

Research Article

Experimental Investigations on the Wear Behaviour of Eutectic Al-7075/CNT/Graphite Composites Manufactured by a Combination of Two-Stage Stir and Squeeze Casting Techniques

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The dry sliding wear performance of eutectic Al-7075-CNT-Gr composites was estimated using a pin-on-disc wear test. According to the results, the wear and friction coefficients dropped gradually as the weight % of graphite elements improved. The composite's wear resistance increased significantly as the sliding speed increased from 1 m/s to 2 m/s at 49 N while the load remained constant. 7075-7.5 wt percent Gr amalgamated, on the other hand, had a more significant coefficient of friction as the sliding speed increased from 1 m/s to 2 m/s at 49 N. After the test, the researchers looked at how the worn-out surfaces of the specimens originated. The mechanically mixed layer of oxides and iron was used as an effective tribolayer to increase the wear resistance at more incredible sliding speeds in the wear test.

1. Introduction

As a result, aluminum alloys are commonly used because of their high productivity and low weight [1]. For researchers, the combination of aluminum's stronger strength with its superior comparable low weight piqued their interest in studying its different features in greater depth [2, 3]. Reinforcements are applied to aluminum alloys in order to enhance their performance [4]. Among

the advantages of metal matrix composites (MMCs) are improved dimensional stability and fatigue resistance by enduring cyclic loads, for example, which are only some of the benefits. MMCs have various benefits over polymer matrix composites (PMC), including increased hardness and flexibility, increased temperatures, increased electrical conduction, increased thermal conduction, and improved transverse performance [5–7]. Radioactivity survival, minimal or no corruption, improved joining properties. Wear

is the most common cause of component and assembly replacement in the industrial sector. When it comes to industrial wear, abrasion accounts for 55 percent of the problem, while adhesion accounts for 15 percent [8]. Marine applications benefit from its improved mechanical qualities and improved corrosion resistance. It is possible to modify the qualities of AMCs to suit automobile components that require greater wear resistance by adjusting the kind, size, and percentage of reinforcements [9, 10]. Aluminum is typically reinforcing with porcelains such as SiC and Al_2O_3 . Another important factor in AMC mechanical and tribological qualities is the kind of composite and augmentation dispersing fabrication procedure [11]. The precipitate hardenable aluminum alloy AA7075 (Al-Zn-Mg-Cu) is widely utilized in the aviation, defense, maritime, and automotive sectors. AA7075 aluminum alloy is a precipitation hardening alloy with zinc (5.1–6.1 wt%), magnesium (2.1–2.9 wt%), and copper (1.2–2.0 wt%) as the primary alloying components.

In excess to boosting the wear confrontation of constituents to which they are applied, carbon nanotubes (CNTs), which are one-dimensional allotropes of carbon, have piqued researchers' curiosity since their discovery due to their exceptional material properties. According to the law of mixtures, a higher CNT volume fraction leads to the more excellent mechanical performance of the composites. CNTs are utilized as solid lubricants for their lubricating properties. They also reduce the coefficient of friction (CoF). MMNCs reinforced with CNTs have been developed using a variety of fabrication methods. A lubricant coating is created between the CNTs and the surfaces they slide across [12–15]. Multiwalled CNT (MWCNT) attachment forces are feeble in metal matrix composite (MMC) systems, allowing the composite to roll or glide across contact surfaces readily. The composite CoF is reduced because of the poor connection among the surfaces [16]. CNTs serve as spacers that prevent rough surfaces from rubbing against one other, which improves wear resistance.

Researchers analysed to really optimise dry sliding wear loss in copper-multiwalled CNT composites via response surface methodology. The performance of this L16 orthogonal array of pin-on-disc tribometers was evaluated [17, 18]. The function of wear load and sliding distance of prepared composites. There was an estimated 76.48% MWCNT content, followed by 12.18% and 9.91% loading and sliding distance, which were shown to be the most significant influences on wear loss. AA6061 stir casting and graphene nanoparticle-particulate composites were studied by [19, 20]. Stir casting was used to create AA6061 samples reinforced with a fixed weight percent of SiC (10 percent of aluminum alloy 6061) and a variable weight percent of graphene. Multiple tests, including tensile and impact hardness and wear microstructure analysis, were performed on the specimens. In comparison to SiC-reinforced aluminum, graphene dramatically increased mechanical characteristics. Using a pin-on-disc apparatus, Sahin and Murphy [21] studied the effects of wear factors and thermal behaviour on dual surface roughness of aluminum silicon carbide-graphite composite material with a 200 mm grit size.

TABLE 1: Configuration of Al-7075-silicon alloys.

Element	Silicon	Iron	Magnesium	Aluminum
Weight percentage	12.8	0.02	0.21	Balance

For its higher ultimate toughness, flexibility, and improved wear characteristics, MMCs are increasingly used in the manufacturing process. Solid-state contacts can have either one or both of their two surfaces exposed that might be worn away due to wear [22, 23]. Graphite is a naturally occurring form of pure carbon with a unique hexagonal crystal structure grouped in numerous parallel graphene layers. The remarkable potential of Gr powders as a solid lubricant for polymers and metals is due to their layer lattice structure. Solid lubricants are used to minimize friction in situations where sliding contact occurs. To decrease friction and wear, the solid lubricant acts as a barrier between the sliding pieces to protect them from harm. The improved tribological properties of aluminum alloy-graphite composites make them an excellent choice for automobile engine internal combustion engine, bearings, and bushings. Because graphite particles work as solid lubricants, they are further added to aluminum alloy matrices to make alloy identity [24]. An excellent weight/strength ratio and less thermal extension constant make eutectic aluminum and silicon alloys ideal for various tribological applications. A rise in graphite particles consumed is shown to boost the wear confrontation of 6061 Al alloy composites [25]. In comparison to aluminum and silicon composites, Bakshi et al. [26] found that Al-Gr composites exhibited better wearing properties than Al/SiC. Ghorade et al. [27] examined the wear proportion of aluminum and silicon graphite particles and discovered that the tribological behaviour of the matrixes was pretentious by the graphite composites and silicon phase. Researchers found that aluminum alloy-graphite particles have decreased roughness and wear rates [28].

Adding graphite particles to Al alloy-SiC-reinforced composites improves their wear resistance, according to [29]. Compo cast Al-Si alloys with graphite particles were examined for their wear properties after being squeeze cast. According to a study, enhancing the graphite composition of the worn pin minimizes lubrication and temp rise. There are graphite granules in the matrix that are responsible for the excellent wear resistance, as stated in [30]. Aluminum alloy graphite bearings have a better performance because of a tribo-induced graphite-rich coating on their surfaces, according to [31]. It is necessary to regulate the distribution and contact between the two components so as to investigate the possibility of utilizing Al/graphite matrix as mechanical constituents and to maximise behaviour. When it comes to composites, the stir casting method has a difficult time dispersing graphite elements evenly in the aluminum alloy. Because of the nature of the stir casting method, it is susceptible to a number of problems, including segregation, insufficient wetting of the Gr granules by the fluid aluminum alloy, and increased pores as an outcome of gas trapping during the manufacturing process. To augment the diffusion of Gr elements in the aluminum composites, an altered two-

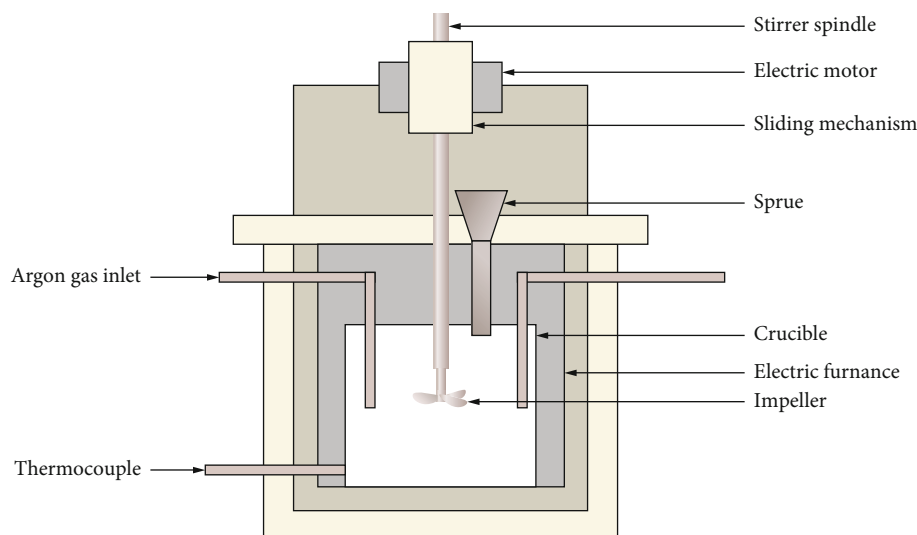


FIGURE 1: Diagram of altered two-stage stir casting setup.

stage stir casting technique might be used in conjunction with other techniques. When the composite slurry has reached a semisolid state, it is necessary to stir [32].

Mixture is heated to liquid Al temperature, and the second step of churning begins until the slurry is placed into an appropriate mold. Preventing the buildup of graphite particles in the melt was a primary goal. As a means to avoid the confesion of graphite elements on the crucible partition, the radial impeller with a 0.7 IOD/CID ratio (impeller outer dia to crucible inner dia) is utilized. The stirrer position control device moves the impeller vertically into the slurry at a rate of two millimeters per second during the stirring operation [33]. Squeeze casting, on the other hand, uses high pressure to solidify the composite melt in the mold cavity in an environment free of turbulence or gas trapping. Composites constructed from Al-graphite were created utilizing a blend of the reformer stir casting and squeeze casting techniques [34]. Dry sliding wear and frictional properties were studied using aluminum and silicon alloy-graphite compounds with variable weight percentages of graphite elements, respectively.

2. Experiments

The matrix material employed in this investigation was eutectic Al-7075-CNT, while the solid lubricant was graphite particles (50–120 microns in size). Table 1 indicates the Al-CNT chemical arrangement. The composites were made using a mix of squeeze casting and an improved two-stage stir casting [12]. To provide pressure to the molten composite in the mold cavity, a universal testing machine was fine-tuned. Gravity and pressurized castings are integrated into squeeze casting. Molten metal is poured into a warmed die in general. After the molten metal head has been filled, a ram is utilized to apply high pressure to it slowly. This pressurization ensures that metal flows freely throughout the solidifying casting, reducing shrinkage and porosity.

Figure 1 shows the diagram of the altered two-stage stir casting setup. When the graphite crucible was fully charged

with Al-7075 alloy, the furnace heat was raised to the liquidized heat of Al-7075 to melt the granules of Al-7075 completely; the furnace was turned off. At the vortex side, warmed graphite elements were poured into the crucible. Wetting between Al-7075 matrix and graphite particles was improved by adding 1.5 percent Mg to melt. To get to the semisolid condition, the melting heat was lowered to 575°C. For three minutes, the semisolid mixture was stirred constantly. To prevent the furnace from oxidising, two cc/min of argon gas was continually pumped into it. The slurry was heated to a liquidus temperature of 660°C, and 300 rpm was used to stir for 3 minutes at this temperature. Finally, the warmed mold cavity was filled with composite slurry kept at 350°C. For 40 seconds, a 50 MPa squeeze pressure was admitted to the melt via prepared punch till solidification was complete. The sample was detached from the mold assemblage after the punch was retracted.

2.1. Hardness. A Brinell hardness test was achieved on aluminum-7075 compound and complex samples utilizing a Brinell hardness testing rig with a span of 10 mm and a force of 4.9 kN on a diameter of 10 mm (500 kgf). It took about 30 seconds for the system to become operational. In order to reduce the likelihood of segregation, three evaluations were engaged on separate samples and the mean value was taken into consideration.

2.2. Dry Sliding Wear Test. Figure 2 reveals the pin-on-disc wear testing machine. Under a continuous typical load of 49 N (5 kgf) and gliding speeds of one and two meters per second, the wear tests were passed out with the aid of a pin-on-disc wear trial apparatus and a data gathering system. The basic components of the equipment are an electrical motor with a carbon disc connected to it as well as a lever arm while weightiness is applied to it. It was possible to measure the height loss of the sample pins in microns with an accuracy of 1.0 micron using the linear variable differential transducer that was included in challenging device. A path diameter of 100 mm was used in this investigation. We made



FIGURE 2: Pin-on-disc wear testing machine.



FIGURE 3: Wear sample.

pin specimens that were 6 mm square and 30 mm long to test our hypothesis. Abrasive paper grades 600 and 1000 were used to polish the specimens prior to wear testing. A 15-minute wear experiment was passed out at a temperature of 30 degrees Celsius. At the conclusion of 800 seconds in this investigation, wear loss readings were recorded (13.3 minutes). Each condition was evaluated on a minimum of three samples. Figure 3 reveals the wear sample.

3. Results and Discussion

The Al-7075-7.5 weight percent Gr composite was made using a two-stage stir casting process trailed by a squeeze casting process, affording to the manufacturer. According to the image, which can be seen here, the graphite elements are evenly isolated throughout the aluminum composite, which is a good thing. A clean boundary among the Al-7075 composite and the Gr elements confirms an excellent interfacial connection between the two materials. There is no aggregation of graphite particles in the composite, nor is there any porosity. The toughness of aluminum-graphite mixtures decreases as the quantity of Gr in the mixture raises. The lower hardness of Gr compared to the Al-7075-

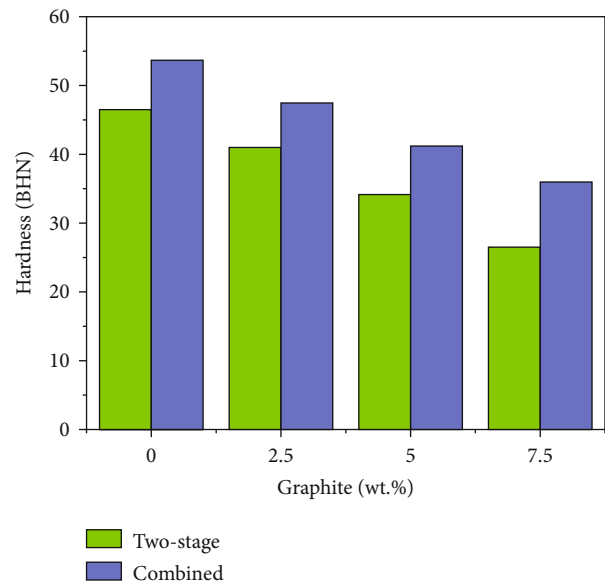


FIGURE 4: Hardness of specimens.

Si alloy is to blame in this instance. When evaluated to the toughness of the Al-7075 alloy, the toughness of the Al-7075-7.5 weight percent graphite alloy was approximately 33 percent lesser than that of the aluminum-7075 alloy. A comparison of the hardness of two-stage stir cast composites made by squeeze casting with the hardness of two-stage stir cast composites made by stir casting was carried out. The hardness of Al-7075-7.5 wt percent graphite mixture samples produced using the squeeze casting technique was 31 percent greater than that of specimens produced using the two-stage stir cast technique, and it is shown in Figure 4.

This is because there is no porosity in the aluminum matrix and the graphite elements are evenly detached. The Al-7075-7.5 wt percent graphite elements were a direct result of this. Gliding speeds of 1 and 2 m/s at 49 N load are shown in the wear loss curves for the Al-7075-7.5 wt percent Gr composite, respectively, and it is shown in Figures 5 and 6.

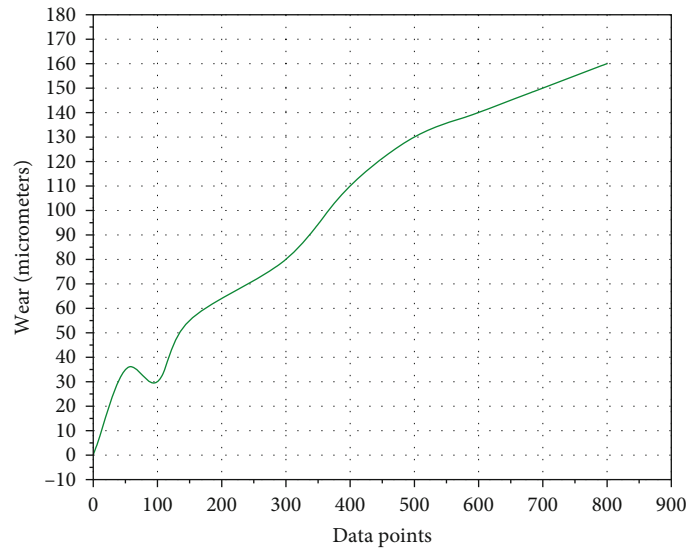


FIGURE 5: Sliding against steel at 1 m/s and 49 N, an Al-7.5 wt% Gr composite shows the typical wear curve depicted in the graph.

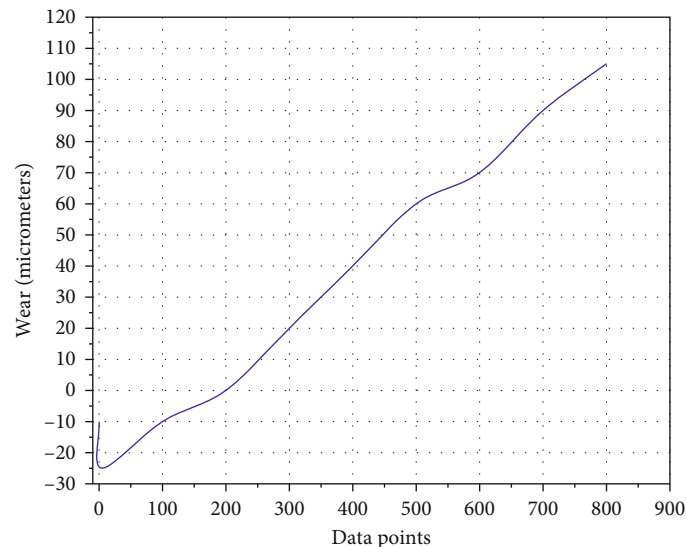


FIGURE 6: Al-7.5 weight % graphite composite versus steel is displayed in the wear curve as a purpose of sliding speed at 2 m/s and stress of 49 N.

Al-Gr composites show an increase in wear as the amount of sliding time rises. When slipping over a worn surface over extended distances, the tribolayer becomes unstable and causes this. As shown in Figure 7, the graphite component of the aluminum-Gr mixtures increases the wear confrontation of the compounds. So Gr elements serve as a solid lubricant and increase wear confrontation as a result of this process. The least amount of wear loss was observed in composites containing 7.5 percent graphite. It has a wear resistance that is around 2.2 extra greater than that of Al-7075 amalgam when subjected to a gliding velocity. A greater interfacial interaction between Al and graphite particles also contributes to this increase in wear resistance, minimizing sliding damage.

Sliding at high speeds creates frictional heat, which increases oxidation and makes it simpler to build tribo film. Al-graphite composites were shown to lose less wear as slid-

ing velocity was. To increase the wear confrontation of aluminum-7075-graphite complexes, it is necessary to add titanium; it is necessary to increase the sliding velocity while maintaining a constant loading. With a force of 49 N applied, sliding at a speed of 1 m/s results in the most wear, whereas sliding at a slower speed results in the least wear. As [2] reported, the same phenomenon was seen in composites made of Al-7075-Gr (0–6%).

Figure 8 depicts the matrices and composites' time-versus-friction coefficient curves at gliding velocities of 1 and 2 m/s. With increasing graphite concentration in Al-7075-CNT, the coefficient of friction (CoF) lowers, consequential in a final value of 0.79 for the Al-7075-7.5 wt percent composite when subjected to one meter per second and 49 N of force at the same time. When the quantity of Gr in the material increases, the CoF reduces with time,

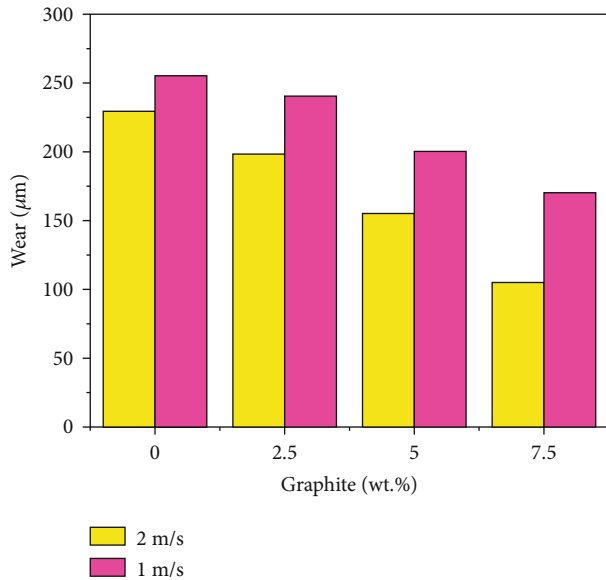


FIGURE 7: Graphite contented and sliding speeds of 1 m/s and 2 m/s affect the wear rate underneath a continual typical load of 49 N.

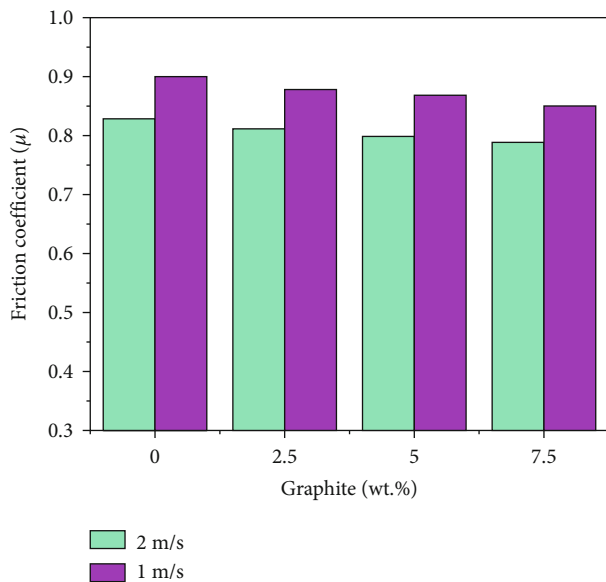


FIGURE 8: The friction coefficient altered with graphite content and sliding speeds between 1 and 2 m/s just below a typical load of 49 N.

regardless of the sliding speed. Graphite particles produce a thin layer on the worn surface that decreases the CoF by a factor of two as their percentage on the surface increases. When the force is applied to the Al-7075-7.5 wt percent Gr composite, gliding speed increases from 1 m/s to 2 m/s, and the friction coefficient raises from 0.79 to 0.85. According to the data, the friction coefficient increased by 8% when Al-7075-7.5 weight percent Gr composites were utilized. Asperities in composite pin and counter steel disc materials may become more adherent at higher sliding speeds, which could account for the observed increase in adhesion.

Plowing grooves and thin sheets of material have been removed from the surface of Al-7075's worn surface, indicat-

ing that the material has been delaminated. With Al-7075 alloy matrix, in comparison to carbon steel discs, the deformations on metal cross surfaces handle it better into the substrate and remove material more severely. Large plastic deformation at the groove's margins is also observed, which causes subsurface cracking that results in increased material loss. The amount of material removed by wear on Al-7075-2.5 wt percent Gr composite is less than the amount of material removed by wear on Al alloy. Because graphite particles were used, the wear grooves were also narrower in the sliding direction as an outcome of the inclusion of Gr elements. When comparing the worn substrate of the Al-7075 alloy with the edges of the grooves, plastic deformation was seen. Wear resistance of the system is raised as an outcome of the graphite materials preventing the Al-7075 matrix from coming into direct contact with other components. When compared to Al alloy, composite wear losses are much lower. With 40 N applied to the surface at a gliding speed of 2 m/s, the composite wears away. When observed at the same magnification, the sliding markings acquired at 2 m/s velocity are smoother than those obtained at low velocity (1 m/s). At speeds of one to two meters per second, graphite particles spread over worn surfaces and serve to boost wear resistance, according to the study.

It is also possible to generate iron oxide at greater sliding velocities by combining graphite particles with oxygen in the air and the counterface. An MML (mechanically mixed layer) of oxides and graphite particles has formed and may be seen on a worn composite pin. Before the wear testing, an Al-7075-7.5 wt% graphite compound was applied to the surface. According to the findings, this film is primarily composed of aluminum, carbon nanotubes (CNT), magnesium, and carbon, of all existing in the aluminum-7075 alloy-graphite compound. A greater intensification image of the aluminum-7.5 wt percent graphite compound surface layer (the area of the rectangle) on normal load of 49 N and a gliding speed of 2 m/s is shown under a normal load and sliding velocity. On the scuffed and scratched surface of the Al-7075-CNT, elements such as Fe and O were discovered in small quantities, as well as traces of other elements. The wear superficial of the Al-7075 alloy did not show any signs of MML contamination. The pace at which MMLs are formed depends on the rate of wear and the mechanism of wear. Due to the extreme plastic deformation and subsequent removal of Al-7075 that occurs as a result of heavy loads, the production of MML is delayed. According to [14], both the rate of MML generation and the rate of MML fracture must be identical in order to maintain the steady-state wear condition.

Sliding at 49 N, the wear substrate of the Al-7075-7.5 wt percent graphite compound has an increased number of oxides. At a speed of 2 m/s, force of 49 N, about 40% of the oxide component was found on the worn substrate. This proposes that the oxidised wear process is more prevalent when sliding at higher speeds than at lower speeds. The presence of additional O indicates that Al-7075, graphite, and iron were oxidised during the sliding process, which is consistent with the fact that the wear process is exposed to the atmosphere. As a result, oxidation is accelerated at the

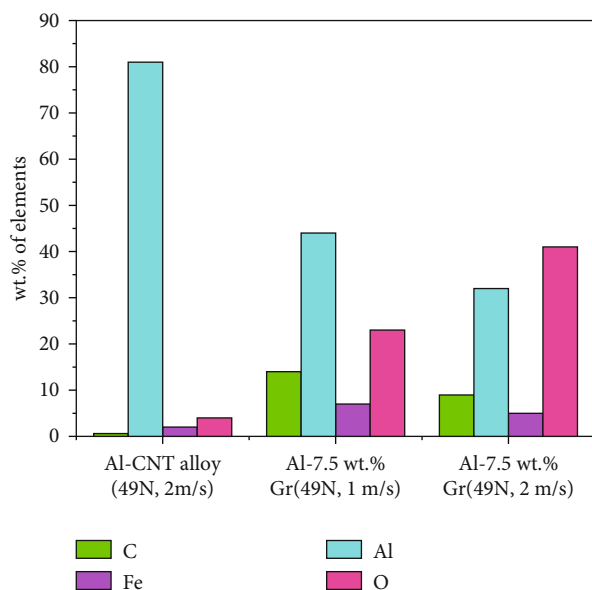


FIGURE 9: Sliding speed on the worn surface of the aluminum alloy and the aluminum-7.5 weight percent graphite material in contradiction of the counter steel were used to determine the mass percentages of aluminum, iron, carbon, and oxides.

interface between the sliding parts as an outcome of the greater sliding velocity. A thin oxide layer develops on the worn substrate, further increasing the composites' wear resistance. Constituents from together contact surfaces, for instance, Fe oxide, graphite, and aluminum oxide, are mixed together in the mechanically mixed layer to form a composite material (MML) and it is shown in Figure 9. For example, this study shows that at greater sliding velocities, wear particles disperse over the worn surface and form a tribolayer that performs as a lubricant, thereby increasing the wear resistance of the surface.

4. Conclusions

These composites were created using two-stage stir casting processes that were modified, as well as squeeze casting processes. In comparison to the Al-7075 alloy alone, it has been demonstrated that Al-7075-Gr composites have a lower hardness. Graphite granules diminish toughness in a linear pattern as they are included into composite materials. The creation of a graphite layer on the composite's surfaces reduces wearing and frictional coefficients of Al-7075-Gr composites with rising graphite content. Dry sliding wear resistance of Al-7075 with 7.5 weight percent graphite is 2.2 larger than that of the original alloy, and it retains the maximum wear confrontation among some of the alloys. Since the tribolayer on the composites' surfaces was kept at a constant level, the test findings show that wear resistance is linear with increasing sliding velocity. Friction coefficient rose by 10% since 1 m/s to 2 m/s by 49 N of applied tension, which represents 10% more friction in the Al-7075-7.5 wt% Gr composite. The sufficient amount of graphite contented can be inoculated to the Al-7075 alloy without affecting the

alloy's mechanical characteristics in terms of improving the tribo features of composites.

Data Availability

The data used to support the findings of this study are included within the article. Further data or information is available from the corresponding author upon request.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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