Kovove Mater. 60 2022 121–129
DOI: 10.31577/km.2022.2.121

Study of mechanical and wear behaviour of AA5083 graphene reinforced composites

S. Sendhil Kumar[1], S. Dharani Kumar[2], U. Magarajan[3]*, S. Divya[4]

[1]*Department of Mechatronics Engineering, Akshaya College of Engineering and Technology, Coimbatore, India*
[2]*Department of Mechanical Engineering, KPR Institute of Engineering and Technology, Coimbatore, India*
[3]*Department of Mechanical Engineering, Bharath Institute of Higher Education and Research, Chennai, India*
[4]*Department of Mechanical Engineering, Sri Eshwar College of Engineering, Coimbatore, India*

Received 8 June 2021, received in revised form 4 April 2022, accepted 14 April 2022

Abstract

AA5083 aluminium alloy is an excellent casting material with inadequate strength and poor wear properties. To increase its deficient mechanical and wear properties, researchers have conducted a lot of research in the past decades. Based on the research, graphene can be considered a good reinforcement due to its outstanding mechanical properties. The present paper discusses the properties of AA5083 Metal Matrix Composites (MMCs) reinforced with graphene particles. Aluminium MMCs were fabricated using the stir casting method by varying graphene reinforcement (5 and 10 wt.%) with AA5083 (specimens B and C). The Scanning Electron Microscopy (SEM) and Energy-Dispersive X-ray Spectroscopy (EDAX) analysis results confirmed the presence of graphene in the AA5083 matrix. The test results show that the tensile strength, flexural strength, impact strength, and hardness were enhanced with the addition of graphene particles in the AA5083 matrix. The tribological behaviour of the MMCs was compared with the AA5083 matrix using a pin-on-disc wear test. The increase in wt.% of graphene reinforcement enhanced the wear resistance of the proposed MMCs. The large wear debris and crater were not noticed in the worn surfaces of the MMCs specimens.

Key words: AA5083, metal matrix composites, mechanical properties, wear behaviour, graphene

1. Introduction

Nowadays, AA5083 aluminium alloy is widely used in automotive, aircraft, marine, and defence applications. These conventional aluminium alloys are replaced by MMCs for better mechanical, wear, and corrosion resistance properties. Since AA5083 is a non-heat-treatable aluminium alloy, its strength and wear properties cannot be improved by the heat-treatment process. Hence, the properties of AA5083 can be improved by adding reinforcement particles. MMCs increase the strength and wear resistance of the composites by adding reinforcements [1–3]. The mechanical properties of composites manufactured by squeeze casting and vortex methods were lower than the stir casting method [4, 5]. Stir casting is one of the most suitable processing techniques for improving mechanical and wear properties by adding reinforcements. The investment and manufacturing cost of the solid-state process method was much higher than the stir casting method [5]. A few hard ceramic particles, such as MWCNT [6], B_4C [7, 8], SiO_2 [9], and SiC [10], have been mixed with AA5083 matrix metal using the stir casting method. The effect of wear and flexural strength on MWCNT AA5083 MMC processed by stir casting method was studied, and its enhancement in wear resistance and flexural strength was 50 and 52 % compared with AA5083 [6]. Graphene was considered an excellent reinforcement in the aluminium matrix because of its outstanding mechanical and thermal properties [3]. Graphene enhanced the mechanical and wear properties of AA6061 MMC processed by stir casting technique [11]. 1 wt.% of graphene reinforcement in the AA7055 matrix improved the compressive

*Corresponding author: e-mail address: magarajan84@gmail.com

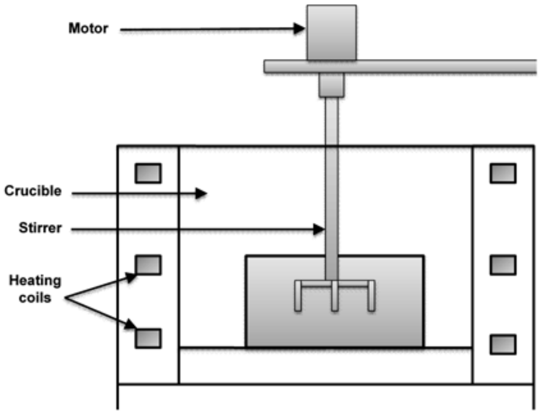

Fig. 1. Stir casting setup used for making composite specimens.

Fig. 2. Cast specimens.

strength and hardness of the MMC [12]. The minimum usage of graphene reinforcement in the aluminium matrix significantly enhanced the tribological properties [11]. The wear rate of AA5083 was higher than that of the AA5083/B_4C composites, which were fabricated by the stir casting method [8]. The addition of SiC reinforcement particles increased the mechanical properties of AA5083 [9]. Also, enhancement in true stress value was noticed in AA5083-graphene nanoplates MMCs processed by hot pressing and extrusion [3].

From the highlighted research works, it was understood that graphene is a good reinforcement with the aluminium matrix as MMC composites. In this paper, graphene/AA5083 MMC with various graphene contents was fabricated using the stir casting method. Besides, the effect of the graphene content on the mechanical and wear behaviour of the graphene/AA5083 MMC has also been investigated. Finally, worn surfaces of the MMC were investigated by SEM.

2. Base material and reinforcement

In this paper, AA5083 is used as a matrix material for manufacturing the MMC. This aluminium alloy consists of magnesium (4.0–4.9 %) and manganese (0.4–1.0 %) as its extensive alloying elements. Graphene having lateral dimensions of 5–10 μm and thickness of 5–10 nm was used as the reinforcement. Graphene has outstanding properties such as modulus of elasticity (0.5–1 TPa), tensile strength (130 GPa), and thermal conductivity (5.3×10^3 W m^{-1} K^{-1}). Graphene has a distinguished concentration in the field of composites [5] and has proven to be an excellent reinforcing material for the aluminium MMC [6].

3. Preparation of AA5083 composite

An AA5083 plate is sliced into pieces of 15 mm × 15 mm × 8 mm to be easily placed in the graphite crucible. Initially, the AA5083 sliced plate of the measured quantity is preheated for 2 h at 350 ℃ in a muffle furnace to eliminate the oxides present in the material. The preheated AA5083 is melted in the crucible at the liquid temperature of 700 ℃. Later the graphene powder is added manually. The blend is stirred at 300 rpm for 10 min using a stirred blade coupled with the motor, as shown in Fig. 1. The appropriate stirring produces excellent mixing of materials and results in an orderly microstructure.

At last, the slag is removed from the molten composite. Finally, the molten metal is transferred to the preheated low carbon steel mould of 100 mm × 100 mm × 20 mm to prepare the MMC plates for testing. After solidification, the MMC plates are extracted from the mould. The extracted specimens are shown in Fig. 2. The same procedure is adopted for different compositions of graphene reinforcement. Three specimens are prepared, specimen A contains only AA5083 matrix, specimen B contains 5 wt.% graphene, and specimen C 10 wt.% grapheme.

4. Chemical composition confirmation test

The presence of graphene in AA5083 MMC is confirmed by Energy Dispersive Spectroscopy (EDS) analysis. Figures 3a,b depict the EDS spectrum of specimen B and specimen C MMCs. The individual peak corresponds to the existence of a chemical element in the MMC. From the EDS, it is observed that the highest peak coincides with aluminium as the matrix material. Next to the aluminium peak, the corre-

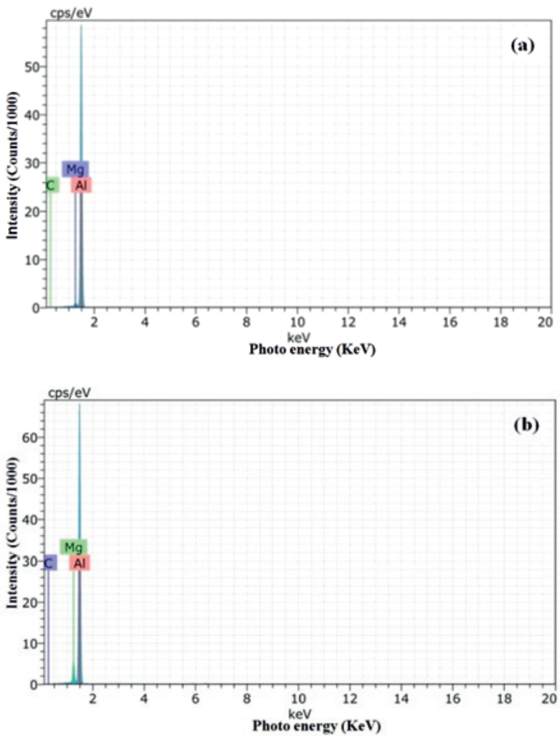

Fig. 3. Graphene reinforced MMC: (a) EDS spectra, specimen B and (b) EDS spectra, specimen C.

sponding peaks are magnesium and graphene elements in the MMC represented in the EDAX image. Figure 3b shows the presence of graphene in AA5083 with 10 wt.% of graphene MMC (specimen C). It can be thus recorded that the graphene particles are present in the AA5083 matrix. EDAX of both MMC specimens illustrates no significant existence of silicon carbide, alumina, and magnesia. The presence of oxides in the aluminium is removed as slag before pouring the molten metal into the mould.

5. Testing of mechanical and wear properties

A wire Electric Discharge Machining (EDM) is used to machine the composite as per the standard size for investigating the mechanical and wear properties of the MMC. The first and foremost testing is a tensile test, used to evaluate the tensile strength and percentage of the elongation. The tensile test is carried out using Universal Testing Machine (UTM) as per the ASTM standard. The specimens are prepared as per the ASTM E08-8 standard. To investigate the flexural strength of the composites, the bending tests are carried out using the UTM machine as per the ASTM-A370 standard. The impact strength of the composite specimens is estimated using the Charpy impact testing machine as per ASTM E23-04 standard. Finally, the Brinell hardness test was conducted with reference to the ASTM E10-07 standard using the 10 mm steel ball indenter at a penetration load of 500 kgf. All four tests are performed at room temperature of 28 ℃, and each test is carried out three times to attain an accurate average value for each mechanical property.

After mechanical tests, a wear test is conducted using the pin-on-disc wear testing apparatus (TR--201LE, Ducom, India). The disc with the specification of 80 mm diameter and 15 mm thickness made of EN31 grade steel with the hardness of 62 ± 2 HRC is utilized in the testing. The wear test is performed using the process parameter of load (15 N), sliding speed (1.0 m s^{-1}), sliding distance (2000 m), and sliding time (30 min). The composite specimens are machined into a cylindrical pin with dimensions of 10 mm diameter and 8 mm length.

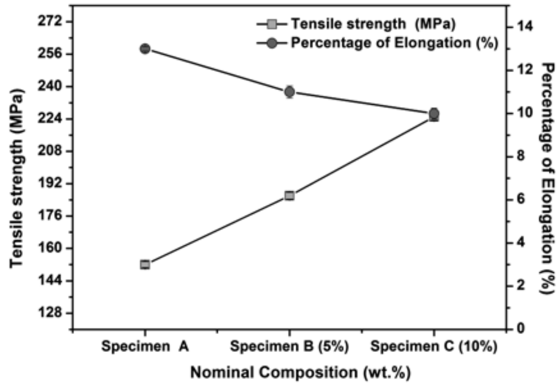

Fig. 4. Tensile properties of specimens A, B, and C.

6. Results

To evaluate their mechanical and wear properties, metal matrix composites were subjected to different tests. Based on the testing of MMCs, consecutive results are noticed.

6.1. Tensile test results

The tensile test results of different specimens are shown in Fig. 4. The tensile strength and percentage of elongation for three specimens are determined. The increase in tensile strength of AA5083 composite is observed due to the addition of graphene as reinforcement. The tensile strength of specimen B (5 wt.%) is 152 MPa, and specimen C (10 wt.%) is 225 MPa. The presence of graphene particles acts as a barrier for dislocation motion in the matrix, and it provides a better strengthening mechanism during the tensile loading. A higher strengthening mechanism helps to improve the strength of the material [13]. However, the percentage of elongation is reduced from 13 to 11 %. The addition of graphene declines the elongation percentage com-

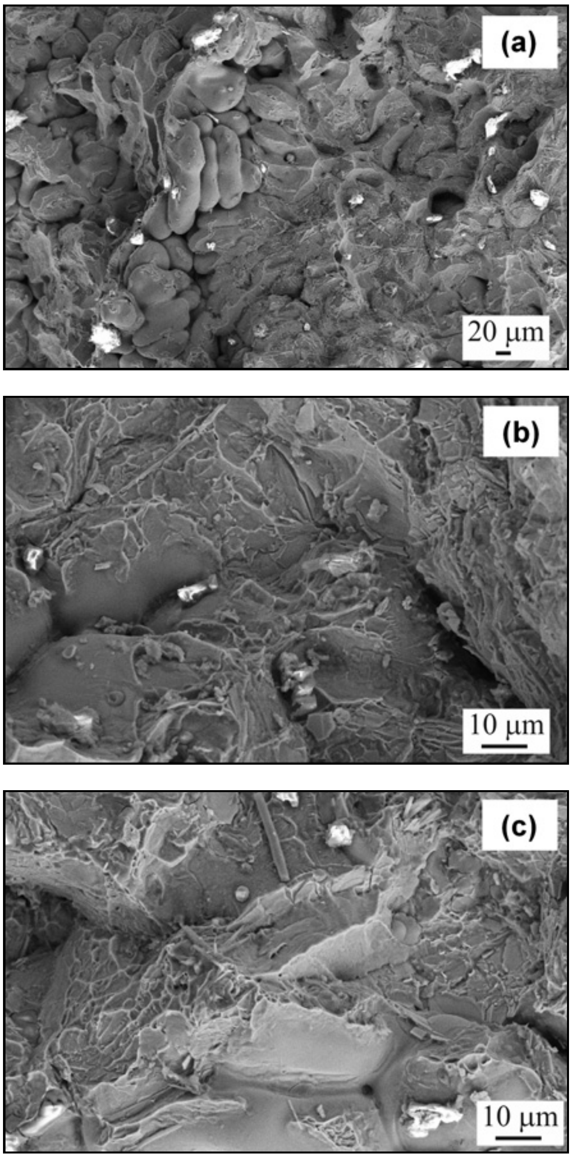

Fig. 5. SEM image of tensile fracture in specimens A, B, and C.

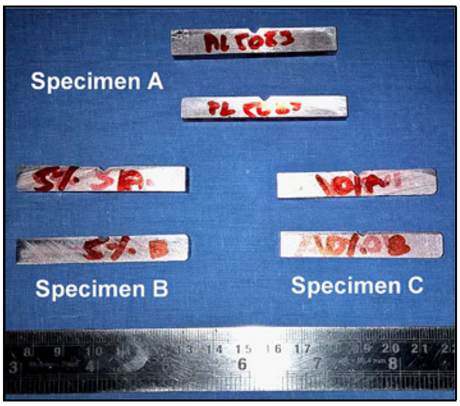

Fig. 6. Samples for flexural strength testing.

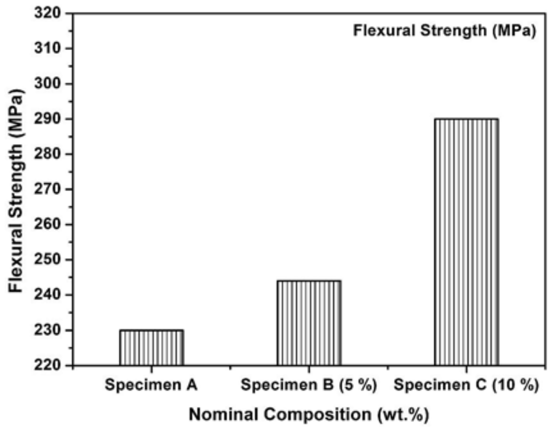

Fig. 7. Flexural test results of specimens A, B, and C.

pared to that of AA5083 without reinforcement. The dissimilar thermal coefficient expansion between the reinforcement and matrix produces a higher temperature during the tensile test. This elevated temperature produces more local stress at the boundary, restricting the larger plastic deformation and causing lower elongation [13]. A similar reduction in elongation percentage is observed in [5, 6]. Figures 5a–c illustrate the fracture SEM images of tensile tested specimens. The tensile failure of the MMCs is controlled by the progressive failure of the graphene particles. The tensile tested samples are depicted in Fig. 6.

6.2. Flexural test results

The flexural strength of the composite specimens is determined using a three-point bending test. The test is conducted as per the ASTM standard in the UTM machine. Figure 7 shows the comparison of the flexural strength of the three specimens. The flexural strength increases with increasing graphene, and it is observed that the flexural strength of MMCs is higher than that of the AA5083 matrix material, and similar results are reported [8]. It has been noted that the flexural strength of specimen C is 20 % higher than that of specimen A.

The reinforcement property provides a tough interface and better transfer of loads from the matrix to the reinforcements. An increase in reinforcement results in a higher thermal coefficient mismatch and leads to Orowan strengthening effect. Orowan strengthening effect increases the strength of the composites [3], and it is the main reason for higher tensile and flexural strength.

6.3. Hardness test results

The hardness test is carried out with the help of a Brinell hardness tester. The Brinell hardness

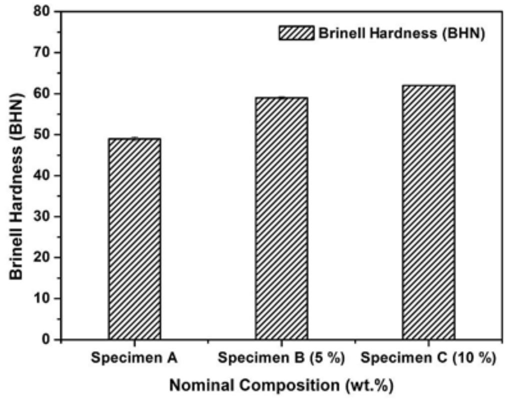

Fig. 8. Hardness results of specimens A, B, and C.

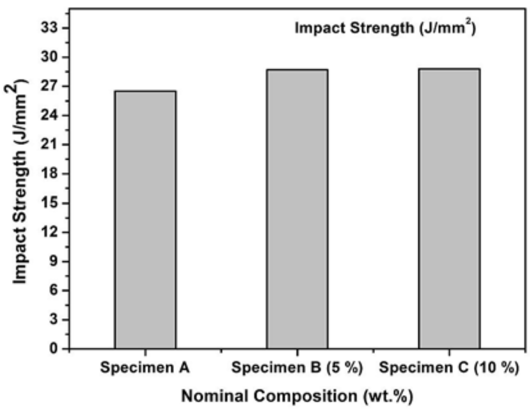

Fig. 9. Charpy impact test results of specimens A, B, and C.

test results of three different specimens are shown in Fig. 8. The graph shows that the hardness of AA5083 is improved from 49.41 BHN to 59.3 BHN after adding 5 wt.% graphene particles. This is due to the proper bonding of reinforcement particles in the matrix and the good refinement of the MMCs. It is noticed that there is an increase in hardness as the wt.% of graphene increases. 10 wt.% of graphene improved the hardness by 62.15 BHN. The superior hardness is noticed in specimen C (10 wt.%), which is 20 and 5 % higher than in specimens A and B. The graphene accumulation may lead to higher slippage between graphene flakes, inhibiting grain growth. More graphene reinforcing particles react as a grain development inhibitor, causing fine grains to form, enhancing the hardness. However, the process fills the voids and reduces the defects [5, 11]. This could be one reason for the higher hardness in specimen C (10 wt.%). The higher reinforcement helps decrease the density of the MMCs and further improves the hardness. Similar hardness was noticed in the AA5083 MMCs reinforced with MoS_2 contents varying from 1 to 4 wt.% [6].

6.4. Impact test results

Figure 9 shows the impact strength of three specimens. The bar chart implies that the impact strength increases with the addition of graphene in the AA5083 matrix. It can be observed that there is no significant difference between the impact strength of specimen B (5 wt.%) and specimen C (10 wt.%). The major reason for not having any improvement in the impact strength is due to the existence of more carbide. Hence, it leads to a decrease in ductility and an increase in hardness. A similar observation was noticed in the Ti-Al composites with carbides and graphene Al composites; where the amount of carbides increases, there is a reduction in the impact strength [15, 16]. However, there is no significant improvement in the increase of graphene weight percentage. The improvement in impact strength of graphene reinforcement MMC was 8.28 % higher than that of the pure AA5083 alloy.

6.5. Influence of carbide on mechanical properties

The microstructure of AA5083 composites of specimens A, B, and C are shown in Figs. 10a–c. The existence of carbide in the aluminium matrix can be noticed in the microstructures. However, more carbides are observed in specimen C compared with specimen B. The addition of graphene is larger in specimen C compared to specimen B. Figures 11a–c characterize the higher magnification SEM images of specimens B and C. The SEM shows the presence of carbides and graphene inclusions in the AA5083 composites. The carbides are shown in the form of black regions, and the graphene is seen in the white regions. The more dispersed carbide formations are noticed in specimen C compared to specimen B due to a higher volume of graphene particles present. The presence of carbide in aluminium MMC enhances the strength of the composite material [17, 18]. The tiny diffused carbide particle is the reason for an increase in the mechanical properties of MMCs. However, the addition of graphene in AA5083 reduces the ductility due to the accumulation of carbide particles. Similar results were observed in the AA6061 graphene reinforced composites [11]. The increase in wt.% of graphene in the MMCs results in the formation of more carbides and an increase in tensile, flexural strength, and hardness. However, the impact strength is not improved significantly in higher wt.% of graphene, which may be due to the higher formation of carbides in specimen C (10 wt.%).

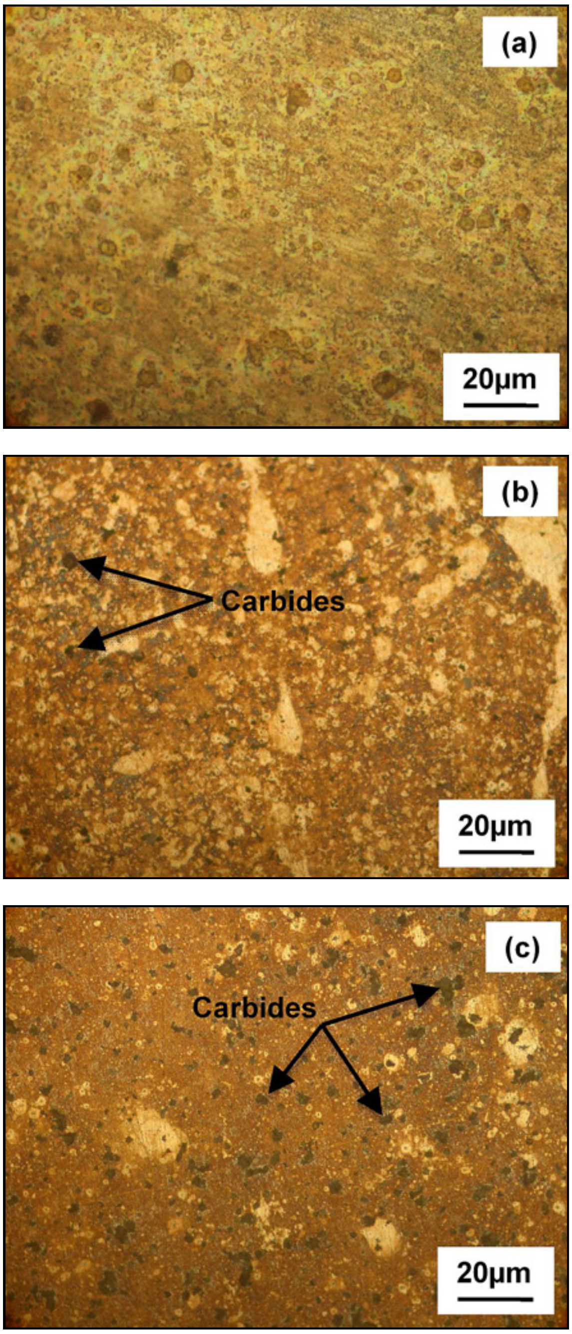

Fig. 10. Microstructure of AA5083 composites: (a) specimen A, (b) specimen B, and (c) specimen C.

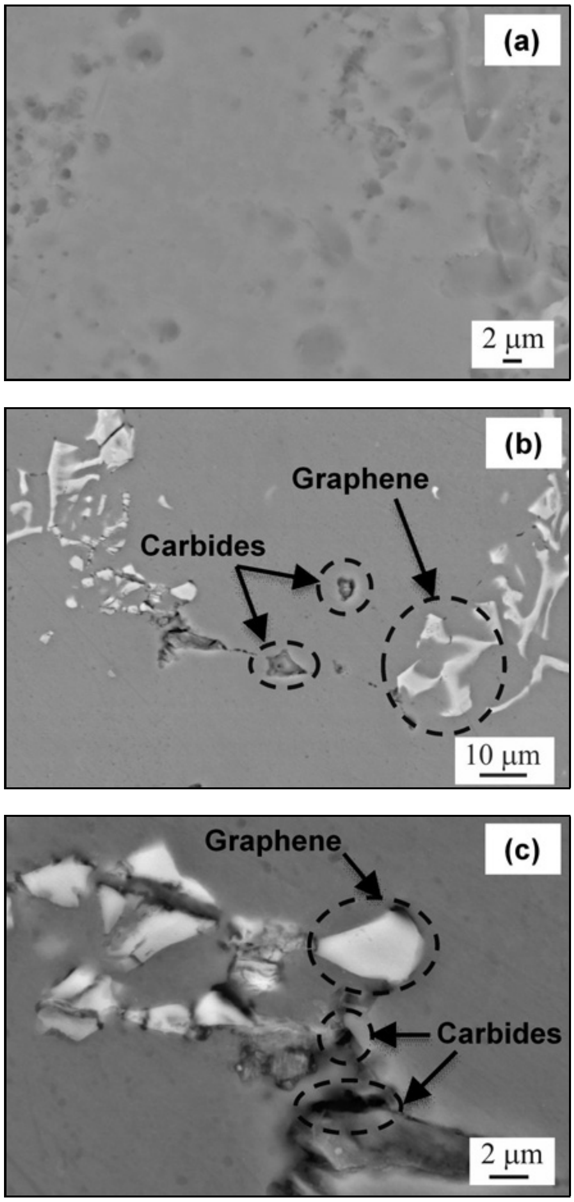

Fig. 11. SEM images of AA5083 composites: (a) specimen A, (b) specimen B, and (c) specimen C.

6.6. Wear test results

The wear test is performed for all three specimens of AA5083. Figure 12 shows the comparative results of wear (in microns) for AA5083 matrix and graphene reinforced composites. Wear in microns for each specimen is evaluated based on the frictional force and normal force between the rotating disc and pin. The graph shows that the wear resistance of the graphene/AA5083 MMCs is lesser than that of the AA5083 matrix.

The graphene tribo film reduces the shear stress level transferred to the sliding material beneath the contact area, resulting in lower plastic deformation in the lower surface region. Hence, it is the reason for higher wear resistance in the AA5083 MMCs. Similar phenomena were observed during the wear test of graphene-reinforced AA7075 composites [11]. Moreover, MMCs with 10 wt.% of graphene (specimen C) content show excellent wear resistance properties. The wear decreases with the addition of graphene and reaches a minimum at 10 wt.% graphene. It is about 43 % lower than that of the AA5083 matrix mate-

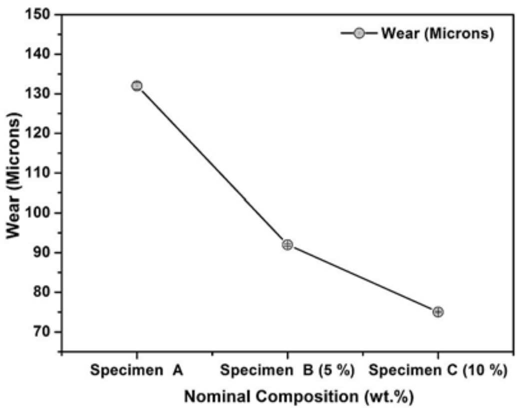

Fig. 12. Wear test results.

rial, where the wear resistance of MMC increases with the increase of graphene reinforcement particles. The higher graphene particles in the aluminium matrix act as load-bearing elements and provide excellent bonding strength in the MMCs. However, hardness was the main point for improving the wear property of AA5083 composites [9]. The existence of graphene particles in the AA5083 significantly improved the hardness property of the MMCs, resulting in better wear resistance of the composites. The higher hardness graphene reinforcement composites result in higher wear resistance properties.

6.7. SEM analysis of wear surfaces

Figures 13a–c show the SEM images of the worn surfaces of the MMC. Compared with the AA5083 matrix, the graphene/reinforced composites show less severity on the worn surfaces. The larger area of crater surface and wear debris were noticed in specimen A (Fig. 13a). The soft behaviour of the matrix material easily formed a detached surface against the hard surface disc. Hence, it was the reason for higher wear and more worn surfaces. Less debris and a small area of crater surface were observed in specimen B (Fig. 13b). However, tiny debris and a small frictional surface were noticed in specimen C (Fig. 13c). The reduction of less worn surface and debris in specimen C (10 wt.%) was mainly due to the increase in the weight percentage of graphene. The smeared graphene particles from the surface of composites form a tribofilm layer between sliding surfaces, which avoids direct contact with the disc surface. A similar phenomenon was noticed in the graphite reinforced aluminium composites [12]. This tribo film and hardness properties greatly resist the shear stress and plastic deformation against the wear load between the pin and disc. However, it also changes the wear failure mechanism from abrasive to adhesive. The graphene in the AA5083 matrix enriches the load-bearing capacity and reduces the wear failures against the hard counter surface disc.

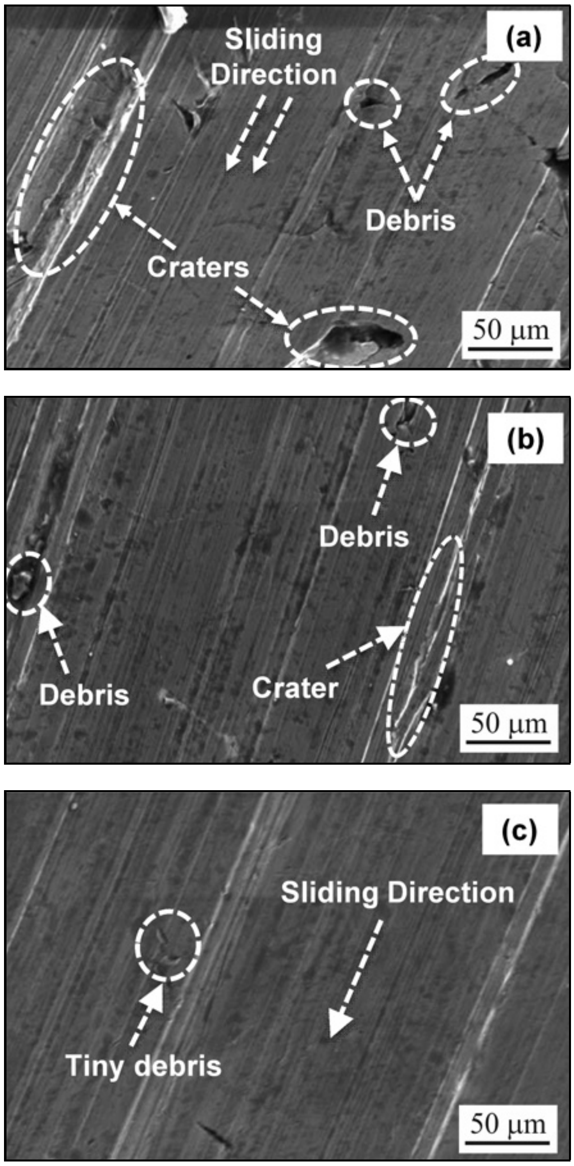

Fig. 13. Worn surfaces of specimens: (a) A, (b) B, and (c) C.

7. Conclusions

This paper highlights the fabrication of graphene reinforced AA5083 MMC using the stir casting method, followed by examining mechanical and wear properties. Based on the results, the following observations were inferred:

– EDS analysis confirmed the dispersion of graphene particles in the AA5083 matrix, and the adequate mixing of graphene in the matrix was confirmed by the SEM examination.

– The addition of graphene in the AA5083 exhibits better mechanical properties.

– The tensile strength increases from 152 to 225 MPa after successfully adding 5 wt.% of graphene. However, it was 32 % higher compared to the unreinforced AA5083 alloy.

– The graphene particles in the AA5083 significantly improved the flexural strength and hardness of the MMC, and it was superior to that of unreinforced AA5083. Thus flexural strength and hardness of specimen C (10 wt.%) were 20.68 and 20.96 % higher than the unreinforced AA5083. The effect of Orowan strengthening mechanisms and the existence of carbide particles enhanced the mechanical properties.

Adding 10 wt.% of graphene particles to the AA5083 matrix, the impact strength has been increased about 8 % more than AA5083. However, there was no significant difference in the impact strength with increased wt.% of graphene from 5 to 10 wt.%.

– The wear resistance of the MMC increases drastically with the addition of graphene reinforcement due to the increase in hardness. The wear resistance of the MMC was 43 % higher than that of the unreinforced AA5083. The graphene in the MMC exhibited superior wear resistance due to forming a thin film layer against the tribo surface.

– The wear debris and crater surface were more in the AA5083 matrix compared to the graphene MMCs. The increase in the wt.% of the graphene in the matrix reduced the size of wear debris and restricted the crater formation. The 10 wt.% graphene reinforced AA5083 MMC can be considered appropriate material for a choice of wear and structural applications.

– To conclude, mechanical and wear properties increased with the existence of carbides in the MMC. However, there is a reduction in ductility, and no significant improvement in impact strength was noticed in specimen C (10 wt.%); this may be due to more concentration of carbides in the matrix. Hence the creation of carbides in the MMC acts as a tough and good effect on enhancing the mechanical properties.

References

[1] V. K. Sharma, V. Kumar, R. S. Joshi, Investigation of rare earth particulate on tribological and mechanical properties of Al-6061 alloy composites for aerospace application, Journal of Materials Research and Technology 8 (2019) 3504–3516. https://doi.org/10.1016/j.jmrt.2019.06.025

[2] H. R. Ezatpour, M. H. Sabzevar, Y. Huang, Investigation of microstructure and mechanical properties of Al6061-nanocomposite fabricated by stir casting, Materials & Design 55 (2014) 921–928. https://doi.org/10.1016/j.matdes.2013.10.060

[3] H. Zhang, C. Xu, W. Xiao, K. Ameyama, C. Ma, Enhanced mechanical properties of Al5083 alloy with graphene nanoplates prepared by ball milling and hot extrusion, Materials Science and Engineering: A 658 (2016) 8–15. https://doi.org/10.1016/j.msea.2016.01.076

[4] A. Sanaty-Zadeh, Comparison between current models for the strength of particulate reinforced metal matrix nanocomposites with emphasis on consideration of Hall-Petch effect, Materials Science and Engineering: A 531 (2012) 112–118. https://doi.org/10.1016/j.msea.2011.10.043

[5] S. Sendhil Kumar, S. Dharani Kumar, U. Magarajan, Investigation of mechanical and wear behaviour of graphene reinforced aluminium alloy 6061 metal matrix composite, Kovove Mater. 58 (2020) 341–349. https://doi.org/10.4149/km_2020_5_341

[6] Smart, D. S. Robinson, J. Pradeep Kumar, R. Sanjit Cyrus, Development and investigations of Al5083/CNT/Ni/MoS2 metal matrix composite for offshore applications, Materials Today: Proceedings 19 (2019) 682–685. https://doi.org/10.1016/j.matpr.2019.07.753

[7] Q. Zhao, Y. Liang, Z. Zhang, X. Li, L. Ren, Microstructure and dry-sliding wear behavior of B4C ceramic particulate reinforced Al 5083 matrix composite, Metals 6 (2016) 227. https://doi.org/10.3390/met6090227

[8] R. Singh, M. Shadab, A. Dash, R. N. Rai, Characterization of dry sliding wear mechanisms of AA5083/B4C metal matrix composite, Journal of the Brazilian Society of Mechanical Sciences and Engineering 41 (2019) 98. https://doi.org/10.1007/s40430-019-1593-2

[9] S. Khamsuk, C. Nakvachiratrakul, N. Chomsaeng, Fabrication and characterization of Al5083-2 wt.% SiO2 composite and its aging behaviour, AIP Conference Proceedings 2279 (2020) 1–2. https://doi.org/10.1063/5.0022966

[10] S. Gargatte, R.R. Upadhye, V. S. Dandagi, S. R. Desai, B. S. Waghamode, Preparation & characterization of Al-5083 alloy composites, Journal of Minerals and Materials Characterization and Engineering 8 (2013) 8–14. https://doi.org/10.4236/jmmce.2013.11002

[11] H. G. Prashantha Kumar, M. A. Xavior, Effect of graphene addition and tribological performance of Al6061/graphene flake composite, Tribol. Mater. Surf. Interfaces 11 (2017) 1–10. https://doi.org/10.1080/17515831.2017.1329920

[12] A. Baradeswaran, A. E. Perumal, Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites, Composites Part B: Engineering 56 (2014) 464–471. https://doi.org/10.1016/j.compositesb.2013.08.013

[13] P. Shao, W. Yang, Q. Zhang, Q. Meng, X. Tan, Z. Xiu, J. Qiao, Z. Yu, G. Wu, Microstructure and tensile properties of 5083 Al matrix composites reinforced with graphene oxide and graphene nanoplates prepared by pressure infiltration method, Composites Part A: Applied Science and Manufacturing 109 (2018) 151–162. https://doi.org/10.1016/j.compositesa.2018.03.009

[14] S. Bathula, R. C. Anandani, A. Dhar, A. K. Srivastava, Microstructural features and mechanical properties of Al 5083/SiCp metal matrix nanocomposites produced by high energy ball milling and spark plasma sintering, Materials Science and Engineering: A 545 (2012) 97–102. https://doi.org/10.1016/j.msea.2012.02.095

[15] J. Lapin, A. Klimová, Z. Gabalcová, T. Pelachová, O. Bajana, M. Štamborská, Microstructure and mechanical properties of cast in-situ TiAl matrix composites reinforced with (Ti, Nb)2AlC particle, Material and Design 133 (2017) 404–415. https://doi.org/10.1016/j.matdes.2017.08.012

[16] A. Klimová, J. Lapin, Effect of Al content on microstructure of Ti-Al-Nb-C-Mo composites reinforced with carbide particles, Kovove Mater. 57 (2019) 377–387. https://doi.org/10.4149/km_2019_6_377

[17] J. Lin, L. Wang, G. Chen, Modification of graphene platelets and their tribological properties as a lubricant additive, Tribol. Lett. 41 (2011) 209–215. https://doi.org/10.1007/s11249-010-9702-5

[18] W. M. Tian, S. M. Li, B. Wang, X. Chen, J. H. Liu, M. Yu, Graphene-reinforced aluminum matrix composites prepared by spark plasma sintering, International Journal of Minerals, Metallurgy, and Materials 23 (2016) 723–729. https://doi.org/10.1007/s12613-016-1286-0