Research Article

Stir casted SiC-Gr/Al6061 hybrid composite tribological and mechanical properties

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Abstract
The improvement in the mechanical properties of composites is always an essential requirement for technological development. In this work, hybrid aluminum matrix composites fabricated using the stir casting technique. Silicon carbide and graphite used as reinforcement to improve the mechanical properties. AMCs produced by adding various volume fraction of SiC (5%, 10% and 15%) whereas fixed volume fraction (10%) of the graphite used in composites. The fabricated AMC samples were tested to determine the tensile strength, hardness and wear rate. The wear rate was determined under the different loads (10 N, 20 N, 30 N and 40 N) and sliding velocities (0.4 m/s, 0.8 m/s, 1.2 m/s and 1.6 m/s). Mechanical properties of fabricated AMCs are evaluated and compared with Al6061 alloy. The results discovered that the tensile strength and hardness increased from 490 to 710 MPa and 65VHN to 85VHN respectively with the addition of silicon carbide and graphite particles. The wear rate also increased with the increase of applied load. However, for sliding velocity it surges till 1.2 m/s then decreased steeply.

Keywords Aluminum matrix composites · Graphite and silicon carbide reinforcement · Stir casting · Wear testing

1 Introduction

Aluminum matrix composites (AMCs) are engineering materials having useful characteristics such as high tensile strength, compressive strength, hardness and stiffness. These materials have better abrasive resistance compared to unreinforced alloys. These materials are being utilized in various structural implementation in several industries such as marine, aerospace, automobile etc. [1, 2]. Al 6061 is most utilized matrix material because of its low density, high strength, low electrical resistance, high corrosion resistance and higher machinable properties. However, lower wear resistance has restricted its application.

The mechanical and tribological characteristics of both particulate and fiber reinforced Al 6061composite have improved significantly in recent years. Abdullah et al. [3] investigated that the tensile strength and hardness of aluminum improved with the increase of SiC particles, but the plasticity and malleability of the composites decrease significantly. Idrisi et al. [4] fabricated AMC reinforced with a different fraction of SiC particles using traditional stir casting and ultrasonic vibration based stir casting process. They observed significant increase in density, tensile strength, hardness and compressive strength of the AMCs developed through ultrasonic stir casting route. The stir casting method allows uniform dispersion of reinforcement to the base material and scattering of the agglomeration and reduces the crack like [5–15] flows which affects the physical and mechanical behavior of the composites. Hassan et al. [16] reported a decrease in hardness with an increase in percentage reinforcement of graphite (Gr) in Al/Gr composites. Akhlaghi et al. [17] fabricated Al 2024 composites by adding

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varying fraction (5% to 20%) of Gr as reinforcement and observed that hardness and fracture toughness of AMCs reduced with addition of Gr content. Baradeswaran et al. [18] have recorded a reduction in tensile stress and hardness with the increase in Gr content of AA7075/Gr composites fabricated by liquid casting technique.

Idrisi et al. [19] used the stir-casting technique for the manufacturing of AMC different fraction of SiC microparticles (5% and 10%) and nanoparticles (1 and 2%). Developed AMCs were used to fabricate gears and tested using a unique wear test machine at different applied load and operating time The AMC reinforced with two percent nanoparticles has shown highest wear resistance. Baradeswaran et al. [20] developed Al 7075/Al2O3 composite through liquid metallurgy route and added Gr particles to observe its influence on the wear properties of composite. They reported that Gr reinforced composites had higher wear resistance than Al 7075/Al2O3 composites. Suresh et al. [21–25] investigated the impact of Gr particles on the mechanical behavior of Al6061/TiB2 composites, produced by high energy stir casting technique. The mechanical properties such as tensile strength, hardness and elongation percentage of hybrid composite improved compared to the Al6061 alloy and Al6061/TiB2 composites. Kumar et al. [26] analyzed wear properties of Al7075/(SiC + Gr) composite developed using stir casting method and observed that Gr as a primary reinforcement improved the wear-resistance of the Al7075 alloy and it further improved by adding SiC as a second reinforcement. Ravindran et al. [27] have studied the wear resistance of the hybrid composites, Al2024/(SiC + Gr), produced by powder metallurgy and have reported substantial enhancement in the wear behavior of both soft (Gr) and hard (SiC) reinforced composite as compared to the Al 2024 alloy. The Al/Gr composites and Al/(SiC + Gr) hybrid composites were fabricated through stir casting technique by Suresha et al. [28]. They observed that the hardness of Al/Gr composite was less as compared to the base metal and reduced with adding the fraction of Gr reinforcement. On the other side, the hardness of Al/(SiC + Gr) composites were more compared to Al/Gr composites and base metal.

It is evident from the literature that the main focus has been on the mechanical properties of Gr and SiC reinforced composite using different alloys but minimal research available on the Gr/SiC hybrid composites. It observed that limited literatures are available in which Al 6061 alloy has been used as a base material in the fabrication of Gr/SiC composites. This point has provided a motivation for the current work. The weld-ability and formability of Al6061 alloy make it suitable for many general-purpose applications. Its high strength and corrosion resistance lend type 6061 alloy particularly useful in architectural, structural, and automobile applications. In this work, Al 6061 Gr/SiC hybrid composites fabricated using stir casting technique. The tensile strength and hardness of the fabricated composite was determined. Furthermore, the effect of applied load and sliding velocity on wear rate of Al–SiC–Gr hybrid composites was analyzed.

2 Material and methods

2.1 Materials

In this study, Al 6061 alloy used and matrix material, whereas SiC (average particle size: 40 μm) and graphite (average particle size: 75 μm) particles employed as reinforcement material for the preparation of composites. Commercially available Al 6061 alloy was procured from Miser Aluminum company, Egypt, in the form of ingots. AMCs produced by adding various volume fraction of SiC (5%, 10% and 15%) whereas fixed volume fraction (10%) of the graphite used in composites. Both the reinforcements were purchased from Sigma-Aldrich. Specimens machined to the cylindrical shape of diameter 20 mm and thickness of 10 mm. The chemical composition of matrix material is as shown in Table1. The properties of matrix and reinforcing materials used in the study, as shown in Table 2.

2.2 Preparation of composites

In the first step, the pressurized air infiltration (PAI) technique utilized to prepare MMC using the capsule. A mixture of pre-weighted graphite and alcohol was used to coat the inner surface of the capsule and then dried in the muffle furnace. The SiC particles were inserted in the capsule after baking in muffle furnace at 600 °C and pieces

Table 2 Properties of matrix and reinforcements

Properties	Aluminum	Silicon carbide	Graphite
Tensile strength (MPa)	185	588.0	110
Density (gm/cm^3)	2.70	3.30	1.92
Modulus of elasticity (GPa)	70	345	4.8
Coefficient of thermal expansion (10–6/°C)	23	4.6	1.8

Table 1 Chemical composition of Al 6061 alloy

Alloy	Si	Cu	Fe	Mg	Mn	Cr	Zn	Ti
6061	0.6	0.28	0.7	0.2	0.15	0.2	0.25	0.15

of the Al 6061 alloy was placed over it. The SiC was baked for the uniform mixing with matrix material as it improves the wettability of the mixture. The capsule was positioned and enclosed in the furnace. The furnace temperature was raised to 720 ± 5 °C and then pressurized air valve was opened for 10 s to push the melt to pass through the powder then air valve was closed. The air was maintained at the pressure of 0.7 MPa. The developed billets were used to calculate the volume fraction of SiC particle. The second phase was to melt a pre-weighed quantity of the alloy into a stainless-steel crucible with an electric resistance furnace at a temperature of 660 °C. A chromel–alumel thermocouple set was used to regulate and measure the temperature inside the crucible. Simultaneously, the temperature of AMC billet fabricated with PAI technique was raised till 660 °C in a separate electric furnace then dipped in the molten alloy and stirred at the speed of 50 rpm for 3 min. Furthermore, the speed increased to 1000 rpm and maintained to create a necessary vortex. The mixture was poured into a steel mold and cooled at room temperature [29–31].

3 Characterization

3.1 Tensile testing

The tensile test specimens were prepared from developed AMCs according to the ASTM E08-8 standard. The prepared specimens are shown in Fig. 1. These specimens were tested at room temperature using MTS machine. Total of 3 specimens were tested and average was taken into consideration for each composite.

3.2 Hardness testing

The Vickers hardness has been measured on the disc specimen. The Vickers hardness tester model VM 50 (Buehler micromet II micro hardness tester) was used to determine the hardness of fabricated composites. These testers strictly conform to IS 1754 and ISO 6507-2. ASTM E10 standard was used to produce hardness specimens. The Vickers hardness of the polished samples was determined using diamond cone indenter with a load of 30 N. Five readings were taken and average considered for the analysis.

3.3 Wear testing

Wear test was carried out using Pin-on-Disc device model POD-WTM shown Fig. 2. It consists of a rotary horizontal steel disc driven by variable speed motor. The test sample was placed in the sample holder that was secure against the rough face to the loading lever. The friction coefficient can be measured through two thin spring steel sheets adhere to strain gauges.

The wear rate depends on the sliding speed, applied load, environmental conditions and material properties. The wear test was conducted at four different applied loads (10 N, 20 N, 30 N and 40 N) and a constant rotational speed of 600 rpm. For obtaining repeatable and reliable wear information, full interaction between the specimen and abrasive disc was assured. The steel disk EN-31 was used with the hardness of 60HRC and pin specimen was designed according to the specifications of ASTM G99-95 with a measurements of 8 mm diameter and 50 mm length.

Fig. 1 The tensile test sample geometry

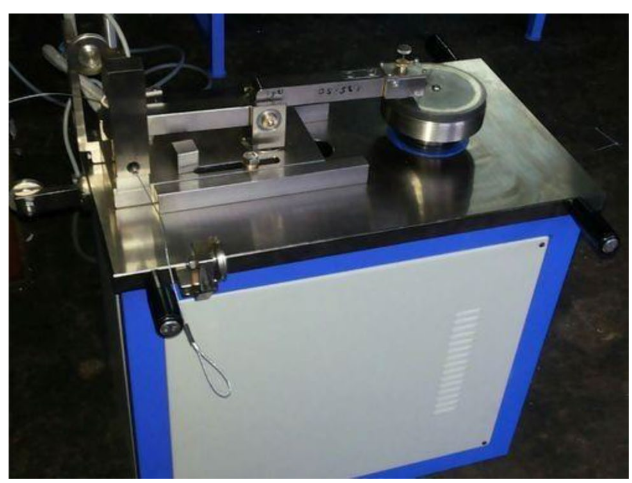


Fig. 2 Pin-on-disc wear tester

4 Result and discussion

4.1 Tensile strength

In Fig. 3 shows the stress–strain curve variation of the developed composites with different volume fraction of reinforcement. It represents that the tensile strength of the SiC/Gr reinforced composite is improved as compared to the Al 6061 alloy. The tensile strength of Al 6061 with 10 vol% SiC + 10 vol% Gr hybrid reinforced composite is higher as compared to Al 6061 with 5 vol% SiC + 10 vol% Gr reinforcement. AMC with 15 vol% SiCp particles and 10 vol% Gr found to be the strongest among all fabricated composites. The tensile strength of the composites improved with the increase of reinforcement fraction. An improvement of 50% in the tensile strength was achieved in AMC with 15 vol% SiC + 10 vol% Gr reinforcement compared to the base material. It is due to the fact that Gr and SiC reinforcement exhibits a decent bonding with Al 6061 alloy which helps in enduring more load as compared to Al 6061 alloy. The surge in tensile strength in AMCs can be ascribed to grain refining, increased dislocation density close to the matrix reinforcement interface, and transfer of tensile force to the strongly bonded SiC and Gr reinforced particles in the aluminum matrix [32, 33]. The tensile strength improvement may be caused by the tight packing of the reinforcement within the matrix phase. The performance of AMCs considerably subjected to the interface properties of the base material and the reinforcements, the interfacial properties further depend on the wettability between the matrix and reinforcements in the fabrication process [34, 35]. Strong bonding between the base material and reinforcements supports an enhancement in the tensile strength of the composites [36–45].

4.2 Macro hardness

The surface hardness of the AMC is measured as one of the most significant factors which affects the wear rate of the composites. Figure 4 shows the effect of reinforcement on the hardness of AMC and it increased with the addition of SiC and Gr particles. The SiC/Gr reinforcement composites found to be harder as compared to the Al 6061 alloy. The hardness of Al 6061 with 10 vol% SiC + 10 vol% Gr hybrid reinforced composite was higher as compared to Al 6061 with 5 vol% SiC + 10 vol% Gr reinforcement. AMC with 15% SiC and 10 vol% Gr particles have the highest hardness among all fabricated composites. It is known that the yield stress is the minimum stress required to make dislocations move. If the material is brittle with no yielding due to the incorporation of brittle silicon carbide and graphite (which are very brittle) in the aluminum, this will act as a barrier for dislocation formation which will take place under the flow stress after yielding [46–50]. These particles protect matrix material from slides cutting, deformation and penetration on the surface of AMCs.

4.3 Wear properties

The wear test was performed on cylindrical pin specimens against a rotating steel disc. The electronic sensors were installed in wear test machine for monitoring the tangential friction force and wear rate. The wear rate was determined based on two variables: applied load and sliding velocity.

The wear test was conducted at 10 N, 20 N, 30 N and 40 N nominal load and rotational speed of 600 rpm

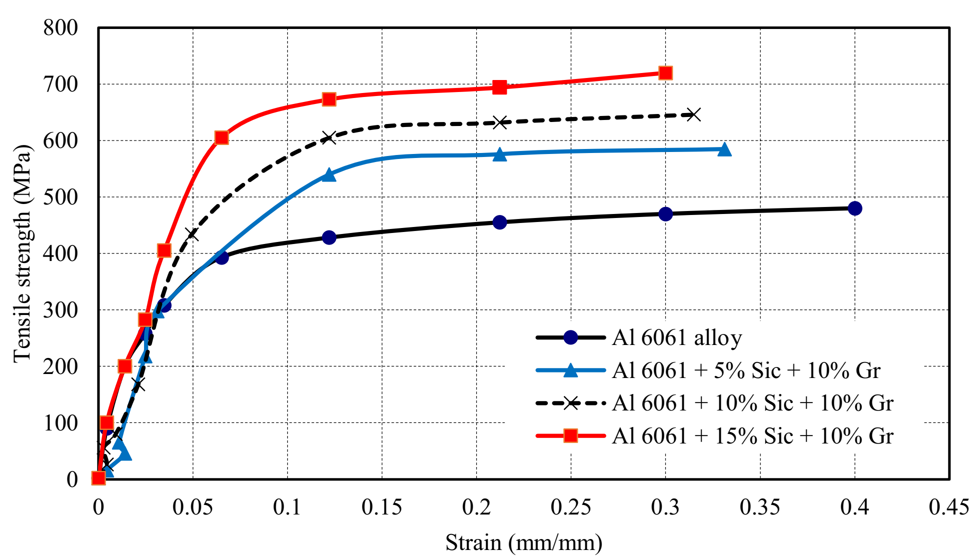


Fig. 3 Stress–strain curve of Al 6061 alloy and composite with varying reinforcement fraction

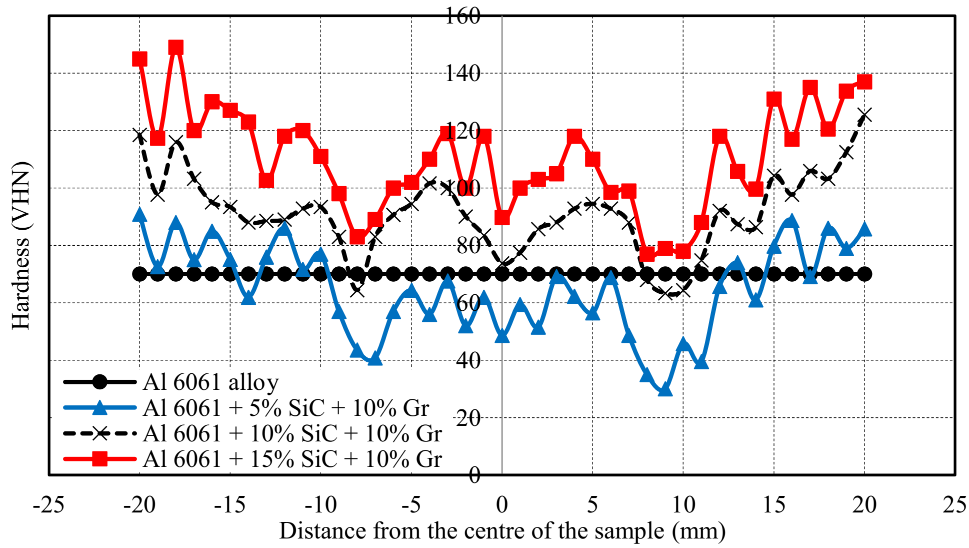


Fig. 4 Effect of reinforcement on the hardness of AMC

as shown in Fig. 5. It was observed that the wear rate increased with increase in the applied load. Idrisi et al. [51] and Miyajima et al. [52] also detected the similar linear trend. In addition, the wear resistance of the unreinforced alloy was determined to be lower than the reinforced AMC with the increase of applied load. The wear resistance of Al 6061 with 10% SiC + 10% Gr hybrid reinforced composite was higher as compared to Al 6061 with 5 vol% SiC + 10 vol% Gr reinforcement. AMC with 15 vol% SiC and 10 vol% Gr particles found to have the largest wear resistance among all fabricated composites. The wear rate reduced by 62.5% at 10 N and 55% at 40 N of applied load for the AMC with 15 vol% SiC + 10 vol% Gr compared to the unreinforced alloy.

Figure 6 shows variation in the wear rate of Al 6061 alloy and Al 6061 alloy composites at different sliding velocity (0.4, 0.6, 0.8, 1, 1.2 and 1.6 m/s) at constant load condition of 40 N. The wear rate was higher in Al 60,061 alloy as compared to developed AMCs at all sliding velocities. It was observed that the wear rate of Al 6061 alloy increased linearly from 7×10^{-3} mm^3/m to 8×10^{-3} mm^3/s at the sliding velocity of 0.4 m/s to 1.2 m/s respectively then wear rate increased steeply to 13×10^{-3} mm^3/m at the sliding velocity of 1.6 m/s. An opposite trend was observed for the AMCs. The wear rate increased linearly up to the sliding velocity of 1.2 m/s and then it decreased steeply at higher sliding velocity. The wear rate increase by 63% from 0.4 to 1.6 m/s for AMC with 5 vo l%SiC + 10 vol% Gr

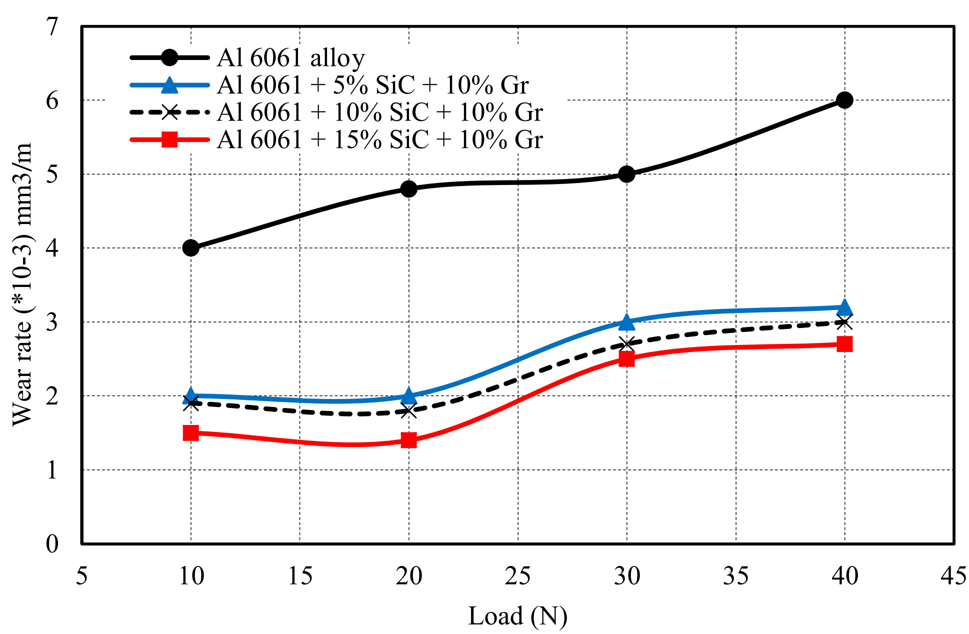
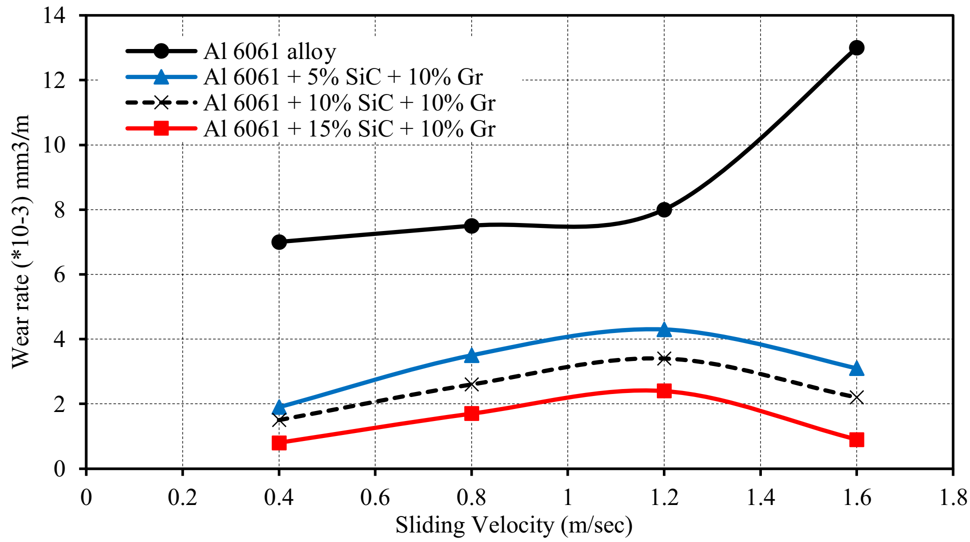


Fig. 5 Effect of load on the wear rate of Al 6061 alloy and composites

Fig. 6 Effect of sliding velocity on the wear rate of Al 6061 alloy and composites



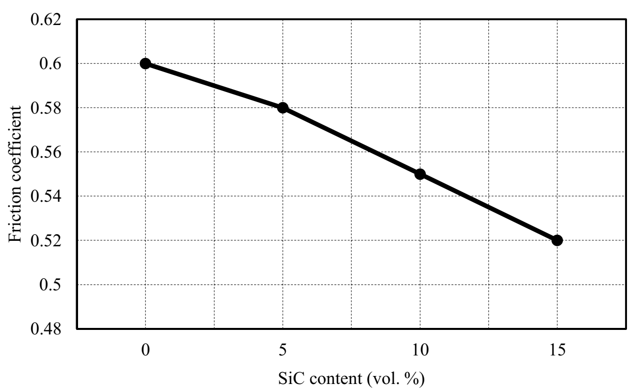


Fig. 7 Effect of SiC vol% on the friction coefficient of Al 6061 alloy and composites

whereas it was only 10% for AMC with 15 vo l%SiC + 10 vol% Gr reinforced particles. The decrease in wear rate with increasing sliding speed could be due to the transformation of thermodynamically meta-stable structure of the carbon bonds and graphite-like structure. Such decrease might also occur at the real contact area where flash temperatures are high. This transformation can facilitate the development of a lubricating tribofilm and reduce wear of the surface [53]. The wear rate decreased with increase in volume fraction of the reinforcement could be due to the presence of graphite in the hybrid composites which is a solid lubricant will lead to reduction in wear rates at higher sliding velocity. Furthermore, SiC particles act as obstacles during the relative motion of the surfaces and oppose the wear of matrix phase.

Figure 7 shows effect of SiC vol% on the friction coefficient of developed AMCs. It indicates the reduction in the coefficient of friction with increase of SiC vol%. The friction coefficient reduced from 0.6 to 0.52 for Al 6061 alloy to the AMC with 15 vol% of SiC. The friction coefficient for AMC with 5 vol% and 10 vol% was observed to be 0.58 and 0.55 respectively.

Figure 8 shows variation in the wear rate of Al 6061 alloy and Al 6061 alloy composites at different sliding distance (250, 500, 750 and 1000 m). The wear rate was higher in Al 60061 alloy as compared to developed AMCs at all sliding distances. It was observed that the wear rate of Al 6061 alloy increased linearly from 3.1×10^{-3} mm^3/m to 7.9×10^{-3} mm^3/s at the sliding distance of 250 m to 1000 m respectively. The wear rate decreased by 45% and 83% at 250 m sliding distance for AMC with 5 vol%SiC + 10 vol% Gr and AMC with 15 vol%SiC + 10 vol% Gr respectively as compared to Al 6061 alloy whereas it was 49% and 69% at 1000 m sliding distance respectively. These results are in line with the trends reported by other investigators [54, 55].

5 Conclusion

AMCs reinforced with silicon carbide and graphite particles have been successfully developed via stir casting process. Following significant conclusions were drawn:

1. The tensile strength has improved by 50% for AMC with 15 vol%SiC + 10 vol%Gr particles as compared to the Al 6061 alloy.
2. The hardness of Al 6061 alloy increased from 65 to 85 VHN by the addition of 15 vol% SiC + 10 vol% Gr particles.
3. Wear resistance of developed AMCs improved with the addition of SiC and Gr particle.
4. It was observed that the wear rate for Al 6061 alloy increased linearly upto the sliding velocity 1.2 m/s

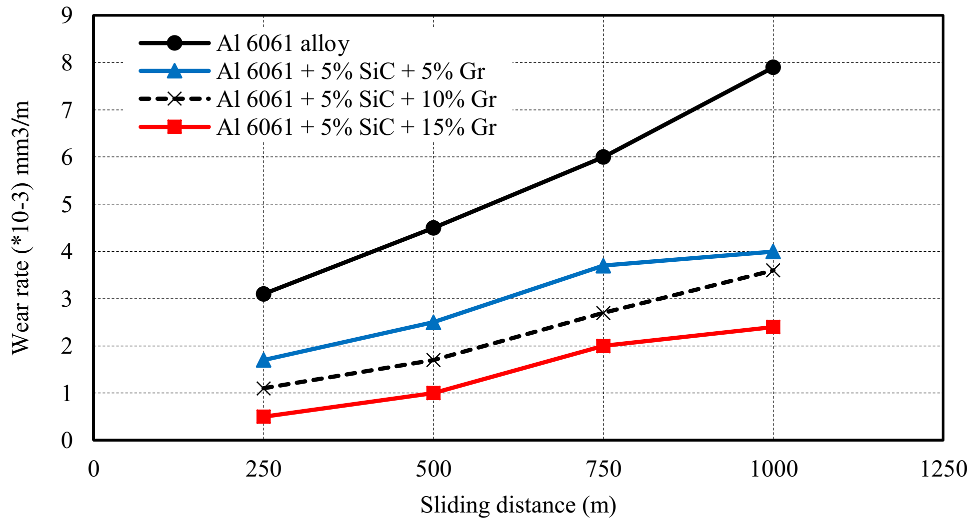


Fig. 8 Effect of sliding distance on the wear rate of Al 6061 alloy and composites

then increased steeply up to 1.6 m/s whereas the opposite trend was observed for AMCs in which the wear rate increased linearly up to the sliding velocity of 1.2 m/s and then it decreased steeply at a higher sliding velocity

Compliance with ethical standards

Conflict of interest On behalf of all authors, the corresponding author states that there is no conflict of interest.

References

1. Bodunrin MO, Alaneme KK, Chown LH (2015) Aluminium matrix hybrid composites: a review of reinforcement philosophies; mechanical, corrosion and tribological characteristics. J Mater Res Technol 4:434–445
2. Idrisi AH, Roy S (2014) Modelling and analysis of aluminium alloy composite connecting rod. Int J Eng 3:3
3. Abdullah Y, Daud AR, Shamsudin R, Harun MB (2009) Flexural strength and fracture studies of Al-Si/sicp composites. Int J Mech Mater Eng 4:109–114
4. Idrisi AH, Mourad A-HI (2019) Conventional stir casting versus ultrasonic assisted stir casting process: mechanical and physical characteristics of AMCs. J Alloys Compd 805:502
5. Aljoboury AI, Mourad A-H, Alawar A et al (2010) Stress corrosion cracking of stainless steels recommended for building brine recirculation pumps. Eng Fail Anal 17:1337–1344
6. Alzafin YA, Mourad A-H, Zour MA, Abuzeid OA (2009) Stress corrosion cracking of Ni-resist ductile iron used in manufacturing brine circulating pumps of desalination plants. Eng Fail Anal 16:733–739
7. Maiti SK, Namdeo S, Mourad AHI (2008) A scheme for finite element analysis of mode I and mixed mode stable crack growth and a case study with AISI 4340 steel. Nucl Eng Des 238:787–800
8. Mourad A, Maiti SK (1995) Mode I and mixed-mode stable crack extensions through stiffened three-point bend specimens. Fatigue Fract Eng Mater Struct 18:645–652
9. Mourad A-H, Maiti SK (1995) Influence of state of stress on mixed mode stable crack growth through D16AT aluminium alloy. Int J Fract 72:241–258
10. El-Sayed M, El Domiaty A, Mourad AHI (2015) Fracture assessment of axial crack in steel pipe under internal pressure. Procedia Eng 130:1273–1287
11. Mourad A-HI (2005) Effect of stress state on mode II stable crack extension. In: Key engineering materials. Trans Tech Publications, vol 297–300, pp 1604–1610
12. Maiti SK, Mourad A-H (1995) Criterion for mixed mode stable crack growth—II. Compact tension geometry with and without stiffener. Eng Fract Mech 52:349–378
13. Maiti SK, Mourad A-H (1995) Criterion for mixed mode stable crack growth—I. Three point bend geometry. Eng Fract Mech 52:321–347
14. Maiti SK, Kishore GK, Mourad A-H (2008) Bilinear CTOD/CTOA scheme for characterisation of large range mode I and mixed mode stable crack growth through AISI 4340 steel. Nucl Eng Des 238:3175–3185
15. Thekkuden DT, Christy JV, Mourad A-HI, Idrisi AH (2018) Assessment of weld quality using control chart and frequency domain analysis. In: American Society of Mechanical Engineers, Pressure Vessels and Piping Division (Publication) PVP
16. Hassan AM, Tashtoush GM, Al-Khalil JA (2007) Effect of graphite and/or silicon carbide particles addition on the hardness and surface roughness of Al-4 wt% Mg alloy. J Compos Mater 41:453–465
17. Akhlaghi F, Zare-Bidaki A (2009) Influence of graphite content on the dry sliding and oil impregnated sliding wear behavior of Al 2024—graphite composites produced by in situ powder metallurgy method. Wear 266:37–45
18. Baradeswaran A, Perumal AE (2014) Wear and mechanical characteristics of Al 7075/graphite composites. Composites B 56:472–476
19. Idrisi AH, Mourad A-HI (2017) Fabrication and wear analysis of aluminium matrix composite reinforced by sic micro and nano particles. In: ASME 2017 pressure vessels and piping conference. American Society of Mechanical Engineers, pp V06AT06A033–V06AT06A033

20. Baradeswaran A, Perumal AE (2014) Study on mechanical and wear properties of Al 7075/Al2O3/graphite hybrid composites. Composites B 56:464–471
21. Suresh S, Moorthi NSV, Vettivel SC et al (2014) Effect of graphite addition on mechanical behavior of Al6061/TiB2 hybrid composite using acoustic emission. Mater Sci Eng A 612:16–27
22. Manivannan I, Ranganathan S, Gopalakannan S, Suresh S (2018) Mechanical properties and tribological behavior of Al6061–SiC–Gr self-lubricating hybrid nanocomposites. Trans Indian Inst Met 71:1897–1911
23. Manivannan I, Ranganathan S, Gopalakannan S et al (2017) Tribological and surface behavior of silicon carbide reinforced aluminum matrix nanocomposite. Surf Interfaces 8:127–136
24. Esakkiraj ES, Suresh S, Moorthi N et al (2014) Study of mechanical behaviour of stir cast aluminium based composite reinforced with mechanically ball milled TiB2 nano particles. In: Diaz PM, Palanikumar K, Kumar PR (eds) Advanced materials research. Trans Tech Publ, Zurich, pp 410–415
25. Suresh S, Moorthi NSV, Vettivel SC, Selvakumar N (2014) Mechanical behavior and wear prediction of stir cast Al–TiB2 composites using response surface methodology. Mater Des 59:383–396
26. Kumar R, Dhiman S (2013) A study of sliding wear behaviors of Al-7075 alloy and Al-7075 hybrid composite by response surface methodology analysis. Mater Des 50:351–359
27. Ravindran P, Manisekar K, Rathika P, Narayanasamy P (2013) Tribological properties of powder metallurgy—processed aluminium self lubricating hybrid composites with SiC additions. Mater Des 45:561–570
28. Suresha S, Sridhara BK (2010) Effect of silicon carbide particulates on wear resistance of graphitic aluminium matrix composites. Mater Des 31:4470–4477
29. Idrisi AH, Deva S (2014) Development and testing of metal matrix composite by reinforcement of SiC particles on Al 5XXX series alloy. Int J Sci Res Eng Technol 3:697–704
30. Edition MHD (1998) Aluminum and aluminum alloys, chemical compositions and international designations. In: Davis JR (ed) ASM International, pp 426–430
31. Idrisi AH, Singh VD, Saxena V (2014) Development and testing of Al5083 alloy reinforced by SiC particles. Int J Sci Res Eng Technol 2:697
32. Karthigeyan R, Ranganath G, Sankaranarayanan S (2012) Mechanical properties and microstructure studies of aluminium (7075) alloy matrix composite reinforced with short basalt fibre. Eur J Sci Res 68:606–615
33. Madhu Kumar YC, Shankar U (2012) Evaluation of mechanical properties of aluminum alloy 6061-glass particulates reinforced metal matrix composites. Int J Mod Eng Res 2:3207–3209
34. Pai BC, Ramani G, Pillai RM, Satyanarayana KG (1995) Role of magnesium in cast aluminium alloy matrix composites. J Mater Sci 30:1903–1911
35. Kondoh K, Kawakami M, Imai H et al (2010) Wettability of pure Ti by molten pure Mg droplets. Acta Mater 58:606–614
36. Yousef BF, Mourad A-HI, Hilal-Alnaqbi A (2013) Modeling of the mechanical behavior of polyethylene/polypropylene blends using artificial neural networks. Int J Adv Manuf Technol 64:601–611
37. Yousef BF, Mourad A-HI, Hilal-Alnaqbi A (2011) Prediction of the mechanical properties of PE/PP blends using artificial neural networks. Procedia Eng 10:2713–2718
38. Tekmen C, Cocen U (2003) The effect of Si and Mg on age hardening behavior of Al-SiCp composites. J Compos Mater 37:1791–1800
39. Sabry I, Mourad A-HI, Thekkuden DT (2020) Optimization of metal inert gas-welded aluminium 6061 pipe parameters using analysis of variance and grey relational analysis. SN Appl Sci 2:175
40. Mourad A-HI, Abu-Assi A (2007) Characterisation of ductile crack growth behaviour through a novel normalised P-ΔLL master curve. In: ASME 2007 pressure vessels and piping conference. American Society of Mechanical Engineers Digital Collection, pp 75–84
41. Arunachalam R, Piya S, Krishnan PK et al (2019) Optimization of stir–squeeze casting parameters for production of metal matrix composites using a hybrid analytical hierarchy process—Taguchi-Grey approach. Eng Optim. https://doi.org/10.1080/0305215X.2019.1639693
42. Idrisi AH, Ismail Mourad A-H, Abdel-Magid B, et al Impact of the harsh environment on E-glass epoxy composite. In: ASME 2019 pressure vessels & piping conference. American Society of Mechanical Engineers Digital Collection
43. Idrisi AH, Mourad A-HI (2019) Impact of the harsh environment on GFRE and GFRPol composite. In: OCEANS 2019 MTS/IEEE SEATTLE. IEEE, pp 1–5
44. Mourad A-HI, Idrisi AH, Wrage MC, Abdel-Magid BM (2019) Long-term durability of thermoset composites in seawater environment. Compos Part B Eng 168:243–253. https://doi.org/10.1016/j.compositesb.2018.12.076
45. Mourad A-HI, Idrisi AH, Zaaroura N et al (2020) Damage assessment of nanofiller-reinforced woven kevlar KM2plus/epoxy resin laminated composites. Polym Test. https://doi.org/10.1016/j.polymertesting.2020.106501
46. Straffelini G, Bonollo F, Molinari A, Tiziani A (1997) Influence of matrix hardness on the dry sliding behaviour of 20 vol% Al2O3-particulate-reinforced 6061 Al metal matrix composite. Wear 211:192–197
47. Rahimian M, Parvin N, Ehsani N (2010) Investigation of particle size and amount of alumina on microstructure and mechanical properties of Al matrix composite made by powder metallurgy. Mater Sci Eng A 527:1031–1038
48. Kumar S, Balasubramanian V (2008) Developing a mathematical model to evaluate wear rate of AA7075/SiCp powder metallurgy composites. Wear 264:1026–1034
49. Idrisi AH, Mourad AHI (2019) Wear performance analysis of aluminum matrix composites using artificial neural network. In: 2019 advances in science and engineering technology international conferences (ASET). IEEE, pp 1–5
50. Idrisi AH, Mourad A-HI, Thekkuden DT, Christy JV (2018) Wear behavior of AA 5083/SiC nano-particle metal matrix composite: statistical analysis. In: IOP conference series: materials science and engineering. IOP Publishing, p 12087
51. Idrisi AH, Mourad A-HI (2019) Wear performance analysis of aluminum matrix composites and optimization of process parameters using statistical techniques. Metall Mater Trans A 50:5395–5409
52. Miyajima T, Iwai Y (2003) Effects of reinforcements on sliding wear behavior of aluminum matrix composites. Wear 255:606–616
53. Zhang G, Liao H, Li H et al (2006) On dry sliding friction and wear behaviour of PEEK and PEEK/SiC-composite coatings. Wear 260:594–600
54. Stojanovic B, Babic M, Mitrovic S et al (2013) Tribological characteristics of aluminium hybrid composites reinforced with silicon carbide and graphite. A review. J Balk Tribol Assoc 19:83–96
55. Mahdavi S, Akhlaghi F (2011) Effect of SiC content on the processing, compaction behavior, and properties of Al6061/SiC/Gr hybrid composites. J Mater Sci 46:1502–1511