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Feasibility Study on Tribology and Surface Morphology Characterization of Hybrid Composites

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Abstract

Objectives: To investigate the tribological behaviour of aluminium hybrid composites. Aluminium alloy (LM 25) is utilised in the aerospace and defence industries. Its wear properties are further improved to increase the lifespan of the components used in these sectors. Due to their ability to resist wear, graphite and silicon carbide are often used to manufacture machine tools. The objective is to identify the wear parameters of the LM 25 alloy. It was examined after stir-cased and strengthened with silicon carbide and graphite in various weight ratios. **Methods**: The dry sliding wear behaviour for aluminium alloys containing 2, 4, and 6 wt.% silicon carbide and a fixed 2 wt.% graphite is investigated using stir-casting composites. These process parameters included loads of 15, 30, and 45 N, sliding speeds of 0.55, 1.10, and 1.65 m/s, and sliding distances of 333, 666, and 999 m. **Findings:** According to the test results, the overall wear loss of SiC-reinforced hybrid composites was less compared to both unreinforced alloys and Al/Gr composites. The tribological behaviour of a composite consisting of 4% SiC and 2% Gr was significantly improved compared to the base alloy. **Novelty:** The novelty of this study is to induce a brake disc made of an Al alloy with wear-resistant SiC/Gr particle-reinforced aluminium composites committed to its surface. The role of tribology in determining material behaviour is shown to be important in controlling material removal.

Keywords: LM25Al Alloy; Silicon carbide; Graphite; Double stircasing; Wear resistance; Worn surface morphology

1 Introduction

Composite has rapidly been utilized in both aerospace and automobile applications, as it improves wear strength and increases stiffness [(1)]. Aluminum alloys excellent casting qualities, low densities, and higher specific buckling resistance set them apart from competing materials. In recent decades, aluminium alloy composite material strengthened by strong ceramic particulates has developed potential alternatives and usage for a wide range of applications, including connecting rods, pistons, cylinder blocks, and brake drums[2]. Among other aspects, hybrid composites must have improved ductility and strength to suit these applications. Further, introducing a reinforcing particle consisting of silicon carbide with graphite to an aluminium matrix increased strength and wear rate[3]. During the reinforcements, particles are stirred into a liquid processing melt, resulting in less damage and delivering a higher material. This technique integrates the reinforcing particles into the aluminum substrate, resulting in a material with good wettability[4]. Further increasing its temperature decreases extreme wear. It is feasible to identify that the sliding velocity, load, and distance influence the material characteristics used to generate the friction coefficient with wear loss outcome[5]. This research aims to improve the hybrid composites developed from LM25-SiC-Gr in terms of their tribological characteristics and microstructure. As a result, to attain this goal, the material wear resistance is enhanced while the specific wear rate (SWR) and friction coefficient should be decreased.

It is suggested aluminium alloy reinforced with particulates like Al_2O_3, SiC, and BA exhibits improved tensile strength, durability, and tribological properties[6]. According to the investigations, the percentage ratio of reinforcement influences composites' mechanical performance and wear behaviour. The problems associated with attaining homogeneous distribution with minimum porosity in casting are suggested by various methodologies and strategies to overcome manufacturing difficulties[7]. It is prepared LM6/Al2O3/SiC/Graphite hybrid composites by a stir casting process[8]. Under different conditions, the dominant wear behaviour was studied using an EN31 steel disc. At higher load conditions, silicon carbide and graphite particles produce flaking traces and grooves on the wear surface, increasing the wear loss in the composites; the sliding speed and surface temperature of the specimen also increase. An attempt has been made to study the influence of LM25 reinforcing graphite (Gr) with silicon carbide (SiC) on the wear behaviour of hybrid aluminium composites.

From the above literature, it is observed that aluminium is widely used in industrial and bio-medical sectors based on its compatible properties. It is essential to ascertain their mechanical and tribological properties in specific environments, like the wheels and connecting rods. Metallic materials like aluminium (Al) and their alloys are appropriate choices due to their non-toxicity, inertness, and favourable mechanical properties. These experiments are done in a dry sliding environment with a computer-aided pin-on-disk tribometer. Finally, the hybrid composites are examined using scanning electron microscopy and discover composites with subsurface microstructures on worn surfaces.

2 Methodology

2.1 Fabrication for aluminum hybrid composites

For this study, the matrix aluminum LM25 was selected since it offers an excellent combination of strength and wear resistance when subjected to high temperatures and as shown in Table 1. The liquid metallurgy process approach was utilized during the fabrication of the composites. In addition, SiC particulates with a cube structure of 15 μm and a flaked structure of Gr with a size of 9.4 μm were utilized to reinforce particles and are depicted with their SEM micrographs in Figure 1.

Table 1. Physical and Mechanical Properties

Constituent	Properties
Density	2.69 g/cm^3
Electrical Conductivity	39 S/m
Coefficient of Thermal Expansion	23.6 K
Specific gravity	2.68 kg/m^3
Thermal Conductivity	0.36 Wm^{-1}K^{-1}
Freezing Range	615-550 $^\circ$C
Tensile Strength	130-150 MPa
Brinell Hardness	55-65 MPa

Therefore, to execute the experiment, five distinct composites were constructed: LM25AA, LM25-2%Gr, LM25-2%SiC-2%Gr, LM25-4%SiC-2%Gr, and LM25-6%SiC-2%Gr. Based on a literature review, a size of 15 μm as SiC and 9.4 μm as Gr reinforcement particulates was chosen to focus on their potential applications and tribological properties[9]. A double stir-casting process was utilised in this work to fabricate aluminium alloy and aluminium hybrid composites. The reinforcing particulates were initially preheated at 400°C to minimise dampness and increase the wettability of molten LM25AA. The furnace temperature can reach 800 °C with a complete melt into a matrix. Subsequently, liquid Al alloys were cooled into a semi-solid condition at around 605 °C inside the furnace. Moreover, pre-heated reinforcing particles are incorporated at this temperature and stirred manually into the slurry for 10 min.

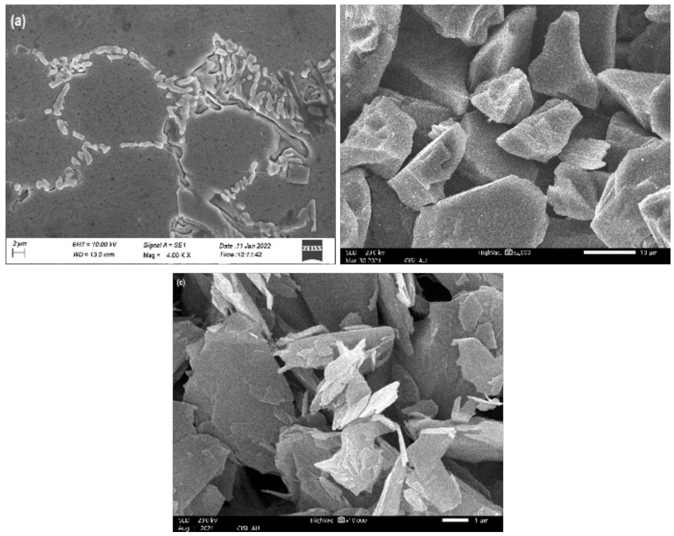

Fig 1. SEM micrographs of received specimens: (a) LM25aluminum alloy, (b) silicon carbide powders, and (c) graphite powders.

Whereas magnesium acts as a wettability agent, a pure magnesium piece with a weight of 2% is added to the liquid melt. The following method uses a mechanical stirrer at 500 rpm for 15 minutes. This hybrid slurry was superheated at a temperature above 720 °C, which aids in increased dispersion for reinforcing particles into aluminum alloy composites. Finally, liquid metals were poured into a die to form the desired sample of the required form and size of hybrid composites Figure 2 shows the schematic representation of the stir-casting setup and electric heat furnace.

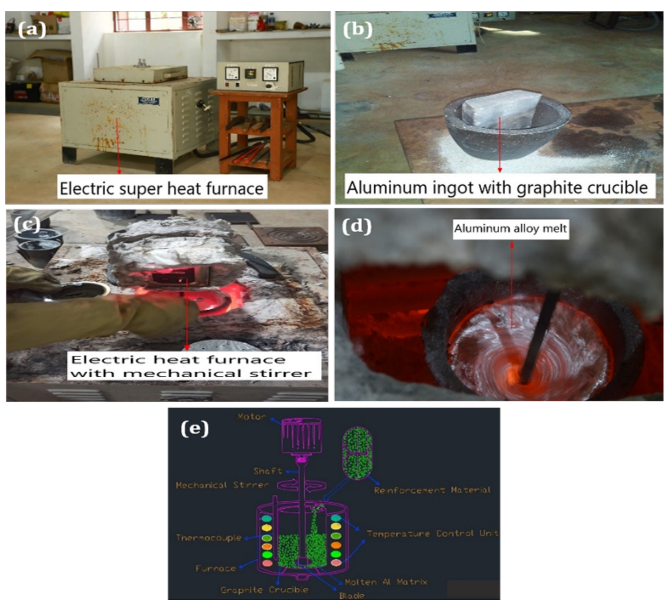

Fig 2. Fabrication of MMCs in setup details for a) Electric super heat furnace, b) Aluminum ingot with graphite crucible, c) Electric heat furnace with a mechanical stirrer, d) Aluminum alloy melt, and e) Schematic drawing for stir-casting.

2.2 Wear test

The dry sliding wear tests were carried out with the standards established by ASTM G99-05 for pin-on-disc apparatus (Ducom, model No: TR-20LE-PHM-250), as shown in Figure 3. We used a worn disc made of EN31 hardened steel in the pin-on-disc. A dead weight sample was made using a cylindrical pin 8 mm in diameter and 32 mm long. The purpose of this specimen is to apply force to a pin against a sliding disc. An experiment was performed on the wear and friction characteristics of a sample with a track diameter of 46 mm by varying the load, sliding speed, and sliding distance for the aluminum matrix alloy and hybrid composites. A dry test at a constant speed of 692 rpm for 10 minutes revealed that the selected material influenced the specimen's behaviour. After each test, the pin and counter face disc was wiped with acetone to remove any residue. The test pin was weighed before and after the procedure to an accuracy of 0.1 mg to determine the amount of wear that had occurred. The friction coefficient was calculated using the force applied and the tangential load received from the strain gauges. Each test was performed three times, and the average results were reported. The sliding velocity of the test sample can be determined by following the equation given below[(10)].

$$V = \frac{\pi * D * N}{60000} \quad (1)$$

The following specific wear rate (SWR) is to be calculated by utilizing the equation, which is as follows:

$$\text{Ko} = \frac{\Delta m}{\rho * F * d} \quad \text{mm}^3/\text{N}-\text{m} \quad (2)$$

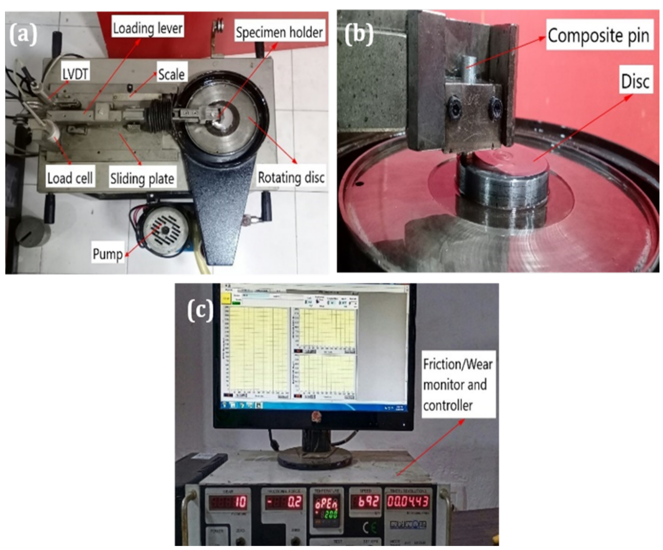

Fig 3. Wear setup details for a) Pin on abrasive disc wear testing machine, b) Pin on disc loading position, and c) Control panel.

3 Results and Discussion

3.1 Effects on load

A variation in wear loss (SWR) of the load applied at the constant sliding velocity of 1.65 m/s with a sliding distance of 999 m is depicted in Figure 2a. It has been demonstrated that as applied load increases, overall wear loss of hybrid composites increases. The increased wear loss for all materials studied at increasing loads is attributed to higher plastic deformation and delamination wear. Also, composites with graphite composition are simpler to fracture from the matrix while sliding. As a result, Al/2%Gr composites incur increased wear loss. Under all loads studied, Al/4%SiC/2% Gr composites exhibit the lowest wear loss. Figure 3a depicts the relationship between load and variations in the friction coefficient. The friction coefficient of aluminum LM25 and hybrid composites grows with rising load in the 15–45 N load range. However, for all loads tested, the friction coefficient for an Al/2%Gr mono composite was lower than that of hybrid composites. The intensity of plastic deformation rises as the load increases inversely, which improves the interaction of SiC particulates with the counter surface and the migration of aluminum matrix on its counter surface. These factors could lead to a higher friction coefficient when the load increases.

3.2 Effects on sliding distance

A variation in wear loss (SWR) as the sliding distance was applied in the range between 333 - 999 m is displayed in Figure 2b. The load was held constant at 45 N throughout the experiment. It has been discovered that increasing the sliding distance leads to increased wear loss (SWR) in all materials. The Al/4%SiC/2%Gr composite had lower wear loss with a sliding velocity of 1.65 m/s compared to similar composites. This process occurs when hard SiC particulates are dislodged while sliding, resulting in a mechanically mixed layer between the surfaces in contact[(11)]. The overall variation in friction coefficient during the sample for LM25 Al, Al/Gr mono composite, and Al/SiC/Gr hybrid composite is illustrated in Figure 3b. When sliding with a constant velocity of 1.65 m/s, the coefficient of friction consistently increases with sliding distance for all materials studied. The lubricant layer in the contact areas was formed by spreading graphite particulates and detached SiC particles that were mechanically abraded. It has described the wear behaviour and mechanisms of Al alloy-5% SiC particle composites. The wear rate increased with the applied load, whereas speed had a mixed effect[(12)]. During a sliding distance, the films get detached from the area of contact and driven off over a contact surface region where their coefficient of friction increases as the sliding distance increases.

3.3 Effects on sliding velocity

This relationship between composite wear loss (SWR) and sliding velocity is illustrated in Figure 2c. It has been discovered that raising the sliding velocity reduces wear loss for all materials. In addition, Al/4%SiC/2%Gr composites had lower wear loss at all sliding speeds when compared to other composites. Because graphite particles are solid lubricants, they can reduce wear loss by forming a tribolayer at a surface contact when sliding velocity increases[(13)]. When its graphite reinforcement content exceeds 2%, wear loss tends to rise. This result could be attributed to the decrease in the fracture toughness of the composite. A variation between sliding velocity and the friction coefficient is illustrated in Figure 3c. It has been discovered to have a significant effect on the friction coefficient with all materials studied, and similar observations are made in addition to silica carbide[(14)]. This Al-2%Gr mono composite demonstrated excellent anti-friction behaviour across all sliding speeds tested, while an Al/4%SiC/2%Gr hybrid composite had the highest friction coefficient. Because the SiC reinforcing within these composites is squashed out onto their contact surface, forming a mechanically mixed layer, and due to the scattered graphite granules created by the lubricating film within the contact surface, this coefficient of friction increases as the sliding velocity increases. This lubricating layer is disengaged by the contact area and driven away from the sliding surfaces. Therefore, when the sliding velocity increases, the coefficient of friction also increases.

3.4 Wear mechanism analysis of SEM

Micrographs taken with a scanning electron microscope utilizing wear on an aluminum LM25 alloy surface and the composite materials under a load of 30 N are shown in Figures 4, 5, 6, 7 and 8. The SEM micrographs within the surface morphology of an aluminum LM25 alloy matrix are illustrated in Figure 4. Because the existence of deep permanent grooves, micro-cutting, grain pull-outs, and fracturing of the oxide debris might have increased wear loss as shown in Figure 4a and Figure 4b. In addition, finer grooves identify worn surfaces revealed by hybrid composites, and Figures 5, 6, 7 and 8 display slight plastic deformation on the groove margins. The substrate morphology has varied as the SiC weight percentage has increased. Because of the graphite reinforcement, these surfaces seem to be smooth. Furthermore, the surface morphology of an Al/2%Gr mono composite after it has been worn is depicted in Figure 5a and Figure 5b. Due to the lubricating effect on graphite, its surface morphology was such that an Al/2%Gr composite was relatively smooth and had fewer grooves[(15)]. Similar observations were made on 5% of SiCp reinforced with Al composites and found that the wear rate of both composites increased with increasing sliding distance and applied load. The surface degradation of composites increases with increasing load[(16)]. This primary wear form appears to be ploughing out the surface material. A delamination layer on a specimen margin and a surface worn during sliding to detect plastic flow were seen in Figure 6a and Figure 6b on hybrid composites constructed of LM25 2% SiC and 2% Gr. When subjected to loads of 30 N, the delamination layer exhibited micropores, although this structure suggested significant wear due to high heat generated by wear debris. On a worn surface, Figure 7a and Figure 7b exhibit incredibly tiny microcrystals with graphite particulates having lower amounts of oxide particles. Moreover, the tiny particles can be quite densely packed against each other. It forms a film on the contacting surface after adhering to it. Finally, using Al/4%SiC/2%Gr hybrid composites results in decreased plastic deformation of the pin contact. As a result, the Al-4%SiC-2%Gr composites have a low risk of excessive wear, with abrasion and delamination being the most predominant wear mechanisms[(17)] The subsequent increase in weight fraction

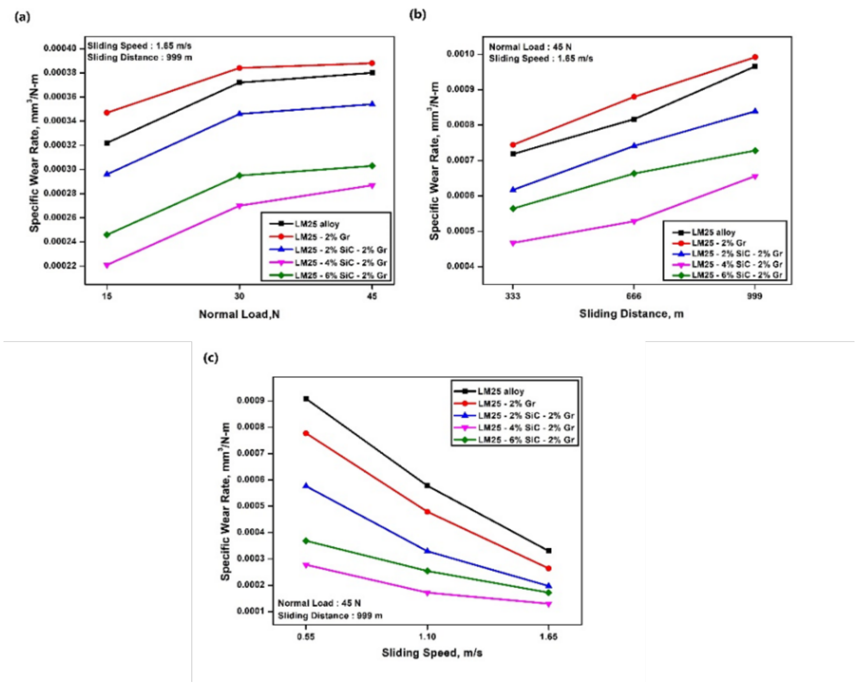

Fig 4. Variation in wear loss (SWR) for aluminum LM25 with hybrid composites given (a) load, (b) sliding distance, and (c) sliding speed

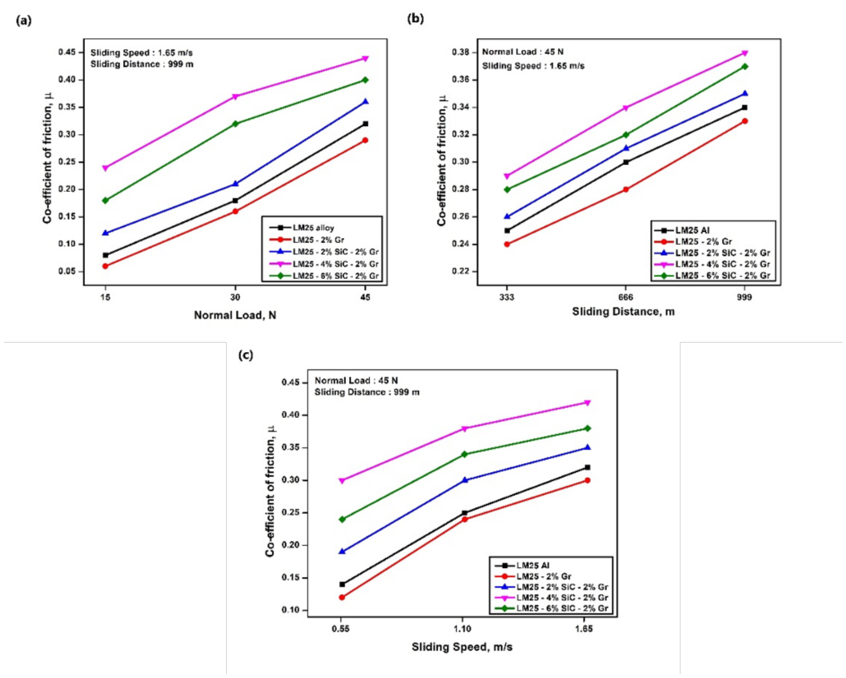

Fig 5. Shows the variation of coefficient of friction with aluminum LM25 with hybrid composites as a function of (a) load, (b) sliding distance, and (c) sliding speed

to produce the LM25/6 %SiC-2 %Gr hybrid composites resulted in deeper grooves with mild plastic deformation along their edges, as seen in Figure 8a and Figure 8b. Despite the hybrid composite material showing thin films, the specimen exhibits deep grooves and brittle fractures on the surfaces due to the excessive pits in the matrix and poor wettability with its reinforcing particulate[18]. As a result, when compared to similar materials, the overall surface for LM25/4%SiC-2%Gr hybrid composites was extremely smooth.

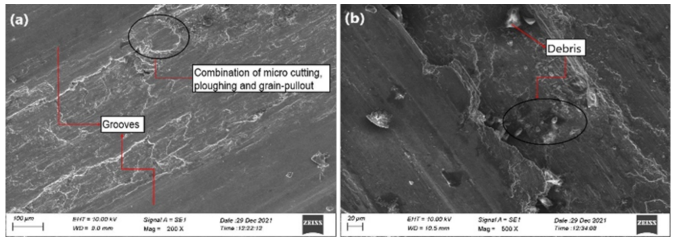

Fig 6. llustrates the SEM using a worn surface with aluminum LM25 under a 30 N load. a) Micrographs at low magnification and b) Micrographs at high magnification

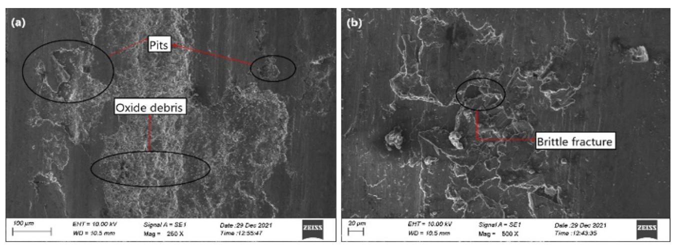

Fig 7. llustrates the SEM using a worn surface with aluminum LM25/2%Gr under a 30 N load. a) Micrographs at low magnification and b) Micrographs at high magnification

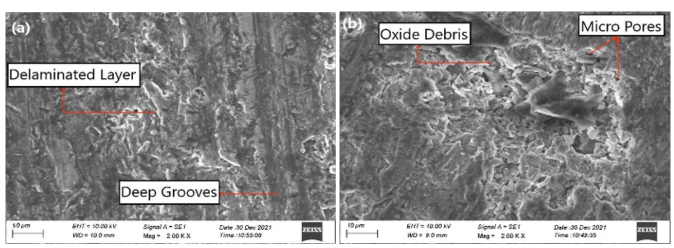

Fig 8. llustrates the SEM using a worn surface with aluminum LM25/2%SiC–2 %Gr under a 30 N load. a) Micrographs at low magnification and b) Micrographs at high magnification

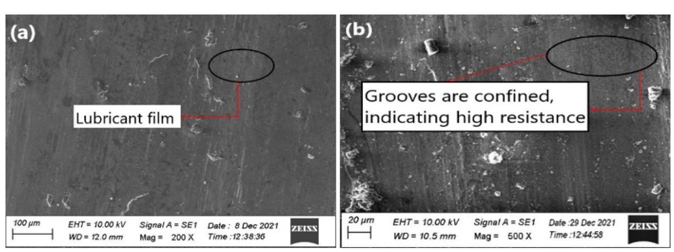

Fig 9. llustrates the SEM using a worn surface with aluminum LM25/4%SiC–2 %Gr under a 30 N load. a) Micrographs at low magnification and b) Micrographs at high magnification

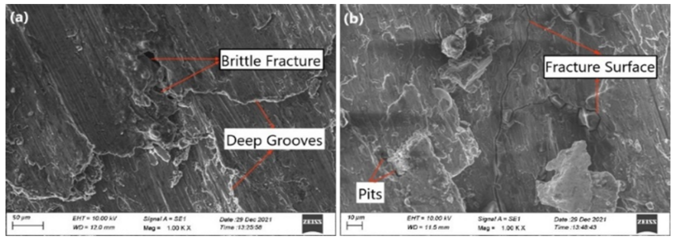

Fig 10. llustrates the SEM using a worn surface with aluminum LM25/6%SiC–2 %Gr under a 30 N load. a) Micrographs at low magnification and b) Micrographs at high magnification

4 Conclusion

This objective is to reduce the cost generated at the outset. Additionally, adding SiC to Al alloy with constant graphite was fabricated through the stir-casting technique. The significance of this research is that it aims to create a brake disc Al alloy with a wear-resistance hybrid composite linked to its surface. The wear test demonstrated that the LM25 alloy with SiC/Gr bonding on the surface has a feasible technical potential. The limitations of this alloy include its susceptibility to corrosion in salt water and its low fatigue strength. From these tests, we were able to draw the following conclusions:

- The percentage of reinforcement particles directly impacts tribological properties. An increase in the inclusion of particulates restricts the deformation of a material, resulting in improved wear resistance.
- The hybrid composites had higher wear resistance with increased friction coefficients than the matrix under all loads and sliding speeds investigated.
- In addition, Gr and SiC reinforcement with aluminum LM25 alloy improve the wear resistance of composites due to the presence of silica and alumina content.
- In a hybrid composite of 4% SiC and 2% graphite, delamination and oxidative wear were the predominant wear mechanisms as in research. In addition, when the SiC content increased, the wear debris decreased.
- Creating smooth graphite-rich tribo layers seems to be a critical aspect of determining the wear mechanism of the hybrid composites; a higher amount of SiC with Gr reinforcement results in an increased friction coefficient.
- This research aims to use materials, particularly for the automobile sector, which requires significant resources to fabricate cylinder and piston rings.
- The LM25/6%SiC–2%Gr reinforced with aluminum was constructed from the specimen to produce the results of deep grooves, brittle fractures, more pit formation, and poor wettability on the surfaces of the hybrid composites. Future studies could increase the weight fraction of graphite.
- Future research focuses on thermal characteristics and chromium carbide coatings to improve the corrosion resistance of Al alloy.

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