et al.*, "Thermal conductivity as influenced by the temperature and apparent viscosity of dairy products," *J. Dairy Sci.*, vol. 100, no. 5, pp. 3513–3525, 2017, doi: 10.3168/jds.2016-12051.

[25] A. SUJATNO, R. SALAM, A. DIMYATI, P. SAINS, and B. MAJU, "Studi scanning electron microscopy (SEM) untuk karakterisasi proses oxidasi paduan zirkonium," *J. Forum Nukl.*, vol. 9, no. November, pp. 44–50, 2015.

[26] O. P. CHOUDHARY and P. KA, "Scanning Electron Microscope: Advantages and Disadvantages in Imaging Components," *Int. J. Curr. Microbiol. Appl. Sci.*, vol. 6, no. 5, pp. 1877–1882, 2017, doi: 10.20546/ijcmas.2017.605.207.

[27] M. BRIANNALA, K. SUARSANA, and I. SANTHIARSA, "Pengaruh Temperatur Sintering Al Matrik dengan Penguat SiCw + Al2O3 Terhadap Sifat Porositas dan Keausan," *J. Ilm. Tek. Desain Mek.*, vol. 8, no. 2, pp. 546–550, 2019.