Jurnal Teknologi
https://jitekin-upiyptk.org/ojs
2022 Vol. 12 No. 2 Hal: 76-81 p-ISSN: 2301-4474, e-ISSN: 2541-1535

Investigation of Metal Matrix Composites Aluminium Reinforced Graphite Particles Produced Using Powder Metallurgy

Nanang Fatchurrohman[1]✉, Anis Nabilah Binti Mamat[2] , Mutiara Yetrina[3], Rifki Muhida[4]

[1,3,4] Fakultas Teknik, Universitas Putra Indonesia YPTK Padang, Lubuk Begalung, Padang, Sumatera Barat, Indonesia
[2] Faculty of Manufacturing and Mechatronics Engineering, Universiti Malaysia Pahang, Kuala Pahang, Pekan, Malaysia

n.fatchurrohman@gmail.com

Abstract

Many industries have been in demand for metal matrix composites (MMC), especially in the aerospace and automotive sectors. The advancement of MMC is being investigated to improve the material's mechanical properties. MMC is a composite material consisting of at least two materials. One of them would act as a matrix, and the other materials would serve as reinforcement. MMC allows for overcoming the specific limitations of metallic and ceramic materials by blending their mutually exclusive property profiles. The main objective of this research is to successfully fabricate aluminium and graphite metal matrix composites using powder metallurgy. In this research, powder metallurgy was used, where aluminium and graphite were blended according to the sample volume ratio. Both graphite and aluminium were in the form of metal powder. Graphite powder with each ratio of volume percentages of 0%, 1.5%, 3%, 4.5%, and 6% was mixed with aluminium powder. The blended material is produced by powder metallurgy via the compaction process using the hydraulic press brake machine. Subsequently, the compacted sample was sintered using a laboratory furnace at 600°C for 4 hours. The mechanical tests show that the highest tensile strength and Young's modulus were obtained by MMC aluminium – 1.5 % volume graphite. While for the highest hardness was achieved by aluminium – 4 % volume graphite.

Keywords: Metal Matrix Composites, Aluminium Matrix, Graphite Reinforcement, Powder Metallurgy, Mechanical Properties.

1. Introduction

Metal matrix composites (MMC) are composite materials containing at least two. One would act as a matrix, and the other materials would act as reinforcement [1]. MMC allows for overcoming the specific limitations of metallic and ceramic materials by blending their mutually exclusive property profiles [2]. The mechanical properties include tensile strength, hardness level, and microstructure [3]. The advantages of the MMCs are high strength, elastic modulus, toughness, and impact properties. Besides that, the MMCs also have low sensitivity to changes in temperature.

Aluminium is widely used primarily in automotive industries because of its lower density, high wear resistance, and many others that contribute to vehicles' excellent design [4]. Pure aluminium is one of the best metals existing in the world since its weight is only one-third of the weight of steel [5]. Moreover, aluminium is the third most abundant element in the world. This makes aluminium suitable for metal alloys and heavy industries in the engineering industry. Since aluminium is well-known in the automotive sector, fabrication of MMC using pure aluminium and graphite with powder metallurgy method was conducted [6].

Graphite is a semi-metal in the form of coal existing on the earth. The mechanical properties of graphite are high tensile strength, low density, high friction and wear resistance, and high thermal conductivity [7]. The addition of reinforcement particles would make changes in the mechanical properties of the material. It includes the matrix's hardness, density, and microstructure [8]. The hardness of the specimen would likely increase linearly, but there was a limit to its increasing hardness. Other than that, the density would also be decreased. This was an advantage in spacecraft industries since airplanes should have a low density for better coordination during flight [9]. Furthermore, the electrical conductivities would likely increase too, because graphite is well known as a good electrical conductor [10].

Powder metallurgy (PM) is a mixing process where metal powders are combined with the reinforcement element to create a composite [11]. PM is chosen because it offers homogeneity for both composition and microstructure of the matrix alloy together with more control over the reinforcement distribution [12]. Other than that, PM is considered to be environment friendly since it produces very little smoke and chemicals into the atmosphere [13], [14].

This research was conducted by using pure aluminium as the base alloy and graphite as the reinforcement. By using graphite as the parameter, both of the materials was mixed. There was a few ratios of volume percentages of graphite that was mixed into the pure

Accepted: 03-10-2022 | Revision: 09-12-2022 | Publication: 27-12-2022 | doi: 10.35134/jitekin.v12i2.70

aluminium. This step is important to observe the mechanical properties of the sample. The mechanical properties levels are expected to increase with increasing graphite content as compared to base alloy [15]. There was four main experiments that was conducted onto the specimen which are the tensile test, micro hardness test, resistivity and also the microstructure test.

2. Research Method

Punch and die was produced in the early stage of research. The die and punch have been designed in order to sustain high pressure of compaction. Steel has been chosen as the material to produce both the die and punch [16]. In order to produce solid sample from powder mixture, the design of the die and punch must be able to withstand circumferential stress and longitudinal stress without failure [17]. A base is also important in order to make sure the sample has smooth surface. It is also important so that during compaction process, both die and punch can be stable and the pressure is applied equally onto the sample surface as shown in Figure 1.

Figure 1. Production of punch using milling machine

The production of punch involves milling machine. The dimension of the dog bone shape is according to the standard ASTM E8 where the gage length is 20 mm and gage width is 6 mm. The simulation of tool path was set in the Catia V5 software. Therefore the milling machine was operated according to the G code that has been generated from the software. A fully carbide end mill is used since the raw material for the punch is steel. The selection of tool must be made properly since the steel workpiece is able to cause wear onto the tool [18].

Figure 2. Sodick VZ300L EDM Wire Cut Machine

The die part is manufactured using the Sodick VZ300L EDM Wire Cut Machine (Figure 2). The shape of the die has been designed using Catia V5 (Figure 3). The drawing is saved as dxf file so that the machine can read and analysed the drawing. The process of die production took about two days to complete since the raw material is steel and the cutting speed has been lowered down.

Figure 3. Catia drawing of die part

2.1. Blending of metal powder

Pure aluminium powder and graphite powder was blended manually using pestle mortar [19]. There was 5 ratios of the MMC (Table 1). The blending process takes 10 minutes to completely blend both of the materials. Next, the metal powders was poured into a die to produce solid metal according to desired shape which is dog bone shape. The dog bone shape has been made according to standard ASTM E8 for metal tensile test.

Table 1. Percentage of volume of pure Al and graphite

Sample number	Pure aluminium (%)	Graphite (%)
1	100	0
2	98.5	1.5
3	97.0	3.0
4	95.5	4.5
5	94.0	6.0

After that, the mould was placed onto the hydraulic press brake machine and was compacted until 25 kN for 30 minutes. Then, the compacted sample was removed from the mould and the sample is sintered in the furnace at 600°C for 4 hours. The completed sample was let to cool down by itself until room temperature.

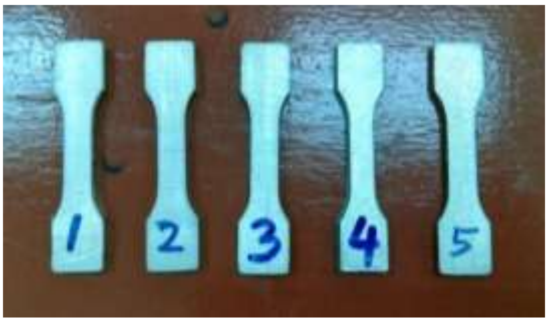

Figure 4. Samples for each ratio

2.2. Compaction process

Compaction is a process where blended metals was poured into the die [20]. During the compaction process, the sample's density was increased and the sample's strength would also be sufficient undergo next process. The sample specimen was poured into the die and a punch was inserted to complete the compaction process. Compaction pressure was applied from both the die and also the punch to create a dense sample (Figure 5). The pore and spaces between the aluminium and graphite particles was reduced. The particles of pure aluminium and graphite would form a bond in order to merge with each other.

Figure 5. Hydraulic press brake machine.

2.3. Sintering process

Sintering is a process where the blended metals was compacted by heating the specimen below the metal melting point to ensure the metal would not melt [21]. The atoms in the materials diffuse across the boundaries of the particles, and the particles would diffuse together to form a solid. The sintering temperature does not have to reach the material's melting point, sintering is often chosen as the shaping process for materials with extremely high melting points.

Figure 6. Narberthem GmBH furnace

For this research, the sample was placed into the furnace during the sintering process. The melting point of aluminium was approximately 660.3°C (Figure 6). In order to perform the sintering process perfectly the heating temperature should be 70 % to 90 % of the aluminium melting point. The sintering process would improve the mechanical properties of the samples by reducing the porosity between particles of the specimen, diffusing both aluminium and graphite into each other. Other than that, the volatile materials or particles in the specimen would also be evaporated so that only pure aluminium and graphite was left. The particles would undergo rearrangement during the sintering which means the particles distribution was improved. Furthermore, the Ostwald ripening would occur where the small particles would like attach onto larger particles and leads to densification.

In this process, the furnace was set to heat at 600°C. The heating rate was set at 10°C per minute therefore it would take 60minutes to reach 600°C. the holding time is set for 4hours.

2.4. Tensile test

Tensile test is where the yield strength and the tensile stress was determined. The shape and size of the specimen was made according to the supposed shape for the test. The tensile test would follow the standard ASTM E8 code [22].

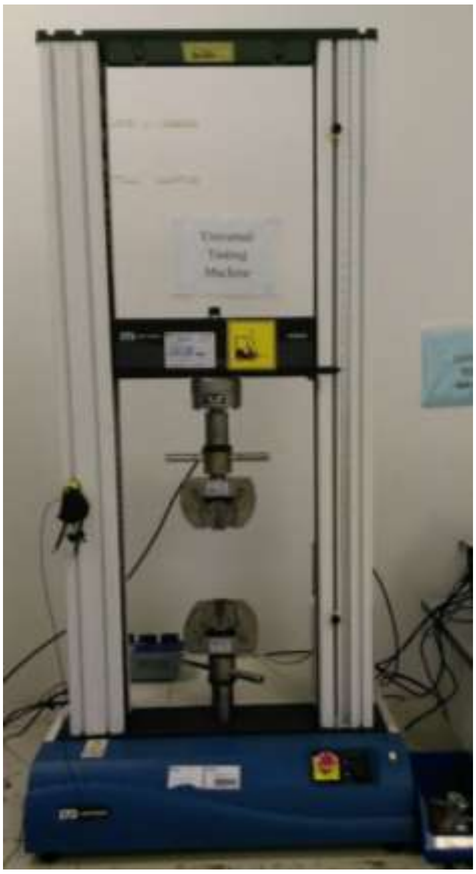

Figure 7. Universal testing machine

The machine that was used in this experiment is the universal testing machine. The dog bone shape sample was attached to the machine specifically at the crosshead section. The machine would slowly extend the sample until it fractures. Usually the specimen would break into two pieces when it fractures. The graph of tensile stress of the sample was shown in the monitor.

2.5. Hardness Test

For the hardness test, the sample should be in block shape. The experiment for hardness test is called the micro Vickers test. A diamond indenter was forced onto the surface of the specmen. The test force was set at 500g for 15 seconds [23]. The indentation process would produce permanent depth on the sample. The permanent depth of indentation was measured by placing the cursor on each edge of the diamond shape. The opposing indenter angle should be 136o. Vickers test that was done this project would follow the ASTM E92-17. The hardness of the material can also indicate the wear resistance and also the ductility of the material.

Figure 8. Universal testing machine

3. Result and Discussion

3.1. Tensile Stress, Strain and Young Modulus

The ASTM E8 test presents data on the strength and ductility of metals under uniaxial tensile forces. The tensile strength of a metal is essentially its ability to withstand tensile loads without failure. Ductility, on the other hand, measures a material's ability to deform under tensile stresses [24].

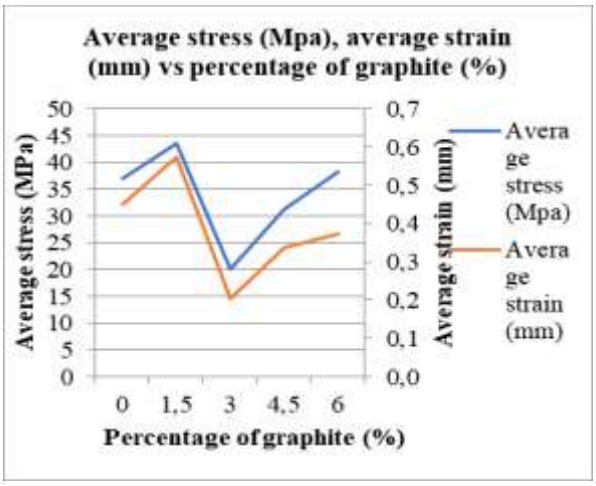

Figure 9. Graph of average stress and average strain against graphite percentage

Results shown in Figure 9 are the average tensile stress and average strain of each sample against the percentage of graphite. There is a slight increase of stress and strain at 1.5% of graphite while at 3% of graphite. The stress and strain has decreased rapidly. From a recent research journal, it stated that the decrease in average stress maybe due to the presence of graphite particles in a metal matrix which are soft particles and act as impurities in the molten metal and increased the porosity content due to which strength of composites decreased [25].

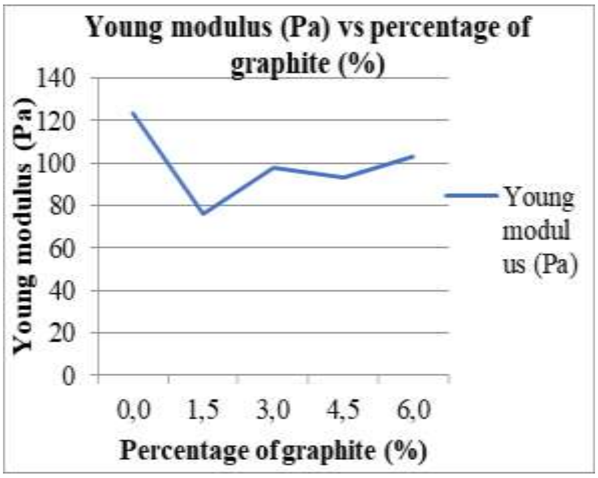

Figure 10. Graph of Young modulus against graphite percentage

From Figure 10, the graph shows that the Young modulus decreases at 1.5% of graphite but increase at 3% of graphite. However, there is a slight decrease of Young modulus at 4.5% but then it continues to increase back.

The trend of the graph for tensile test is not stable which means that there are many other considerations that should have been concerned. The tensile stress may be affected as the thickness of each sample varies. Other than that, the blending process might be defected since it is done manually using pestle and mortar. The distribution of graphite and pure aluminium particles may did not disperse uniformly. The results obtained can be used in further investigation of tensile strength of aluminium graphite MMC but further consideration should be done in order to obtain accurate result for each sample.

3.2. Hardness level of each sample

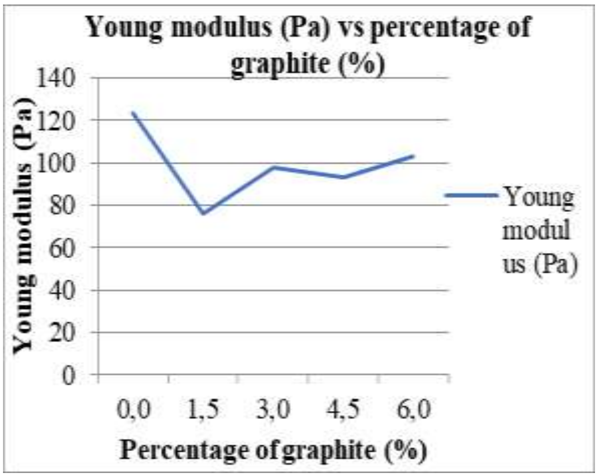

Figure 11. Graph of hardness against percentage of graphite

From Figure 11, it shows that the average hardness of each ratio increase steadily until it reaches 4.5% of graphite. However, at 6% of graphite the average hardness started to decrease. From a published journal, it stated that the hardness increases with increased graphite content up to 6% of graphite anyhow beyond 6% of graphite a decrease in hardness is observed which may be attributed to saturation of graphite in the aluminium matrix. Therefore, the graphite content directly affects the overall hardness of the MMC and the optimum volume of graphite in aluminium metal matrix has been identified as 6%.

4. Conclusion

In the research that has been done, the aluminium graphite MMC has been fabricated using powder metallurgy. Graphite powder with each ratio of volume percentage of 0%, 1.5%, 3%, 4.5% and 6% are mixed with pure aluminium powder. Then, it was subjected into compaction at 25 kN for 3 minutes and sintered at 600°C for 4 hours. It has been found that the addition of graphite into aluminium results in increasing tensile strength and yield stress. Furthermore, the hardness is also increased with increasing graphite content. However, there is a limit to the addition of graphite which is only 6%. The microstructure of each sample is also observed and the dispersion of graphite particles is uniform. Meanwhile, the resistivity is decreased which means that the higher the graphite content in the aluminium metal matrix, the higher the electrical conductivity of the sample.

As conclusion, this project objective of fabricating aluminium graphite metal matrix using powder metallurgy has been done successfully. However, the results obtained can be improved with better parameters and considerations.

References

[1] Jawalkar, C. S., Verma, A. S., & Suri, N. M. (2017). Fabrication of aluminium metal matrix composites with particulate reinforcement: a review. *Materials Today: Proceedings*, *4*(2), 2927-2936. https://doi.org/10.1016/j.matpr.2017.02.174

[2] Baron, C., & Springer, H. (2017). Properties of particle phases for metal-matrix-composite design. *Data in brief*, *12*, 692-708. https://doi.org/10.1016/j.dib.2017.04.038

[3] Su, C., Chen, X., Gao, C., & Wang, Y. (2019). Effect of heat input on microstructure and mechanical properties of Al-Mg alloys fabricated by WAAM. *Applied Surface Science*, *486*, 431-440. https://doi.org/10.1016/j.apsusc.2019.04.255

[4] Wahid, M. A., Siddiquee, A. N., & Khan, Z. A. (2020). Aluminum alloys in marine construction: characteristics, application, and problems from a fabrication viewpoint. *Marine Systems & Ocean Technology*, *15*(1), 70-80. https://doi.org/10.1007/s40868-019-00069-w

[5] Koli, D. K., Agnihotri, G., & Purohit, R. (2015). Advanced aluminium matrix composites: the critical need of automotive and aerospace engineering fields. *Materials Today: Proceedings*, *2*(4-5), 3032-3041. https://doi.org/10.1016/j.matpr.2015.07.290

[6] Reddy, K. S. T., Manohar, H. S., Manjunath, G., & Babu, K. A. (2021). Synthesis and characterization of silicon nitride and graphite reinforced aluminium hybrid metal matrix composites. *Materials Today: Proceedings*, *45*, 304-306. https://doi.org/10.1016/j.matpr.2020.10.653

[7] Imran, M., Khan, A. A., Megeri, S., & Sadik, S. (2016). Study of hardness and tensile strength of Aluminium-7075 percentage varying reinforced with graphite and bagasse-ash composites. *Resource-Efficient Technologies*, *2*(2), 81-88. https://doi.org/10.1016/j.reffit.2016.06.007

[8] Şap, S., Uzun, M., Usca, Ü. A., Pimenov, D. Y., Giasin, K., & Wojciechowski, S. (2021). Investigation on microstructure, mechanical, and tribological performance of Cu base hybrid composite materials. *Journal of Materials Research and Technology*, *15*, 6990-7003. https://doi.org/10.1016/j.jmrt.2021.11.114

[9] Bauranov, A., & Rakas, J. (2021). Designing airspace for urban air mobility: A review of concepts and approaches. *Progress in Aerospace Sciences*, *125*, 100726. https://doi.org/10.1016/j.paerosci.2021.100726

[10] Spain, I. L. (2021). Electronic transport properties of graphite, carbons, and related materials. In *Chemistry and physics of carbon* (pp. 119-304). CRC Press. https://doi.org/10.1201/9781003209065-2

[11] Sankhla, A. M., Patel, K. M., Makhesana, M. A., Giasin, K., Pimenov, D. Y., Wojciechowski, S., & Khanna, N. (2022). Effect of mixing method and particle size on hardness and compressive strength of aluminium based metal matrix composite prepared through powder metallurgy route. *journal of materials research and technology*, *18*, 282-292. https://doi.org/10.1016/j.jmrt.2022.02.094

[12] Garg, P., Jamwal, A., Kumar, D., Sadasivuni, K. K., Hussain, C. M., & Gupta, P. (2019). Advance research progresses in aluminium matrix composites: manufacturing & applications. *Journal of Materials Research and Technology*, *8*(5), 4924-4939. https://doi.org/10.1016/j.jmrt.2019.06.028

[13] Narayan, S., & Rajeshkannan, A. (2015). Workability behavior of powder metallurgy carbide reinforced aluminum composites during hot forging. *Materials and Manufacturing Processes*, *30*(10), 1196-1201. https://doi.org/10.1080/10426914.2015.1004703

[14] Mensah, R. A., Shanmugam, V., Narayanan, S., Renner, J. S., Babu, K., Neisiany, R. E., ... & Das, O. (2022). A review of sustainable and environment-friendly flame retardants used in plastics. *Polymer Testing*, 107511. https://doi.org/10.1016/j.polymertesting.2022.107511

[15] Baradeswaran, A., & Perumal, A. E. (2014). Wear and mechanical characteristics of Al 7075/graphite composites. *Composites Part B: Engineering*, *56*, 472-476. https://doi.org/10.1016/j.compositesb.2013.08.073

[16] Buljak, V., Baivier-Romero, S., & Kallel, A. (2021). Calibration of Drucker–Prager Cap Constitutive Model for Ceramic Powder Compaction through Inverse Analysis. *Materials*, *14*(14), 4044. https://doi.org/10.3390/ma14144044

[17] Rajak, D. K., Wagh, P. H., & Linul, E. (2021). Manufacturing technologies of carbon/glass fiber-reinforced polymer composites and their properties: A review. *Polymers*, *13*(21), 3721. https://doi.org/10.3390/polym13213721

[18] Kumar, R., & Hynes, N. R. J. (2019). Thermal drilling processing on sheet metals: A review. *International Journal of Lightweight Materials and Manufacture*, *2*(3), 193-205. https://doi.org/10.1016/j.ijlmm.2019.08.003

[19] Tekumalla, S., & Gupta, M. (2019). Processing, properties and potential applications of magnesium alloy-based nanocomposites: A review. *Nanocomposites VI: Nanoscience and nanotechnology in advanced composites*, 3-18. https://doi.org/10.1007/978-3-030-35790-0_1

[20] Thiruppathi, K., Raghuraman, S., & Mohan, R. R. (2021). Densification Studies on Aluminum-Based Brake Lining Composite Processed by Microwave and Spark Plasma Sintering. *Powder Metallurgy and Metal Ceramics*, *60*(1), 44-51. https://doi.org/10.1007/s11106-021-00213-5

[21] Sharma, V. M., Pal, S. K., & Racherla, V. (2020). A new sintering method for fabrication of open-cell metal foam parts. *Materials and Manufacturing Processes*, *35*(15), 1717-1726. https://doi.org/10.1080/10426914.2020.1784933

[22] Handika, N., Idhar, R. A., Sjah, J., Arijoeni, E., & Tjahjono, E. (2020). Influence of the Shaping Process on the Tensile Properties of Steel Reinforcement Bars Carbon Steel Grades BJTP24 and BJTS40. *Makara Journal of Technology*, *24*(3), 7. https://doi.org/10.7454/mst.v24i3.3914

[23] Martin, J., Nominé, A. V., Stef, J., Nominé, A., Zou, J. X., Henrion, G., & Grosdidier, T. (2019). The influence of metallurgical state of substrate on the efficiency of plasma electrolytic oxidation (PEO) process on magnesium alloy. *Materials & Design*, *178*, 107859. https://doi.org/10.1016/j.matdes.2019.107859

[24] Hofmann, D. C., Suh, J. Y., Wiest, A., Duan, G., Lind, M. L., Demetriou, M. D., & Johnson, W. L. (2008). Designing metallic glass matrix composites with high toughness and tensile ductility. *Nature*, *451*(7182), 1085-1089. https://doi.org/10.1038/nature06598

[25] Sharma, P., Sharma, S., & Khanduja, D. (2016). Effect of graphite reinforcement on physical and mechanical properties of aluminum metal matrix composites. *Particulate Science and Technology*, *34*(1), 17-22. https://doi.org/10.1080/02726351.2015.1031924