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MECHANICAL AND TRIBOLOGICAL CHARACTERISTICS OF STIR-CASTING Al_2O_3-SiC-Gr/Al6063 HYBRID COMPOSITE

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ABSTRACT
The mechanical characteristics of composite materials play a crucial role in advancing technology. The present investigation employed the stir-casting method to produce hybrid aluminum matrix composites. Silicon carbide and aluminum oxide were selected as reinforcements in order to improve mechanical performance. Aluminum matrix composites (AMCs) were synthesized through the implementation of the stir-casting technique, incorporating varying volume percentages of aluminum oxide (10%, 15%, and 20%) with a consistent volume fraction of silicon carbide (15%) ang 10% graphite(G). The constructed AMCs were subjected to testing in order to evaluate their tensile strength (UTS), hardness (VHN), and wear rate (WR%). The wear rate was quantified across weights (10 N, 15 N, 20 N, and 25 N) and sliding velocities (0.3 m/s, 0.6 m/s, 0.9 m/s, and 1.3 m/s). In this study, a comparison was made between the mechanical characteristics of the manufactured aluminium matrix composites (AMCs) and those of the Al6063 alloy. The work outcomes indicated that the incorporation of silicon carbide and aluminium oxide resulted in a critical reinforcement of both the tensile strength and hardness properties. The tensile strength exhibited a notable rise, rising from an initial value of 590 MPa to a final value of 900 MPa. Similarly, the hardness of the material experienced an upward trend, ascending from an initial measurement of 70VHN to a final measurement of 90VHN. The wear rate exhibited a positive correlation with the magnitude of the applied load. Nevertheless, the variation in sliding velocity yielded distinct consequences. The velocity exhibited a quick increase until it attained a peak value of 0.9 m/s, then undergoing a sharp decline.

KEYWORDS
Aluminium matrix composites, aluminium oxide, and silicon carbide reinforcement, stir casting, wear testing.

INTRODUCTION
AMCs are a class of engineering materials that have advantageous properties like high tensile strength, compressive strength, hardness, and stiffness. The materials exhibit superior resistance to abrasion when compared to alloys that lack

reinforcement. These materials are employed in diverse structural applications across many industries, including marine, aerospace, and automotive sectors, [1, 2]. Aluminum 6063 is widely employed as a matrix material due to its favorable characteristics, including its low density, high strength, low electrical resistance, good corrosion resistance, and superior machinability. Nevertheless, the limited wear resistance (WR) has imposed constraints on its utilization. During the past several years, there has been a notable enhancement in the mechanical and tribological properties of Al 6063 composite, which is reinforced with both particulates and fibers. The study conducted by Shamsudin R. et al., [3].

It has been observed that the inclusion of SiC particles in aluminum leads to enhancements in both tensile strength and hardness. However, this improvement is accompanied by a notable drop in the flexibility and malleability of the resulting composites. Idrisi and colleagues [4].conducted a study in which they produced an AMC reinforced with varying proportions of SiC particles. The fabrication process involved both classic stir casting and a more advanced method known as ultrasonic vibration-based stir casting. A substantial enhancement in density, UTS, VHN, and compressive strength of the AMCs was seen during the utilization of the ultrasonic stir casting method. The stir casting technique enables the homogeneous distribution of reinforcement inside the base material, while also dispersing any agglomerations and minimizing the presence of crack-like flows. These factors have a significant impact on the physical and mechanical properties of the resulting composites, [5-15]. In a work conducted with Tashtoush et al., [16], it was shown that the hardness of Al/Gr composites reduced as the percentage of Gr reinforcement heightened.

In their study, Zare-Bidaki et al., [17] produced aluminum 2024 composites by using different proportions (ranging from 5% to 20%) of Gr as a reinforcing agent. They found that the inclusion of Gr resulted in a decrease in both the hardness and fracture toughness of the AMCs. In their study, Perumal n et al., [18] observed a decrease in UTS and VHN as the Gr content in AA7075/Gr composites produced using liquid casting process increased. In their study, Mao D.et al., [19] employed the stir-casting method to produce AMCs with varying proportions of SiCnp/AMCs. The ductility of the SiCμp/AMCs was kept well, reaching 18 %, and kept the ultimate tensile strength at 200 MPa. In their study, Perumal et al., [20] employed the liquid metal-lurgy technique to fabricate an Al 7075/Al_2O_3 composite. They included Gr particles into the composite to investigate their impact on the composite's wear qualities. According to their findings, it was observed that Gr-reinforced composites exhibited superior WR in comparison to Al 7075/Al_2O_3 composites. The study conducted by Moorthi et al., [21–25] examined the influence of Gr particles on the mechanical properties of Al6061/TiB2 composites, which were fabricated utilizing the high energy stir casting method. The hybrid composite exhibited enhanced mechanical properties, including tensile strength, hardness, and elongation %, in comparison to both the Al6061 alloy and Al6061/TiB2 composites. In their study, Dhiman et al., [26]conducted an analysis on the wear properties of a composite material consisting of Al7075 alloy reinforced with a combination of SiC and Gr. The composite was formed using the stir casting process. The researchers noticed that the inclusion of Gr as a primary reinforcement resulted in enhanced WR of the Al7075 alloy. Furthermore, the WR was further increased when SiC was added as a secondary reinforcement. The WR of hybrid

composites, specifically Al2024/(SiC + Gr), generated using powder metallurgy, was investigated by Manisekar et al., [27]. Their findings indicate a significant improvement in the wear behavior of both the soft (Gr) and hard (SiC) reinforced composites when contrasted to the Al 2024 alloy. The fabrication of Al/Gr composites and Al/(SiC + Gr) hybrid composites was conducted using the stir casting process with Sridhara et al., [28].

In their study, Sabry et al., [29] conducted an analysis of the wear properties of a composite material consisting of Al6061 alloy reinforced with a combination of SiC and Gr. The composite was formed using the stir-casting process. The researchers noticed that the inclusion of Gr and SIc as primary reinforcement resulted in enhanced WR of the Al6061 alloy. Furthermore, the WR was further increased when SiC up to 15 % was added as a secondary reinforcement.

The researchers saw a decrease in the VHN of the Al/Gr composite in comparison to the base metal. Furthermore, the hardness decreased further with the addition of a higher fraction of Gr reinforcement. In contrast, the Al/(SiC + Gr) composites exhibited greater toughness in comparison to the Al/Gr composites and the base metal. The existing body of literature mostly emphasizes the investigation of the mechanical characteristics of composites reinforced with Al_2O_3, Gr, and SiC utilizing various alloys. However, there is a scarcity of study specifically addressing hybrid composites consisting of Al_2O_3, Gr, and SiC. It has been noted that there is a scarcity of literature pertaining to the utilization of Al 6063 alloy as a fundamental material in the production of Al_2O_3/Gr/SiC composites. This particular aspect has served as a driving force for the ongoing research. The Al6063 alloy possesses favorable weldability and formability characteristics, rendering it well-suited for a wide range of general-purpose applications. The type 6063 alloy is highly valued in architectural, structural, and vehicle applications due to its exceptional strength and resistance to corrosion.

In this study, hybrid composites consisting of Al 6063, Al_2O_3, Gr, and SiC were manufactured utilizing the stir casting technique. The UTS and VHN of the composite material that was manufactured were assessed. Additionally, an analysis was conducted to examine the impact of applied load and sliding velocity on the rate of wear in hybrid composites consisting of Al-Al_2O_3, Gr, and SiC.

MATERIALS AND METHODS

Materials

This work utilized the Al 6063 alloy as the matrix material while employing Al_2O_3 (size of 10 µm), SiC (size of 40 µm), and graphite (size of 75 µm) particles as reinforcement materials for the fabrication of composites. The Al 6063 alloy used in this study was obtained from Miser Aluminum Firm Egypt in the form of commercially available ingots. AMCs are fabricated by incorporating different volume fractions of SiC particles, namely 10 %, 15 %, and 20 %. Additionally, a constant volume fraction of 10 % graphite and 15% SiC are utilized in the composite materials. Both reinforcements were obtained from Sigma Aldrich. The specimens were fabricated to exhibit cylindrical morphology, characterized by a diameter of 25 mm and a thickness of 5 mm. Table 1 displays the chemical composition of the matrix

material. Table 2 displays the properties of the matrix and reinforcing materials utilized in the study.

Table 1. shows the chemical makeup of the alloy Al 6063.

Weight (%)	Si	Cu	Fe	Mg	Mn	Cr	Zn	Ti	Si
6063	0.6	0.1	0.35	0.4	0.1	0.1	0.1	0.1	0.6

Table 2. Matrix and Reinforcement Properties

Properties	Aluminum	Aluminum Oxide	Silicon carbide	Graphite
Tensile strength (MPa)	250	240 MPa	588	110
Density (gm/cm3)	2.70	4	3.30	1.92
Modulus of elasticity (GPa)	70	340	345	4.8

Composites preparation

The initial stage involves utilizing the pressurized air infiltration (PAI) technique to create a metal matrix composite (MMC) utilizing a capsule. The interior surface of the capsule was coated with a mixture of pre-weighed graphite and methanol, which was subsequently dried using a muffle furnace. The Al_2O_3 particles were introduced into the capsule following a baking process in a muffle furnace at a temperature of 600 °C. Subsequently, the Al 6063 alloy sections were positioned on top of the particles. The Al_2O_3 was subjected to a baking process to ensure its homogeneous integration with the matrix material, enhancing the resulting mixture's wetting properties. The capsule was strategically placed and securely contained within the furnace. The temperature of the furnace was increased to 720 ± 5 °C, after which the pressured air valve was opened for 8 seconds to facilitate the passage of the molten material during the powder. Subsequently, the air valve was closed. The atmospheric conditions were regulated to a pressure of 0.6 megapascals. The billets that were fabricated were utilized in the determination of the volume fraction of Al_2O_3. In the subsequent stage, a predetermined amount of the alloy was subjected to melting within a stainless-steel crucible, utilizing an electric resistance furnace at 660 °C. The experimental setup involved using a chrome-alumni thermocouple pair to control and monitor the temperature within the crucible. Concurrently, the temperature of the AMC billet, which was manufactured using the PAI process, was elevated to 660 °C in a distinct electric furnace. Subsequently, the billet was immersed in the molten alloy and agitated at a rotational speed of 40 rpm for 3 minutes. Moreover, the rotational speed was elevated to 1200 revolutions per minute (rpm) and sustained to generate a requisite vortex. The mixture was introduced into a steel mold and then cooled to ambient temperature, [29–31].

Testing AND CHARACTRISTICS

Tensile testing

The tensile test samples were fabricated using AMCs following the ASTM E08 8 standard. The specimens that have been prepared are depicted in Figure 1. The

specimens underwent testing at ambient temperature with an MTS machine. Three samples were tested, and each composite's average value was calculated.

Hardness testing

The Vickers hardness of the disc specimen has been determined. The hardness of manufactured composites was assessed using the Vickers hardness tester model MV1PC, specifically the Buehler Micromet II microhardness tester. The testers adhere entirely to the standards set by ISO 6507-2:2018. The ASTM E92 standard was employed in the fabrication of hardness samples. The Vickers hardness of the polished specimen was determined by employing a diamond cone indenter with a force of 30 N. A total of five readings were collected and subsequently averaged for the test.

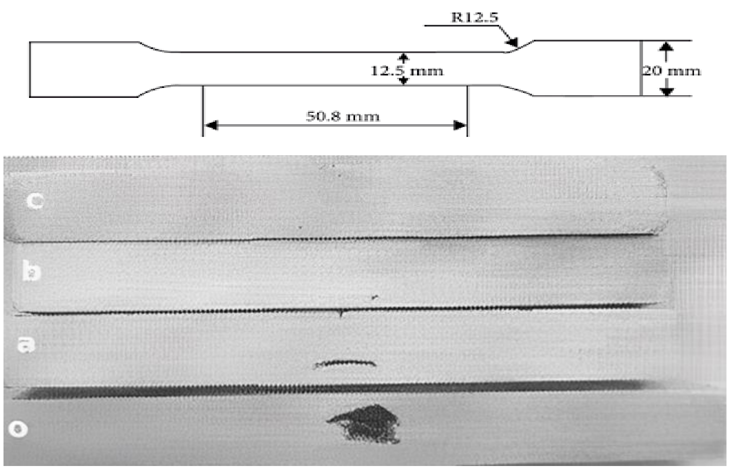

Fig. 1 The geometry of the tensile test sample.

Wear testing

A wear test was conducted with the pin-on-disc device, namely the POD WTM model, as depicted in Figure 2. The apparatus comprises a horizontally oriented steel disc rotated by a motor with adjustable speed. The test sample was positioned within the specimen holder securely fastened onto the coarse surface of the loading lever. The coefficient of friction measurement can be achieved by utilizing two thin spring steel sheets affixed to strain gauges. The wear rate is contingent upon factors such as the velocity of sliding, the magnitude of the applied force, the prevailing climatic conditions, and the material's inherent qualities. The wear test was performed using four distinct utilized loads (5 N, 10 N, 15 N, and 20 N) while maintaining a constant rotating speed of 600 rpm. To ensure consistent and dependable wear data acquisition, measures were taken to ensure complete interaction between the specimen and the abrasive disc. The Mild Steel disk EN 31 was utilized, by a hardness of 599 HRC. The pin sample was developed following the standards outlined in ASTM G99, featuring 6 mm in diameter and 40 mm in length.

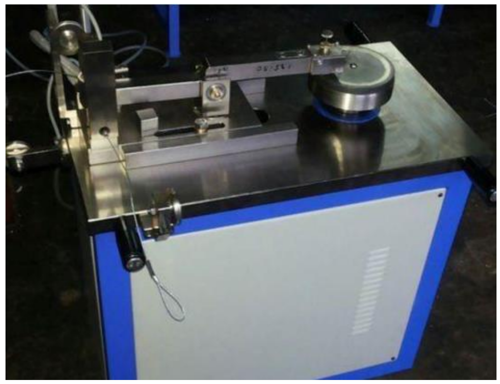

Fig. 2 Wear the tester pin on the disc.

RESULTS AND DISCUSSION

Tensile strength

Figure 3 illustrates the variation of the stress-strain curve for the created composites, which possess varying reinforcing volume fractions. The Al_2O_3/SiC reinforced composite exhibits enhanced tensile strength compared to the Al 6063 alloy. The UTS of the Al 6063 composite, which incorporates a hybrid reinforcement of 10 vol% Al_2O_3 and 15 vol% SiC, exhibits superior performance compared to the Al 6063 composite reinforced with five vol% Al_2O_3 and 15 vol% SiC. The composite material consisting of an AMC with a volume fraction of 20% Al_2O_3 and 15% SiC has been determined to possess the highest strength compared to other composites fabricated. The tensile strength of the composites exhibited enhancement as the reinforcing fraction was increased. A significant enhancement of 50% in the tensile strength was seen in the AMC when reinforced with 20 vol% Al_2O_3 and 15 vol% SiC, compared to the unmodified base material. The enhanced load-bearing capacity of Al 6063 alloy can be attributed to the favorable bonding between SiC and Al_2O_3 reinforcements and the alloy. The increase in tensile strength seen in AMCs can be attributed to several factors, including grain refinement, higher dislocation density near the interface between the matrix and reinforcement, and the transmission of tensile forces to the aluminum matrix through the tightly bound Al_2O_3 and SiC-reinforced particles, [32, 33]. The observed enhancement in UTS can perhaps be attributed to the dense arrangement of the reinforcement material within the matrix phase. The interface properties of both the base material and the reinforcements significantly influence the performance of AMCs. These interfacial qualities, in turn, are contingent upon the wettability between the matrix and reinforcements during the fabrication process, [34, 35]. Establishing a robust link between the base material and reinforcements increases the UTS of composite materials, [36 - 45].

Macroscopic Hardness

The measurement of surface hardness in AMC is considered a crucial component that influences the wear rate in composites. Figure 4 illustrates the impact of reinforcement on the hardness of AMC, wherein the incorporation of Al_2O_3 and SiC particles resulted in a notable increase. The Al_2O_3/SiC reinforcement composites were observed to possess greater VHN than the Al 6063 alloy. The VHN of the Al 6063 composite, which was reinforced with a hybrid combination of 15 vol% Al_2O_3 and 15

vol% SiC, exhibited a greater level of VHN in comparison to the Al 6061 composite, which was reinforced with ten vol% Al_2O_3 and 15 vol. % SiC. The composites manufactured with AMC containing 20% Al_2O_3 and 15 vol. % SiC particles exhibit the highest level of VHN compared to other composites. The concept of yield stress pertains to the minimal stress level necessary to induce dislocation motion. Incorporation of brittle silicon carbide and Aluminum oxide in aluminum renders the material brittle and devoid of yielding. Consequently, the presence of these brittle components hinders the production of dislocations, which typically occur under the flow stress subsequent to yielding, [46]. Including these particles safeguards the matrix material against potential issues such as cutting, deformation, and surface penetration in the context of AMCs.

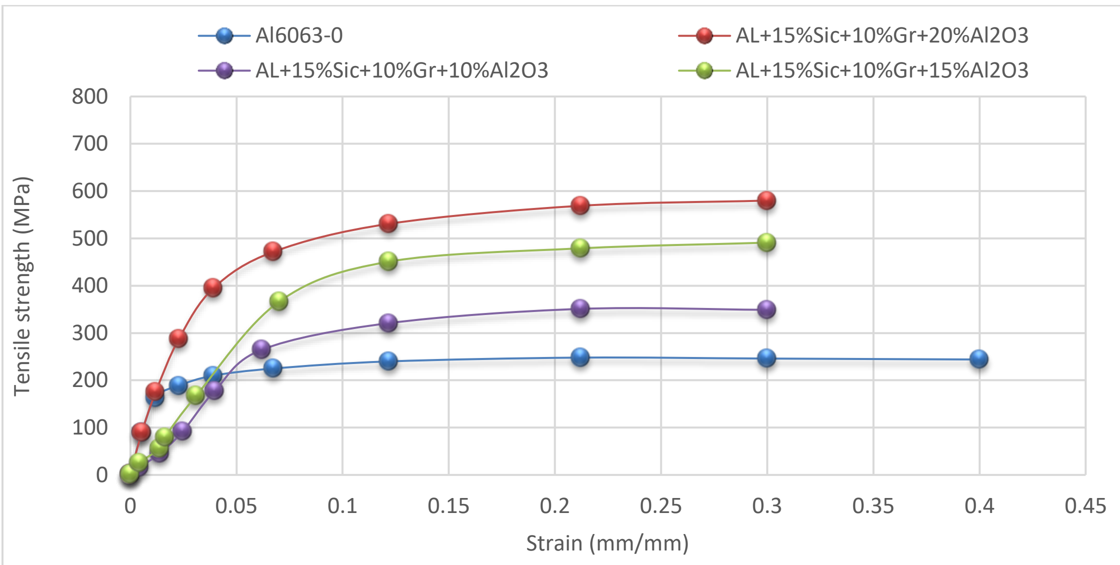

Fig. 3 shows the stress-strain curves for composites and Al 6063 alloys with different reinforcing fractions.

Properties related to wear.

The wear test used cylindrical pin specimens in contact with a rotating steel disc. Electronic sensors were put in a wear test machine to detect the tangential friction force and wear rate. The wear rate was determined by considering two variables: the applied force and the sliding velocity. The wear test was performed at nominal loads of 5 N, 10 N, 15 N, and 20 N, with a rotating speed of 400 rpm. As depicted in Figure 5. An increase in the applied load was associated with an increase in the wear rate. A similar linear trend was also seen by Miyajima et al., [47]. Furthermore, it was observed that the wear resistance of the unreinforced alloy decreased as the applied load increased, in comparison to the reinforced AMC. The wear resistance of the Al 6063 composite, which was reinforced with a hybrid combination of 15 % Al_2O_3 and 15 % SiC, exhibited superior performance compared to the Al 6061 composite, which had a ten-volume Al_2O_3 and 15 % SiC reinforcement.

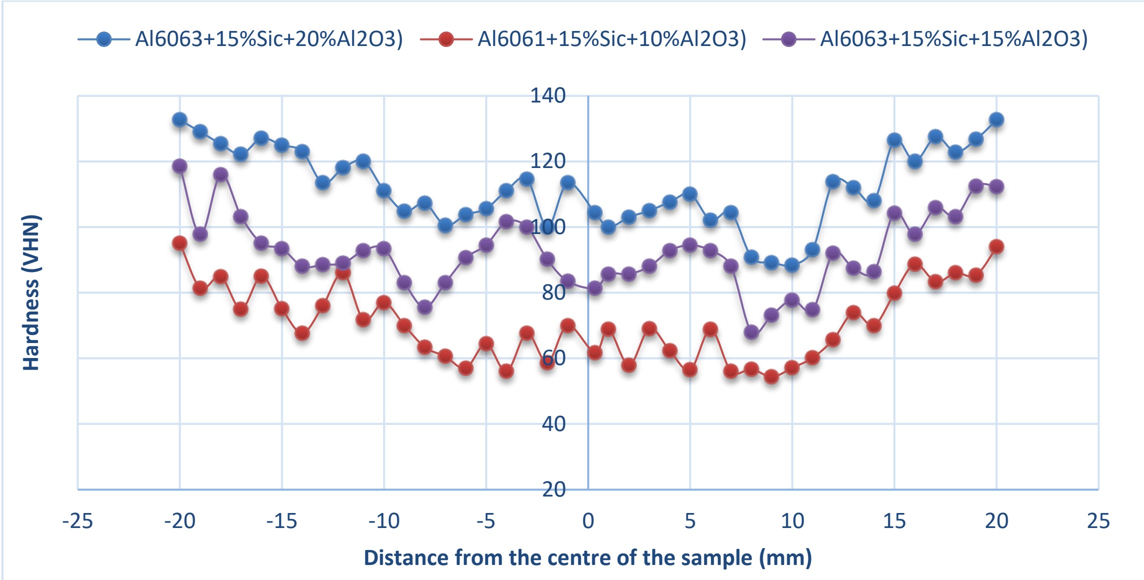

Fig. 4 Impact of reinforcement on the AMC's hardness.

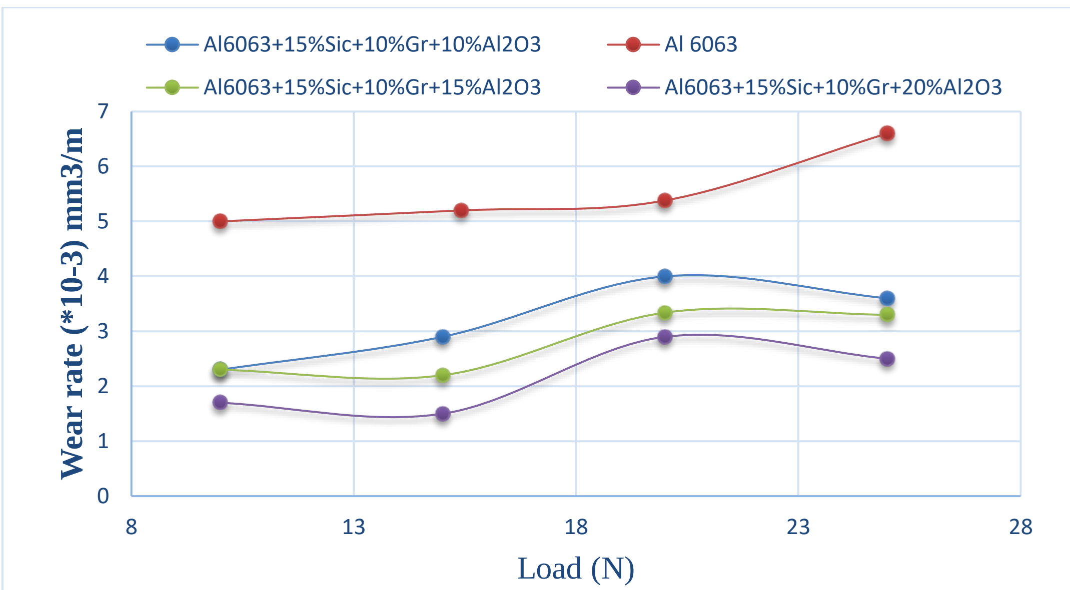

Fig. 5 Load impact on Al 6063 alloy and composite wear rates.

The composite material consisting of an AMC with a volume fraction of 20 % Al_2O_3 and 15 % SiC particles has been determined to exhibit the highest level of wear resistance compared to other composites manufactured. The wear rate of the AMC with 20 vol. % Al_2O_3 + 15 vol. % SiC decreased by 66 % at an applied load of 10 N and by 58.3 % at an applied load of 40 N, compared to the unreinforced alloy.

Figure 6 illustrates the observed fluctuations in the wear rate of Al 6063 alloy and Al 6063 alloy composites across various sliding velocities (0.3, 0.6, 0.9, and 1.2 m/s) under a consistent load condition of 25 N. The wear rate exhibited a more excellent value in the Al 6063 alloy than the produced AMCs across all sliding velocities. The wear rate

of Al 6063 alloy exhibited a linear increase, ranging from 8 × 10^{-3} mm^3/m to 8.4 × 10^{-3} mm^3/s, when the sliding velocity increased from 0.3 m/s to 0.9 m/s, respectively. Subsequently, the wear rate sharply increased to 14 × 10^{-3} mm3/m at a sliding velocity of 1.2 m/s. A contrasting pattern was noted in the case of the AMCs. The wear rate exhibited a linear increase until reaching a sliding velocity of 0.9 m/s, after which it experienced a sharp decline at higher sliding velocities. The wear rate experienced a 66 % rise when the velocity of the AMC increased from 0.3 to 1.2 m/s, with a composition consisting of 20 vol. % Al_2O_3 and 15 vol. % SiC.

In contrast, the percentage of reinforcement particles in the AMC material with 20 volume percent Al_2O_3 and 15 volume percent Gr was just 10 percent. The observed reduction in wear rate as sliding speed increases may be attributed to the transformation of the thermodynamically metastable structure of carbon bonds and the development of a graphite-like structure. A drop of this nature may also manifest at the actual contact area, where elevated flash temperatures are observed. The abovementioned process can potentially enhance the creation of a lubricating tribofilm and mitigate surface wear, as indicated by previous research, [48]. The decrease in wear rate seen with an increase in the reinforcement volume fraction in the hybrid composites may be attributed to the presence of graphite, a solid lubricant. This solid lubricant reduces wear rates, particularly at higher sliding velocities. Moreover, the presence of Al_2O_3 serves as a hindrance during the relative motion of the surfaces, impeding the wear of the matrix phase.

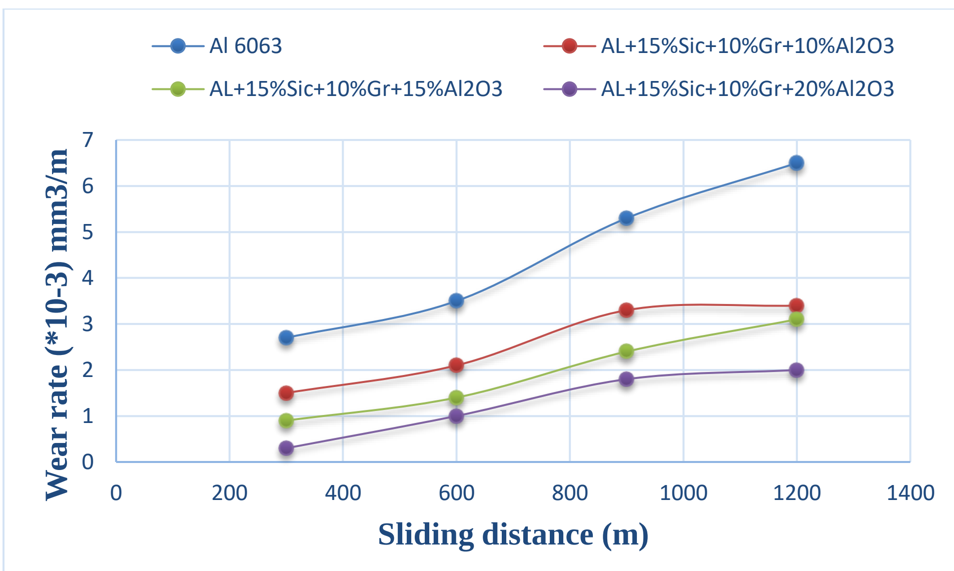

Fig. 6 Sliding velocity impact on the alloy and composites rate of wear.

Figure 7 illustrates the impact of varying Al_2O_3 volume percentages on the friction coefficient of the produced AMCs. This observation suggests a decrease in the coefficient of friction as the volume percentage of Al_2O_3 increases. The friction coefficient of the Al 6063 alloy decreased from 0.6 to 0.52 when the alloy was modified with 20 vol% of Al_2O_3. The observed friction coefficients for AMC with a volume fraction of 10 % and 15 % were 0.58 and 0.55, respectively.

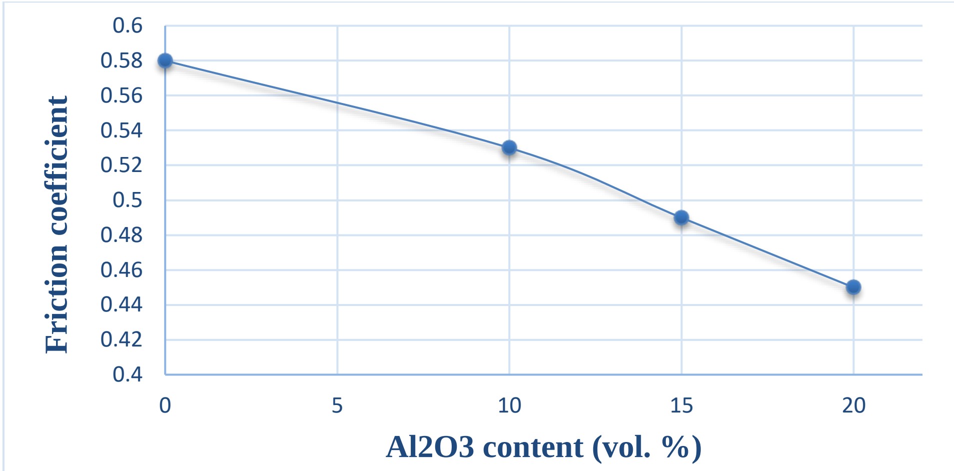

Fig. 7 Al_2O_3 volume percentage effect on Al 6063 alloy and composites' friction coefficient.

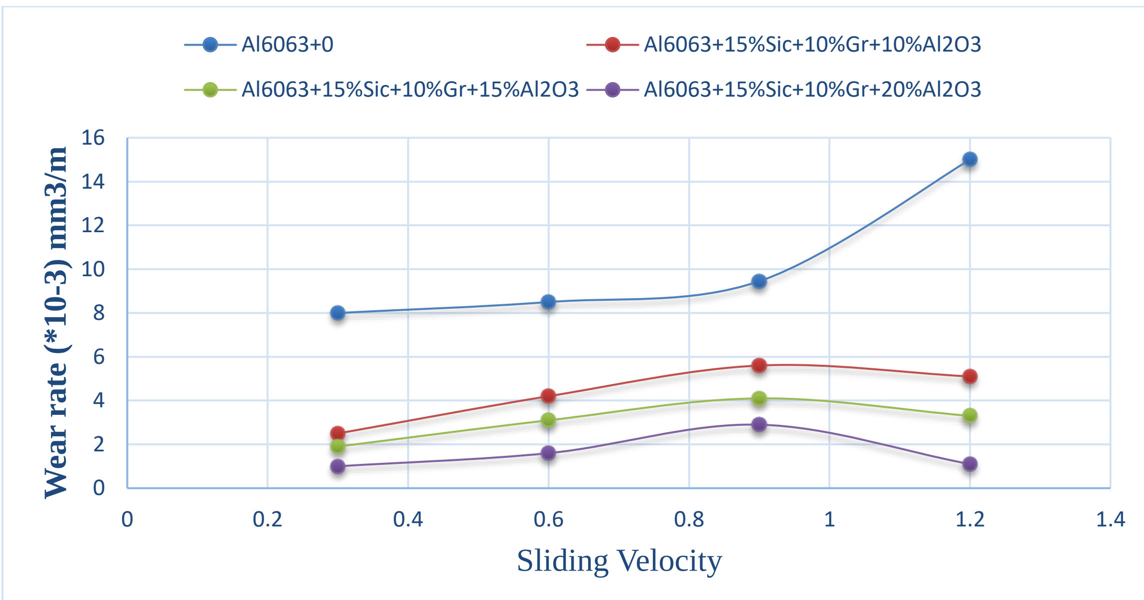

Fig. 8 Sliding distance impact on the alloy and composites wear rate of Al 6063.

Figure 8 illustrates the observed fluctuations in the wear rate of the Al 6063 alloy and the Al 6063 alloy composites across varying sliding distances, namely at 300, 600, 900, and 12000 meters. The wear rate exhibited a more excellent value in the Al 60063 alloy than the produced AMCs across all sliding lengths. The wear rate of Al 6063 alloy exhibited a linear rise, ranging from 2.7 × 10^{-3} mm3/m to 6.5 × 10^{-3} mm^3/s, as the sliding distance progressed from 300 m to 1200 m, respectively. The wear rate showed a reduction of 44 % and 88 % at a sliding distance of 300 m for the AMC containing ten vol% Al_2O_3 + 15 vol. % SiC and the AMC containing 20 vol. % Al_2O_3 + 15 vol. % SiC, respectively, in comparison to the wear rate of the Al 6063 alloy. Similarly, at a sliding distance of 1200 m, the wear rate fell by 47 % and 69.23 % for

the AMCs above. The findings presented are consistent with the patterns seen by previous researchers, [49, 52].

CONCLUSIONS

In conclusion, it can be stated that AMCs, or Aluminum Matrix Composites, have been effectively fabricated using the stir casting method, using reinforcement materials such as aluminum oxide and silicon carbide particles. Several significant findings were derived from the analysis.

1. Adding 20 vol. % Al_2O_3 + 15 vol. % SiC particles to the AMC material has resulted in a 50% increase in its tensile strength compared to the Al 6063 alloy.

2. Incorporating 20 vol. % Al_2O_3 + 15 vol. % SiC particles significantly improved the hardness of Al 6063 alloy, elevating it from 60 to 100 VHN.

3. The wear resistance of the produced AMCs was enhanced by using Al_2O_3 and SiC particles.

4. The study noted that the wear rate of Al 6063 alloy exhibited a linear increase until reaching a sliding velocity of 0.9 m/s, after which it experienced a sharp increase up to 1.2 m/s. Conversely, the wear rate of AMCs displayed a linear increase up to a sliding velocity of 0.9 m/s, followed by a significant decrease at higher sliding velocities.

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