Research Article

Investigate the Possibility of Improving the Properties of Aluminum Scrap Powder by adding Graphite Powder

Prathumrat Nuyang*, Kittisak Sangsana and Channarong Monteanthong
Division of Material and Process Engineering Technology, Faculty of Engineering and Technology, King Mongkut's University of Technology North Bangkok, Rayong, Thailand

Kanokon Nuilek
Department of Materials Engineering, Faculty of Engineering and Technology, Rajamangala University of Technology Isan, Nakhon Ratchasima, Thailand

* Corresponding author. E-mail: prathumrat.n@eat.kmutnb.ac.th DOI: 10.14416/j.asep.2023.04.004
Received: 16 January 2023; Revised: 18 February 2023; Accepted: 30 March 2023; Published online: 24 April 2023

Abstract
Aluminum scraps are derived from industrial waste in the machining process called turning and are rarely reused. Recycling this wasted aluminum is particularly appealing. The Aluminum powder is made from this industrial waste. This article uses a metallurgical technique to prepare and use scrap recycled aluminum. In this study, the goal was to improve the properties of aluminum scraps by adding graphite powder. This study is based on a powder metallurgical process, where aluminum scraps from the machining processes are converted into fine powder (~60 µm) using a ball mill process. The powder is then mixed into a composite of aluminum powder (Al) and graphite powder (GP) using a high-speed mixing method. The GP added to the Al has a particle matter ratio of 0.25, 0.5, 0.75, and 1.0 percent by weight. The composite powder is then compressed into a test specimen and sent for sintering. The study aims to look at the mechanical and electrical properties after the introduction of graphite powder. In ideal circumstances, the study showed an increase in ultimate tensile strength (UTS), young's modulus (E), hardness, and electrical conductivity of composite in comparison with pure aluminum, with a UTS value of 140.32 MPa up from 131.05 MPa, an E value of 49.78 GPa up from 41.48 GPa and a hardness value of 91.88 HV up from 64.69 HV.

Keywords: Aluminum scrap, Graphite powder, Sintering, Composites material

1 Introduction

In the industry today, there is an increasing demand for metal composite materials (MMCs) because they have better qualities than their unreinforced counterparts. This could potentially lead to the development of materials with a higher strength-to-weight ratio, a lower thermal expansion coefficient, and better resistance to thermal fatigue and creep [1], [2]. MMCs have a strong material-to-weight ratio and most of them are used in industrial applications such as aerospace, electronic packaging, and the automotive industries [3], [4]. MMCs consist of a ferrous metal combined with another, typically nonferrous, to form a new material with compelling technical features of its own. This material class was the subject of intensive research in the 1980s and 1990s, and has substantially increased in variety in the recent decade. Metals and alloys are frequently created and molded in large quantities, but they may also be carefully combined with other materials to improve their function. This class of metal matrix composites covers a diverse variety of materials distinguished by their base metal (e.g., aluminum, copper, titanium), other reinforcement (e.g., fibers, particles, whiskers), or manufacturing process (e.g., powder metallurgy, diffusion bonding, infiltration, stir casting) [5]. Some metals (such as copper or silver) and ceramics (such as SiC or chosen types of carbon) are strong heat conductors; nevertheless, their coefficient of thermal expansion (CTE) falls on either side of the desirable range. Because the CTE of metals is too high and that of ceramics is too low, a blend of the two gives the optimum material for this application. This is one of MMCs success stories. Aluminum/SiC infiltration composites are well-established high-performance composites for electronic substrate applications. Carbon compounds, on the other hand, have significantly greater conductivities than SiC. Over the last decade, the price of synthetic diamonds, an efficient heat conductor, has dropped to such a point that diamond particles are now practical engineering materials. As a result, a new generation of MMCs with designed interfaces that combine aluminum, copper, or silver matrices with diamond particles has evolved [6].

Recently, aluminum-based MMCs have increased the interest of many researchers. Aluminum has many outstanding properties, such as lightweight, corrosion resistance, good conductivity, ease of forming, a thermal expansion that can be controlled, resistance to creep and better wear resistance compared to conventional metals [7]–[9], resulting in its wide adoption, especially in the automotive industry [10]. While aluminum is used in its pure form for some applications for example as foils and electrical conductors, it is usually alloyed with one or more other metallic elements to improve the physical qualities of the resulting alloy. Therefore, the use of aluminum scrap is very interesting because it is produced at several stages of the production process before it is used by the final consumer. Aluminum material is otherwise lost throughout the production process, either at the melting phase to form dross or during one of the various machining processes performed on the aluminum piece. During the machine operations of aluminum parts, a large amount of aluminum scrap is left [11]. Aluminum scrap is recycled using various techniques, one of which is the use of powder metallurgy [12], [13]. Aluminum-based composites can be combined with other materials to create new products with a number of properties, such as silicon carbide, graphite, carbon fiber, etc [14]–[17].

Metal matrix composites (MMCs) with aluminum as the principal matrix are becoming increasingly popular. Aluminum matrix composites (AMCs) are replacing standard aluminum alloys in numerous applications. Because of the improved strength-to-weight ratio, being is one of the most sought-after attributes in brake pads, car engine pistons, turbine blades, and so forth are just a few examples. Among the most prevalent uses for AMCs. Al/GP composites have industrial uses, such as wireless communications equipment, satellites, baseplates, and coolers for power semiconductor devices, covers, substrates, interposers, USB flash drives, housings, and other similar complicated structures, which are used in the power electronics business. Graphite is known as a material with a high strength-to-mass ratio. Graphite fiber reinforcement has found widespread use in polymer and epoxy composites. Graphite particles used as reinforcement have found widespread use in work zones, using numerous features and combinations, conveniently in locations where external lubrication is difficult or impossible. Therefore aluminum-graphite composites have a wide range of uses. Some applications of AMCs (Al/GP) are shown in Table 1 [18].

Table 1: Some applications of AMCs (Al/GP) [18]

System	Application	Properties
Al/GP	Base plates and coolers	High thermal conductivity and low density
	Heat sinks and heat spreaders	Low CTE (coefficient of thermal expansion) and a low density
	Discs and rings	Low friction
	Electronic packaging applications	Low density and high thermal conductivity
	Cylinder block, connecting rods and pins, fan bearings, pistons and liners	Self-lubricating, cheap and light materials

In this research, aluminum scraps (Al) were used in the mechanical production (machining). They were cleaned and taken, through the process of reducing their particle size, until they became a powder metallurgy. The graphite powder (GP) that has undergone a particle size reduction until it is a powder is then mixed with similar particles to improve the properties and create added value. Using these scraps, it helps to reduce industrial and household's waste.

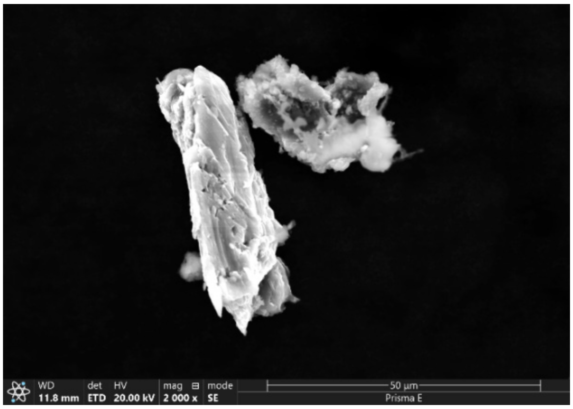

Figure 1: SEM micrographs of aluminum scrap powder at 2,000x.

2 Materials and Methods

2.1 *Materials characterization*

Aluminum scrap derived from the machining processes is ground into a powder by using a ball mill. Dirt and impurities are eliminated by soaking the Aluminum scrap powder (Al 7075) in water several times until getting pure aluminum. The aluminum scraps are sorted using a sieve shaker to a size of around 60 µm and a density of 2.7 g/cm^3. Graphite powder (GP) is used as a reinforcement and supplied by Henan Xingxing Metallurgical Materials Co., Ltd. The particle size of the GP is around 44 µm, has a density of 2.25 g/cm^2, and has a carbon content of 99.9%. Figure 1 shows the morphology of the shape of aluminum scrap powder. Figure 2 shows the curves (a) for the particle size distributions of aluminum scrap and (b) the curves for the particle size distributions of GP.

2.2 *Preparation of Al/GPs composites*

Initially, aluminum scrap powder was mixed with graphite powder in 5 different proportions, as shown in Table 2. Then, it was blended using a high-speed mixing technique to ensure the particles spread equally. The mixture was mixed for 3 min by mixing for 15 s, then pausing for 10 s to reduce heat accumulation. The mixed powder is then compacted into a test specimen by compression using a pressure of 40 MPa for 1 min at a speed of 5 mm/s at room temperature. The process flowchart for preparing composites can be seen in

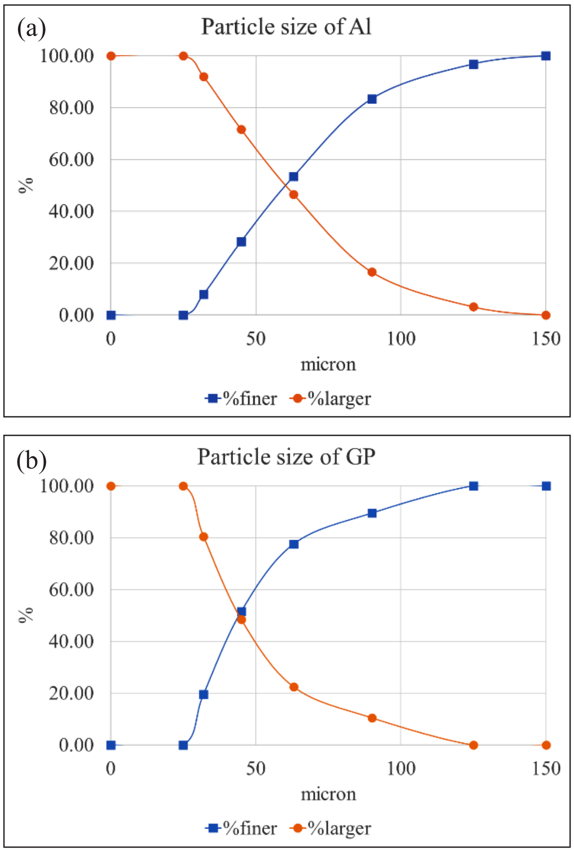

Figure 2: (a) the curves for the particle size distributions of aluminum scrap and (b) the curves for the particle size distributions of GP.

Figure 3. The test specimen for tensile, hardness, impact resistance, and electrical conductivity tests follows ASTM B925 [19] and ASTM B193 [20].

Table 2: Composition ratios of composites materials Condition (wt%)

Aluminum Scrap Powder	GP
100.00	0.00
99.75	0.25
99.50	0.50
99.25	0.75
99.00	1.00

2.3 *Sintering process*

After compacting, the green parts were sintered. The

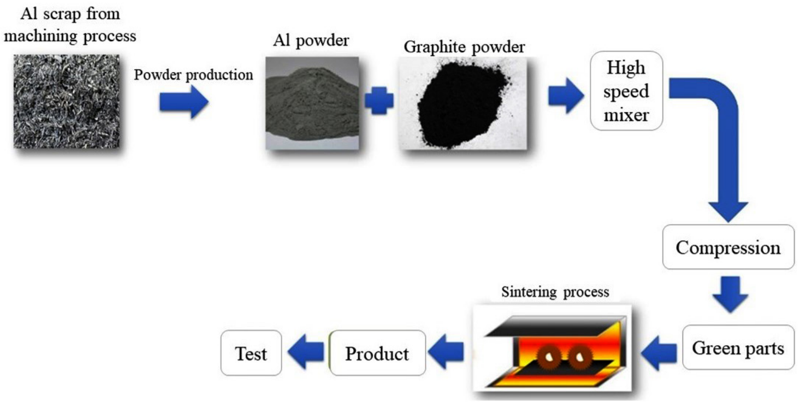

Figure 3: Fabrication procedure for Al/GP composites.

sintering process increases the bonding between atoms. During this process, atomic diffusion takes place and welded areas are produced that will reinforce the connection during sintering. Repeatable results depend on temperature and the atmosphere. Sintering is controlled throughout the heating rate duration. The equipment utilized in the sintering process is tube furnaces. The inert gas used in the technique is argon gas. As the specimen is placed into the furnace the temperature and sintering profile is displayed. The sintering temperature was measured according to the sintering profile in Figure 4. The actual sintering conditions require two steps: The first step is to bring the heat temperature up to 300 °C and hold it for 30 min, with a heating rate of 5 °C/min. In the second step, heat is increased to a maximum temperature of 640 °C, with a holding time of 60 min, and a heating rate of 5 °C/min.

2.4 *Characterization*

The densities of Al/GP composites were measured using the 'Archimedes' method with distilled water. The mechanical testing was conducted at room temperature by using 5 specimens of composite materials at different mixing rates of GP. The tensile test was performed in accordance with ASTM E8 standards [21] at a pulling speed of 0.001 mm/min with a load cell of 5 kN, the ultimate tensile strength (UTS), percent elongation, and Young's modulus (E). The impact resistance test according to ASTM E23 [22] by the Charpy impact test. The microhardness test according to ASTM B933 [23], using a Micro Vickers hardness tester, is specimens from the impact test. The specimens were cut to a size of 10 mm, cold mounting, and grinding the surface to adjust the plane. The hardness of the sintered compact press is determined under a load of 50 gf for a dwell time of 15 s, averaging the values obtained by 6 measurements of each material. The electrical conductivity test was measured using 4 copper wires installed on the workpiece and connected to a DC power system using a multimeter (U3402A) to measure the current through the workpiece. The microstructures and fractured surfaces were inspected using a scanning electron microscope (SEM; Thermo Fisher Scientific Ltd., Waltham, MA USA, Model Prisma E SEM) integrated with an energy dispersive X-ray spectrometer (EDS). The data were statistically analyzed using ANOVA and tests with a 5% significance criterion.

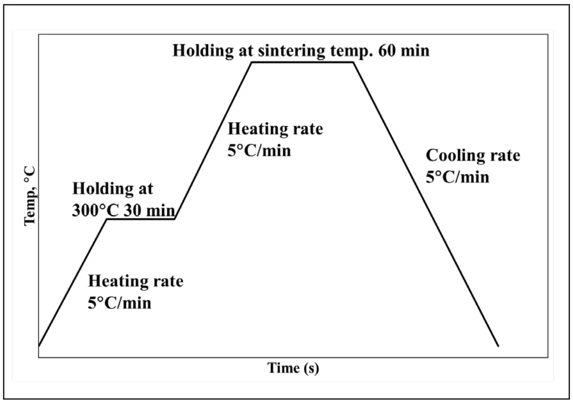

Figure 4: Sintering procedure.

3 Results and Discussion

3.1 *X-ray diffraction pattern of Al/GPs composites*

X-ray diffraction (XRD) analysis was performed on the aluminum scrap, GP, and Al/GP composites in a range of 2θ equal to 5–100° with a scanning rate of 2°/min as shown in Figure 5. The phases of the aluminum scrap are present at 2θ equal to 38.51°, 44.741°, and 65.131° [24], [25] shown in the figure, indicating that the utilized aluminum scrap is pure aluminum. When GP was added, a new peak forms at 2θ equal to 26.531°, confirming that GP was present in the composite powder. The XRD patterns of the Al/GP composite and pure Al are shown, with no unique peak of Al4C3 or other metallic carbides and this could be due to reducing the formation of composite materials. As opposed to that, matrix surfaces can contain the oxygen element in EDS by coating them with a thin oxide film layer, but they could not be found in the XRD. Compound oxide peaks were not visible in the XRD, possibly because they were so small that they blended into the background of the XRD signal, and makes them undetectable. A thin oxide film prevents the production of metallic carbides [26].

3.2 *Density*

Table 3 provides the pure aluminum and Al/GP composite densities, both theoretical and experimental. Theoretical calculations demonstrate that the density of pure aluminum reduces by the addition of GP. Surprisingly, experimentally measured densities for both Al and Al/GP composites were greater than the predicted densities. This is a result of aluminum oxide (oxidation) being produced during the sintering process [24]. Experimental densities were a little higher than theoretical densities because aluminum oxide has a higher density than aluminum and GP. But the experimental density falls off when GP is added. Al/GP composites have a lower density than pure aluminum since the density of GP is lower than the density of pure aluminum. Due to, the fact that GP readily absorbs gas components like oxygen and nitrogen, the Al/GP composites become somewhat more porous, and their relative density decreases. Additionally, easier atom dispersion at high sintering temperatures makes composites more sinterable.

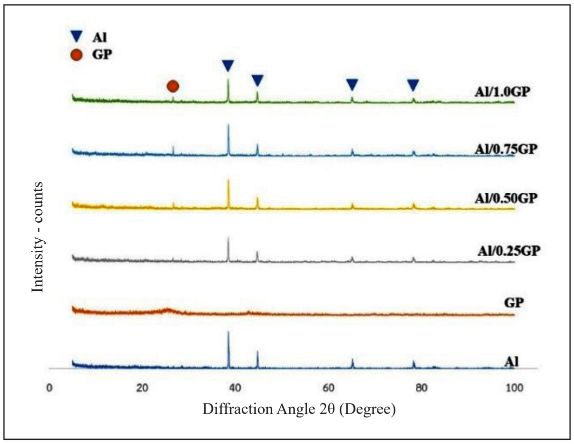

Figure 5: XRD of aluminum scrap, GP and Al/GP composites.

Due to shrinkage during the sintering process, the composites' dimensions change, which affects the density of the composites [26].

Table 3: Theoretical and experimental densities of pure Al and Al/GP composites

Specimen	Apparent Density (g/cm^3)	Theoretical Density (g/cm^3)
Al	2.73	2.70
Al/0.25GP	2.69	2.68
Al/0.5GP	2.65	2.64
Al/0.75GP	2.61	2.60
Al/1.0GP	2.58	2.56

3.3 *Mechanical properties*

In Figure 6, the results can be seen of the impact resistance test on pure Al and Al/GP, and the composite impact resistance values at various mixing ratios. The best impact resistance was determined to be 41.16 KJ/m^2 for pure aluminum, but when the ratio of GP in the material increased, the impact resistance decreased. This proves that composites have altered behavior from ductile materials and are harder and more brittle after adding GP to the material. There is space between the aluminum and the GP inside the composite materials and because of the existence of GP in the workpiece breaks more easily.

Figure 7 shows the tensile strength of pure Al and Al/GP composites. Adding GP to pure Al leads to an increase in ultimate tensile strength and young's modulus

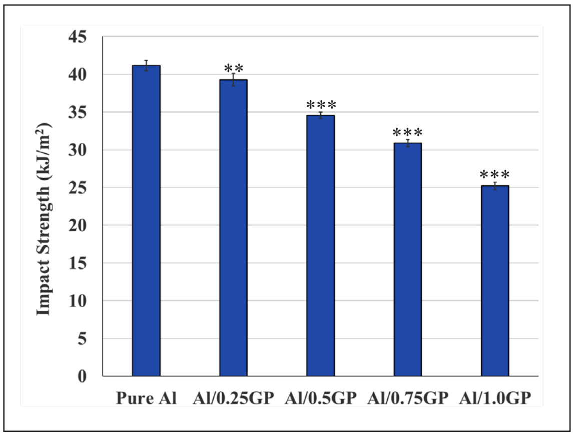

Figure 6: Impact strength of pure Al and Al/GP composites * ($p \leq 0.05$), ** ($p \leq 0.01$) and *** ($p \leq 0.0001$) compared with pure Al indicate results with statistically significant differences.

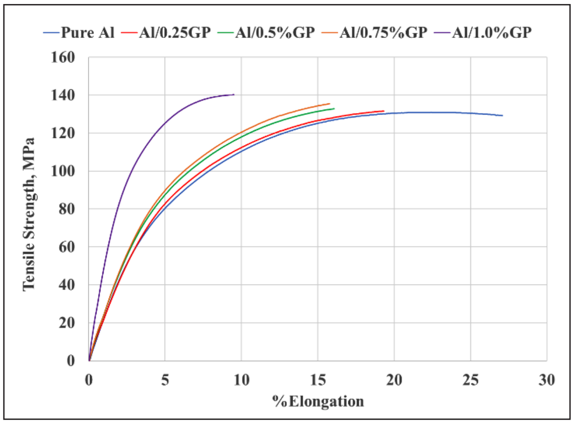

Figure 7: Tensile test of pure Al and Al/GP composites.

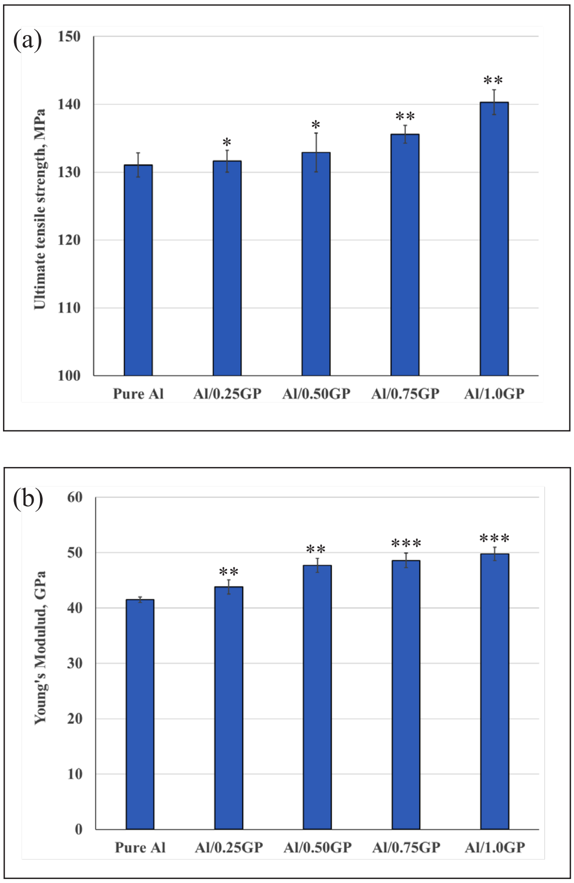

Figure 8: Tensile strength of pure Al and Al/GP composites (a) Ultimate tensile strength and (b) Young's modulus * ($p \leq 0.05$), ** ($p \leq 0.01$) and *** ($p \leq 0.0001$) compared with pure Al indicate results with statistically significant differences.

(up to 140.32 MPa and 49.78 GPa respectively) with 9.58% elongation at break. The best average tensile strengths obtained for the different wt% GP are shown in Figure 8(a). The values given are the average of five samples. The best tensile strength for the Al/1.0GP, exhibited a 7.07% increase compared to the pure Al. Young's modulus was more significant (20.00%), as presented in Figure 8(b). Thus, it is evident that GP affects the strength of aluminum. This increased strength can be attributed to the basic strengthening mechanism of the Al/GP composite. According to the previous studies above, only the Al/1.0GP showed improved mechanical properties and tensile strength, young's modulus including lower density. The increment in mechanical properties for the samples with higher additions of GP can be attributed to the diffusion of carbon into aluminum [27].

Figure 9 shows the Vickers hardness of pure Al and Al/GP composites. The results conclusively demonstrate that GP provides a highly potent strengthening of the aluminum matrix. The dispersion of GP in the matrix aids in refining the grain sizes by fixing the grain boundaries and increasing the hardness of the composite. The micro-hardness of the pure Al is 64.69 HV. As predicted, with the addition of GP, Al hardness increases. Compared to pure Al, the Al/1.0GP composite shows 91.88 HV, which increased by 42.03%. The improvement in the micro-hardness

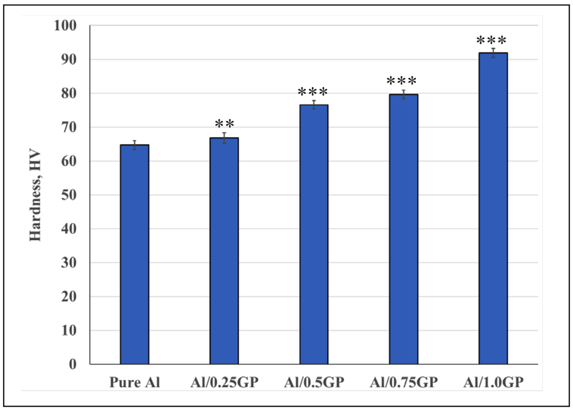

Figure 9: Hardness test of pure Al and Al/GP composites * ($p \leq 0.05$), ** ($p \leq 0.01$) and *** ($p \leq 0.0001$) compared with pure Al indicate results with statistically significant differences.

for Al/GP composite is due to the fact that GP is reinforced into the interface of grain boundary and creates a barrier to the dislocation thus boosting the strain hardening in the plastic deformation [7], [28].

In addition to the mechanical qualities indicated above, the key to obtaining appropriate mechanical properties for the sintering of Al/GP composite is a sufficient sintering temperature. In this study, the appropriate temperature was 640 °C, which caused a significant increase in the tensile strength, young's modulus, and hardness of the Al/GP composite. Therefore, the remnant pores may be sealed, and the particles can contact according to the pressure and temperature are sufficient. Additionally, based on the same mechanical properties of the aluminum sintered at 640 °C. The conclusion is that the mechanical properties of sintered aluminum will reach an extreme value if the bonding at the previous particle boundary is sufficient.

3.4 *Electrical conductivity*

Figure 10 shows the measured electrical conductivity of the as-sintered pure Al and Al/GP composites. It shows that the conductivity of Al/GP composites is 0.966 m/Q-Cm^2, it has better electrical conductivity than pure Al [29] at 89.04%. It demonstrates that when GP is added to Al, GP diffuses throughout the sintering process, improving aluminum's mechanical and electrical conductivity properties.

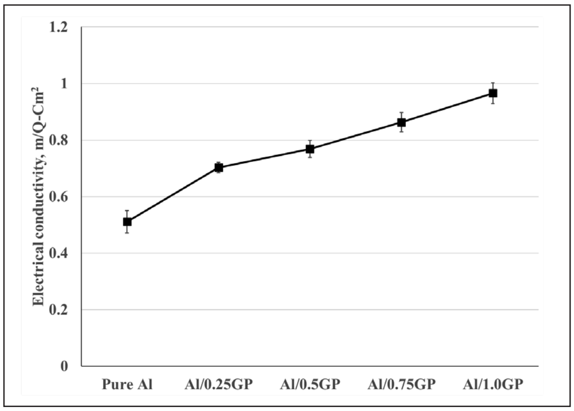

Figure 10: Electrical conductivity of pure Al and Al/GP composites.

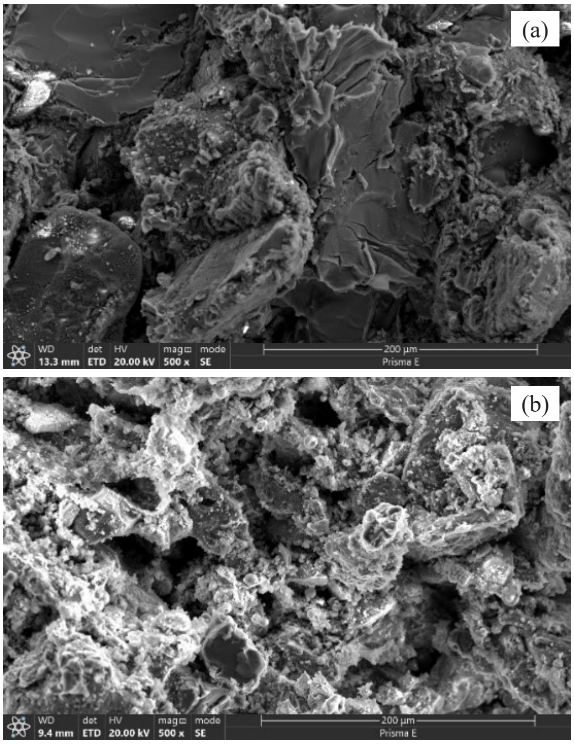

Figure 11: SEM micrographs at 500x of (a) pure Al and (b) Al/GP composites.

3.5 *Morphological properties*

Figure 11(a) shows the surface fracture of the impact test. We can see that the aluminum particles have a relatively good bond, but the test specimen has some pores. The fracture surface of the aluminum is ductile,

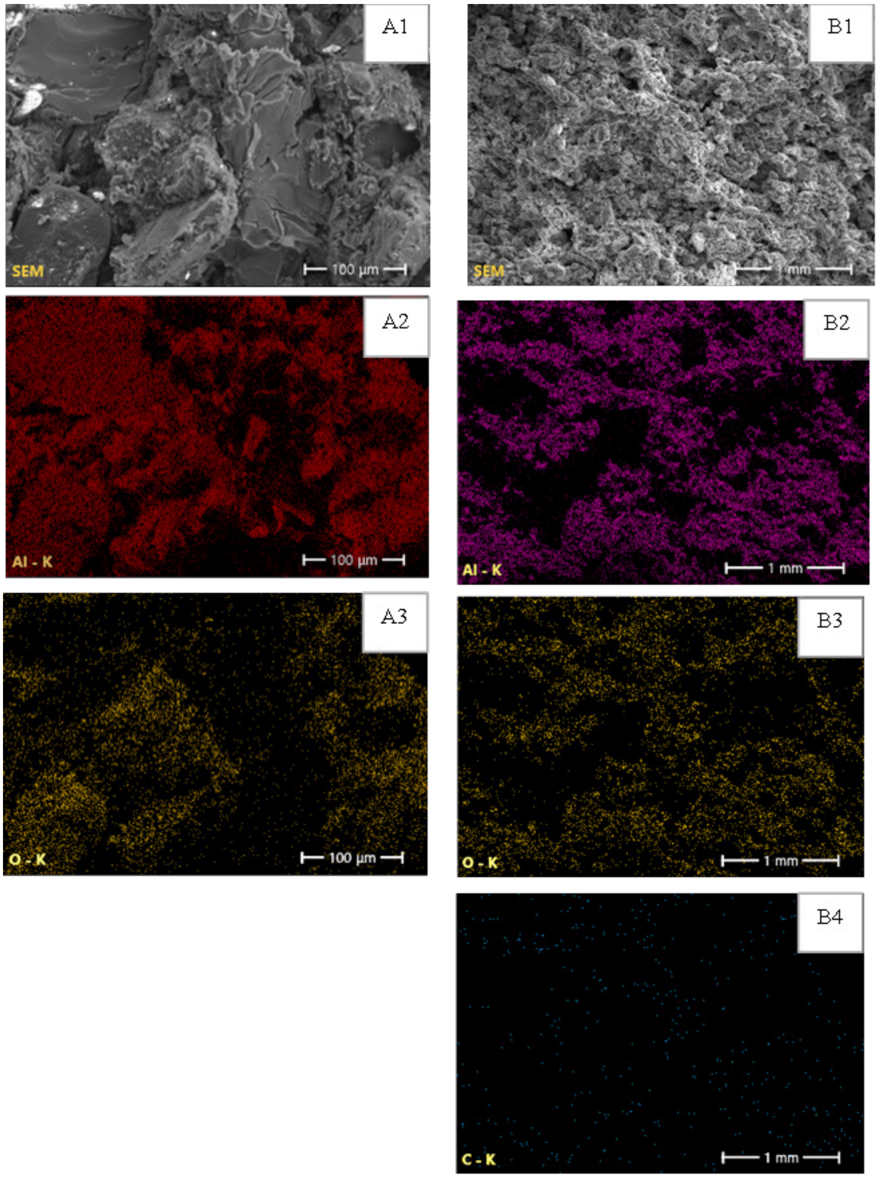

Figure 12: Energy Dispersive X-ray Spectrometer (EDS) of (a) pure Al and (b) Al/GP composites.

and Figure 11(b) is the specimen with 1.0% GP added; the fracture surface of the specimen is brittle. The results of the aforementioned mechanical properties of pure Al and added GP are supported by the SEM.

Since the distribution of GP in the pure Al surface is not visible from SEM, the EDX was tested to see the particles of GP inserted in the Al as shown in Figure 12 ; A1 and B1 show the specimen's morphology; A2 and B2 show the aluminum element; A3 and B3 show the oxygen; and B4 shows the carbon. We found that the GP particles were infiltrated and distributed in the Al. Therefore, we can confirm that the addition of graphite into Al results in a composite material with better mechanical properties. The tensile strength (Young's peak tensile and modulus values) and the electrical conductivity of GP-filled specimens were better than those of pure Al.

4 Conclusions

A study of the amount of graphite added to pure aluminum at the ratios of 0, 0.25%, 0.5%, 0.75%, and 1.0%GP found that the results of the compound composition analysis by XRD were consistent. A peak is found to indicate the presence of aluminum in all mixing proportions, and a peak indicates a higher carbon presence as the proportion of GP increases. According to the findings of the mechanical properties test, the specimen with the Al100% ratio has the maximum impact resistance, making it the hardest according to the ductile qualities of the material. However, the addition of graphite makes composites more brittle and tougher. This has an impact on the mechanical properties, which are affected by the UTS, Young's modulus, and hardness, as well as the electrical conductivity characteristics, which rise with the quantity of graphite. This research can further improve the properties of aluminum. Increase alternatives for materials to be applied in various industrial applications and increase the value of aluminum scrap in the industrial sector. Finally, it serves as a basis for further research work in the future.

Acknowledgements

Many thanks go to Dr. Thapanee Srichumpong at National Metal and Materials Technology Center (MTEC) and Faculty of Engineering and Technology, King Mongkut's University of Technology North Bangkok, Rayong Campus for supporting research facility and other support.

Author Contributions

P.N. and K.N.: conceived and planned the experiments, wrote the main text of manuscript, and made final evaluations of the results; P.N.: carried out the SEM, EDS and XRD measurements and evaluations; K.S. & C.M.: did the density, mechanical, and electrical conductivity test. All authors provided critical feedback and helped shape the research, analysis and manuscript.

Conflict of Interests

The authors declare no conflict of interests.

Reference

[1] Z. M. Gasem, "Fatigue crack growth behavior in powder-metallurgy 6061 aluminum alloy reinforced with submicron Al_2O_3 particulates," *Composites Part B Engineering*, vol. 43, no. 8, pp. 3020–3025, Jun. 2012, doi: 10.1016/j.compositesb.2012.05.031.

[2] L. Dyachkova and E. E. Feldshtein, "On the properties of composites based on sintered bronze with alumina additives," *Compososites Part B Engineering*, vol. 45, no. 1, pp. 239–247, Jul. 2012, doi: 10.1016/j.compositesb.2012.07.024.

[3] N. Chawla and K. K. Chawla, *Metal Matrix Composites*, 2nd ed. New York: Springer, 2006, pp.1–4.

[4] W. D. Callister, Jr., D. G. Rethwisch, *Materials Science and Engineering - An Introduction*, 10th ed. New Jersey:Wiley, 2018, pp. 589–590.

[5] R. Etemadi, B. Wang, K. M. Pillai, B. Niroumand, E. Omrani, and P. Rohatgi, "Pressure infiltration processes to synthesize metal matrix composites– A review of metal matrix composites, the technology and process simulation," *Materials Manufacturing Process*, vol. 33, no. 12, pp. 1261–1290, Feb. 2018, doi: 10.1080/10426914.2017.1328122.

[6] A. Mortensen and J. Llorca, "Metal matrix composites," *The Annual Review of Materials Research*, vol. 40, pp. 243–270, Mar. 2010, doi: 10.1146/annurev-matsci-070909-104511.

[7] C. Prakash, S. Singh, S. Sharma, H. Garg, J. Singh, H. Kumar, and G. Singh, "Fabrication of aluminium carbon nano tube silicon carbide particles based hybrid nano-composite by spark plasma sintering," *Materials Today: Proceeding*, vol. 21, pp. 1637–1642, 2020, doi: 10.1016/j.matpr.2019.11.273.

[8] M. A. Awotunde, A. O. Adegbenjo, B. A. Obadele, M. Okoro, B. M. Shongwe, and P. A. Olubambi, "Influence of sintering methods on the mechanical properties of aluminium nanocomposites reinforced with carbonaceous compounds: A review," *Journal of Materials Research and Technology*, vol. 8, no. 2, pp. 2432–2449, Apr. 2019, doi: 10.1016/j.jmrt.2019.01.026.

[9] M. Bastwros, G.-Y. Kim, C. Zhu, K. Zhang, S. Wang, X. Tang, and X. Wang, "Effect of ball

milling on graphene reinforced Al6061 composite fabricated by semi-solid sintering," *Composites Part B: Engineering*, vol. 60, pp. 111–118, Apr. 2014, doi: 10.1016/j.compositesb.2013.12.043.

[10] E. Yandria, P. Pramudito, R. Ronald, Y. Ardiani, R. Ariatia, R. H. Setyobudia, W. Widodo, M. Zahoor, I. Zekker, and A. Lomi, "Technical design of aluminium scrap processing machines by utilizing direct exhaust air using conveyor drying system," *Proceedings of the Estonian Academy of Sciences*, vol. 71, no. 2, pp. 178–185, May 2022, doi: 10.3176/proc.2022.2.01.

[11] A. T. Tabereaux and R. D. Peterson, *Aluminum Production*. Amsterdam, Netherlands: Elsevier, 2014.

[12] M. Samuel, "A new technique for recycling aluminium scrap," *Journal of Materials Processing Technology*, vol. 135, no. 1, pp. 117–124, Apr. 2003, doi: 10.1016/S0924-0136(02)01133-0.

[13] V. Kučera, F. Průša, and D. Vojtěch, "Processing of Al-Fe scraps by powder metallurgy," *Manufacturing Technology*, vol. 16, no. 4, pp. 726–732, Aug. 2016, doi: 10.21062/UJEP/X.2016/A/1213-2489/MT/16/4/726.

[14] D. A. Saheb, "Aluminum silicon carbide and aluminum graphite particulate composites," *Journal of Engineering and Applied Science*, vol. 6, no. 10, pp. 41–46, Oct. 2011.

[15] M. Nagaral, B. K. Shivananda, Jayachandran, V. Auradi, and S. A. Kori, "Effect of SiC and graphite particulates addition on wear behaviour of Al2219 alloy hybrid composites," *IOP Conference Series: Materials Science and Engineering*, vol. 149, no. 1, Art. no. 012108, 2016, doi: 10.1088/1757-899X/149/1/012108.

[16] A. Ureña, J. Rams, M. D. Escalera, and M. Sánchez, "Characterization of interfacial mechanical properties in carbon fiber/aluminium matrix composites by the nanoindentation technique," *Composites Science and Technology*, vol. 65, no. 13, pp. 2025–2038, Jun. 2005, doi: 10.1016/j.compscitech.2005.04.013.

[17] P. Garg, A. Jamwal, D. Kumar, K. K. Sadasivuni, C. M. Hussain, and P. Gupta, "Advance research progresses in aluminium matrix composites: Manufacturing & applications," *Journal of Materials Research and Technology*, vol. 8, no. 5, pp. 4924–4939, Jul. 2019, doi: 10.1016/j.jmrt.2019.06.028.

[18] H. Faleh, N. Muna, and F. Ştefănescu, "Properties and applications of aluminium-graphite composites," *Advanced Materials Research*, vol. 1128, pp. 134–143, Oct. 2015, doi: 10.4028/www.scientific.net/amr.1128.134.

[19] *Standard practices for production and preparation of powder metallurgy (PM) test specimens*, ASTM B925-08, 2014.

[20] *Standard test method for resistivity of electrical conductor materials*, Astm B193-89, 1990.

[21] *Standard test methods for tension testing of metallic materials 1*, ASTM E8/E8M, 2010.

[22] *Standard test methods for notched bar impact testing of metallic materials*, ASTM E 23-12c, 2012.

[23] *Standard Test Method for Microindentation Hardness of Powder Metallurgy (PM) Materials*, ASTM B933-14, 2014.

[24] M. Rashad, F. Pan, A. Tang, and M. Asif, "Effect of Graphene Nanoplatelets addition on mechanical properties of pure aluminum using a semi-powder method," *Progress in Natural Science: Materials International*, vol. 24, no. 2, pp. 101–108, Apr. 2014, doi: 10.1016/j.pnsc.2014.03.012.

[25] L. Wu, Z. Yu, C. Liu, Y. Ma, Y. Huang, T. Wang, L. Yang, H. Yan, and W. Liu, "Microstructure and tensile properties of aluminum powder metallurgy alloy prepared by a novel low-pressure sintering," *Journal of Materials Research and Technology*, vol. 14, pp. 1419–1429, Jul. 2021, doi: 10.1016/j.jmrt.2021.07.074.

[26] H.-M. Xia, L. Zhang, Y.-C. Zhu, N. Li, Y.-Q. Sun, J.-D. Zhang, and H.-Z. Ma, "Mechanical properties of graphene nanoplatelets reinforced 7075 aluminum alloy composite fabricated by spark plasma sintering," *International Journal of Minerals, Metallurgy and Materials*, vol. 27, no. 9, pp. 1295–1300, Feb. 2020, doi: 10.1007/s12613-020-2009-0.

[27] M. Rahimian, N. Ehsani, N. Parvin, and H. R. Baharvandi, "The effect of sintering temperature and the amount of reinforcement on the properties of Al-Al2O3 composite," *Materials & Design*, vol. 30, no. 8, pp. 3333–3337, Dec. 2008, doi: 10.1016/j.matdes.2008.11.027.

[28] H. Kwon, M. Estili, K. Takagi, T. Miyazaki, and

A. Kawasaki, “Combination of hot extrusion and spark plasma sintering for producing carbon nanotube reinforced aluminum matrix composites,” *Carbon*, vol. 47, no. 3, pp. 570–577, Nov. 2008, doi: 10.1016/j.carbon.2008.10.041.

[29] J. M. Montes, J. A. Rodríguez, and E. J. Herrera, “Thermal and electrical conductivities of sintered powder compacts,” *Powder Metallurgy*, vol. 46, no. 3, pp. 251–256, Sep. 2003, doi: 10.1179/003258903225008544.