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# Mechanical and Wear Behaviour of Az91d Magnesium Matrix Hybrid Composite Reinforced With Graphite

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***Abstract***
*In this experiment, stir casting was used to create hybrid composite materials reinforced with graphite (Gr) and magnesium (AZ91D) particles. These composite materials' mechanical and tribological characteristics were looked into. The test results showed that the hybrid composites with graphite reinforcement showed less wear loss than the AZ91D alloy composites without reinforcement. It was discovered that as the graphite (Gr) content increased, the ultimate tensile strength decreased and the wear resistance increased monotonically with hardness.This study showed that the wear resistance of magnesium composites is significantly increased by the addition of soft reinforcement, such as graphite. All of these findings indicate that hybrid magnesium composites are a great material for applications requiring high strength, ultimate tensile strength, and wear-resistant components, particularly in the aerospace and automotive engineering fields.*
***Keywords:*** *Stir casting; Hybrid composite; Magnesium AZ91D; Mechanical; Wear; graphite (Gr)*

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## I. Introduction

There is a new era for materials with lightweight applications in the modern world. Lightweight materials are in high demand, particularly in the automotive industry. Aluminum alloys were the material of choice in recent years for lightening up automobiles [1-3]. Due to their lower density when compared to aluminium alloys, magnesium alloys have recently been used for weight reduction more frequently [4]. Magnesium has a density that is roughly two thirds that of aluminium, a quarter that of zinc, and a fifth that of steel. As a result, compared to traditional engineering alloys, magnesium alloys offer a very high specific strength [5].There has been a lot of research and development done in the composite fields as a result of the high demands placed on materials for better overall performance. The development of strong yet lightweight materials has become increasingly crucial for increasing energy efficiency by reducing the weight of transportation carriers. Because of this, magnesium alloys offer one of the highest specific strengths of all common engineering alloys. Magnesium alloys also have a strong damping capacity, great castability, and superior machinability. Magnesium alloys have a relatively low mechanical strength, especially at high temperatures, when compared to other structural metals.Numerous efforts have been made to develop magnesium matrix composites and affordable fabrication techniques in response to the need for high performance and lightweight materials for some demanding applications [6–8]. Through the addition of structural filler (such as ceramic whiskers like silicon carbide whiskers and others, aluminium oxide, graphite and other particles, carbon fibres, and carbon nano tubes: CNTs), they are demonstrated to have good mechanical properties [9–12]. The ability to produce a large number of intricately shaped components makes foundry casting processes a preferred processing technique.Because it has been demonstrated to be a very promising method for the production of near net shape composites in a straightforward and cost-effective manner, stir casting is particularly used to produce the PRMMCs. The main challenges in this technology are getting enough liquid metal to wet the particles and getting a uniform distribution of ceramic particles [13]. The composites' Ultimate Tensile Strength and Yield Strength were significantly higher than those of the matrix alloy.

Table 1: Chemical composition of the AZ91D matrix alloy

| % | Al | Mn | Zn | Si | Fe | Cu | Ni | Mg |
|---|---|---|---|---|---|---|---|---|
| AZ91D | 8.5 | 0.15 | 1 | 0.10 | 0.005 | 0.03 | 0.002 | Bal |

A significant factor in the rise in YS and UTS is the load transfer mechanism [14]. Due to their synergistic effect on the composite's hardness and friction coefficient, specific combinations of n-$A1_2O_3$ and CNTs had a hybrid effect on the wear performance [15]. Due to the presence of soft Gr particles, a slight reduction in hardness is seen for the hybrid composite when compared to Mg-SiC composite. Due to the upright effect provided by both reinforcements, the developed composites' wear resistance significantly outperformed that of the magnesium matrix [16]. The literature makes it abundantly clear that adding different reinforcements significantly improves the mechanical properties of magnesium matrix.One might notice that there isn't a lot of research on the impact of graphite particulates on the mechanical properties of magnesium alloy AZ91D. Therefore, the goal of this work is to create a hybrid magnesium matrix composite using the stir casting method while also researching its mechanical characteristics and wear resistance.

## II. Experimental work

### *2.1. Specimen preparation*

The composites were fabricated by the stir casting processroute. Magnesium AZ91D was used as the matrix material inthe present investigation, and details of its composition aregiven in Table 1. Table 2 provides the details of graphite particulates, which were used as reinforcements. Oncethe temperature reached 800 °C in magnesium stir castingmachine, pure magnesium solids and other metals of MgAZ91D were added to the furnace. The metal introduced intothe furnace slowly melts and argon gas was supplied inside thefurnace continuously, since magnesium is inflammable at hightemperature. Finally, when the metals are melted, the stirrer wasallowed to rotate at 700 rpm to blend all the molten metaltogether. Once the mixing is over then the preheated reinforcementparticles were added in the furnace and stirred well withthe liquid metal. The molten metal was poured perfectly into thedie of stir casting furnace by bottom pouring method. Themolten metal solidified through natural convection. The die waspreheated before pouring the molten metal into die forsolidification.

**Table 2:** Details of Reinforcements

| S.No | AZ91D (%) | Gr (%) |
|---|---|---|
| 1 | 100 | 0 |
| 2 | 99 | 1.0 |
| 3 | 98 | 2.0 |

Table 3: Mechanical properties of the samples

| Composition (Wt%) | Density (g/cm$^3$) | Porosity (%) | Hardness (BHN) | Ultimate tensile strength (N/mm$^2$) |
|---|---|---|---|---|
| AZ91D | 1.8091 | 1.42 | 20.5 | 62.1 |
| AZ91D+ 1wt% Gr | 1.8197 | 1.34 | 27.1 | 99.2 |
| AZ91D + 2wt%Gr | 1.8249 | 1.11 | 22.5 | 86.3 |

### *2.2. Hardness measurement*

Hardness of specimen was performed in Brinell scale with aball diameter of 1/16 inch and a load of 100 kgf. The hardnesstest was performed in different regions on the surface ofsample. Table 3 shows the hardness (BHN) of the samples.

### *2.3. Density and porosity measurement*

The theoretical density of magnesium composite was calculatedusing the rule of mixtures. The actual density of pureAZ91D and composite were calculated using Archimedes' principle.The cylindrical sample was weighed in air (Wa), thensuspended in distilled water and weighed again (Ww). Theactual density was calculated according to Eq. (1),

$$\rho_a = \frac{W_a}{(W_a - W_w)} \times \rho_w \qquad (1)$$

where ρa is the actual density and ρw is the density of water.The sample was weighed using a photoelectric balance withan accuracy of 0.1 mg.In accordance with Eq. (1), the actual density of each materialcan be calculated; theoretical density (ρt) of material wascalculated by the ratio of mass to volume. The porosity of eachmaterial can be calculated according to Eq. (2) [17],

$$P = 1 - \left(\frac{\rho_a}{\rho_t}\right) \qquad (2)$$

where P is the porosity of the material, $\rho a$ is the actual densityand $\rho t$ is the theoretic density.
Table 3 shows the value ofdensity and porosity of the samples.

***2.4. Wear testing***
According to the ASTM G99 standard, dry sliding wear tests were carried out using pin-on-disc (Ducom, model No. TR-201 equipment). Steel EN31 served as the counter disc's material. Acetone was used to clean the pins and disc surface prior to testing. All tests were run with sliding speeds of 1 m/s and various applied loads of 5, 10, 20, and 50 N. There were three different sliding distances used: 500, 1000, and 2000 m. Following each test, traces were removed by cleaning the specimen and counter face disc with organic solvents. To calculate the amount of wear loss, the pin was weighed before and after testing with an accuracy of 0.1 mg.

***2.5. Tensile strength testing***
According to ASTM A370-E8 standard, ultimate tensile strength (UTS) was measured using a tensometer. The test was conducted using a 20 kN load cell with a minimum count of 0.1 mm and a speed of 5 mm/min, and the test specimen was prepared in accordance with the standard. The samples' Ultimate Tensile Strength is displayed in Table 3.

## III. Results And Discussions

***3.1. Density and porosity***
The variation in sample density as noted in Table 2 is depicted in Fig. 2. It has been noted that the density rises as the amount of Graphite reinforcements increases. The variation of the samples' porosity is also shown in Fig. 2. From Fig. 2, it is clear that the porosity of the composites decreased as the weight percentage of reinforcements increased. Due to the size of the reinforcements as well as the uniform rotating speed of the stirrer in stir casting, the porosity of composite and hybrid composite has decreased.

***3.2. Hardness and tensile strength***
The variation in sample hardness as listed in Table 3 is depicted in Fig. 3. From Fig. 3, it is clear that as the weight percentage of Gr reinforcement increases, the composites' ultimate tensile strength decreases and their hardness increases. The uniform distribution of Gr in the composites, the high hardness of the Gr reinforcement particles, and the increased density are all factors that contribute to the composites' increased hardness. Graphite addition to composite is also depictedresults in an increase in tensile strength and hardness compared to AZ91D alloy. The increase in the hardness and tensile strength of composites indicates that the ceramic particles made a significant contribution to the strengthening of the magnesium matrix. Graphite serves as a solid lubricant. Hardness rises as the obstacle to dislocation movement does. Strengthening results from the dispersion of Gr particles as a hard phase in the magnesium matrix.

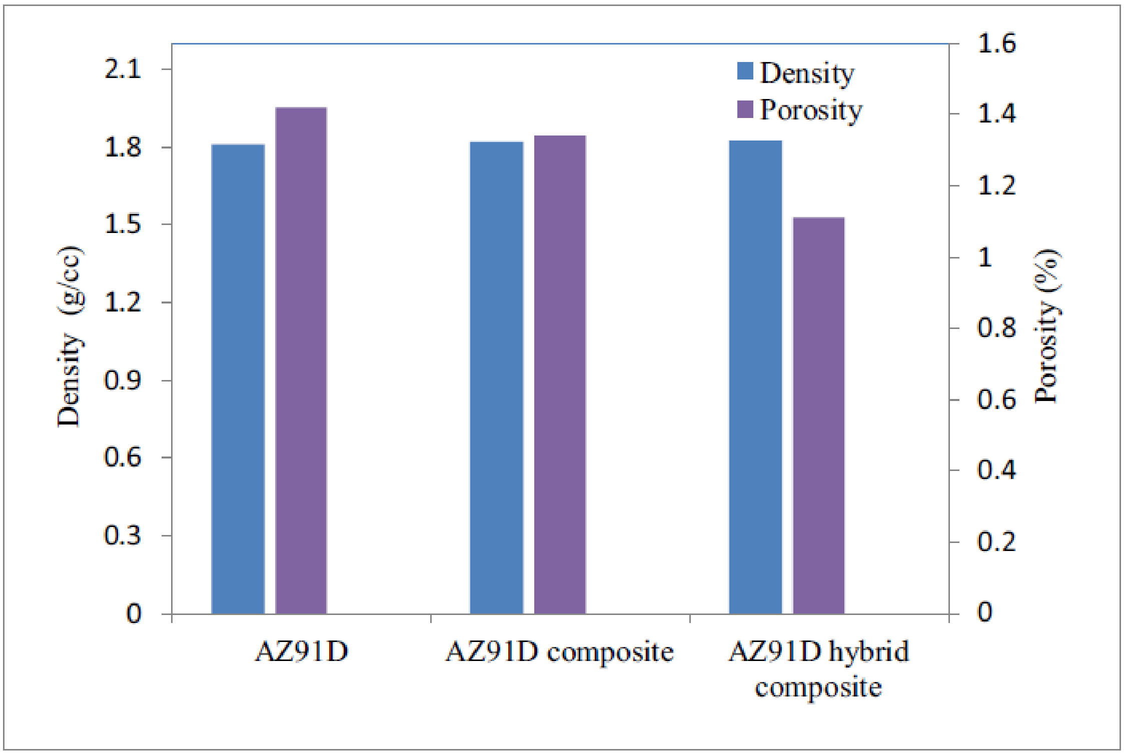


Fig. 2. Variation of density and porosity of samples.

### *3.3. Effect of load*

Fig. 4 depicts how the coefficient of friction changes under normal load. For both AZ91D and AZ91D composites, it has been observed that the coefficient of friction increases with increasing normal load for loads between 5 and 50 N. Additionally, the AZ91D hybrid composite has a lower coefficient of friction than the AZ91D composite. Graphite's presence is the cause of this. Figure 5 depicts the variation in wear loss with applied load for a fixed sliding distance of 2000 m and a constant sliding speed of 1 m/s. It has been found that as the load increases, the wear loss of the AZ91D alloy, composite, and hybrid composite gradually rises.The greater amount of plastic deformation can be used to explain why all the materials under study experienced an increase in wear loss with increasing load. Also, the inclusion ofgraphite into AZ91D alloy decreased the wear loss andwear loss increased in hybrid composite.

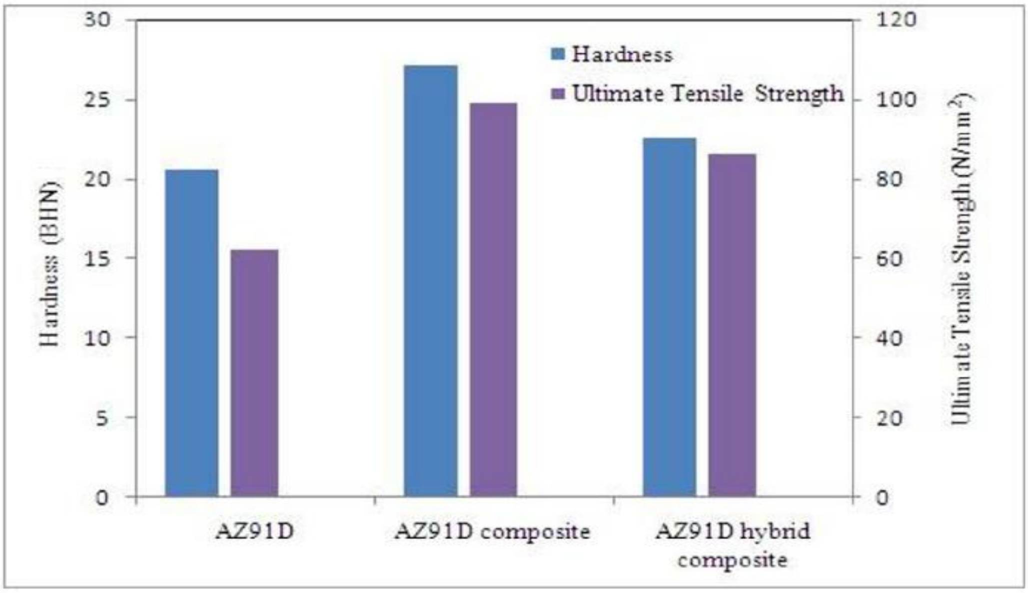


Fig. 3. Variation of hardness and ultimate tensile strength of samples.

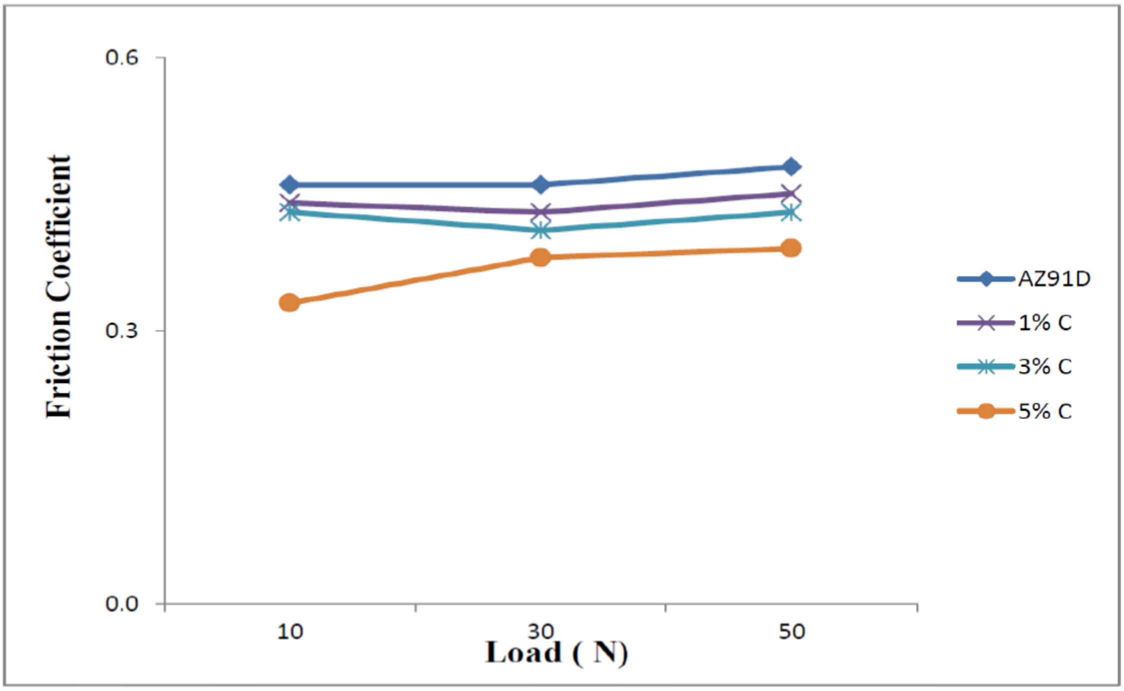


Fig. 4. Variation of co-efficient of friction with applied load.

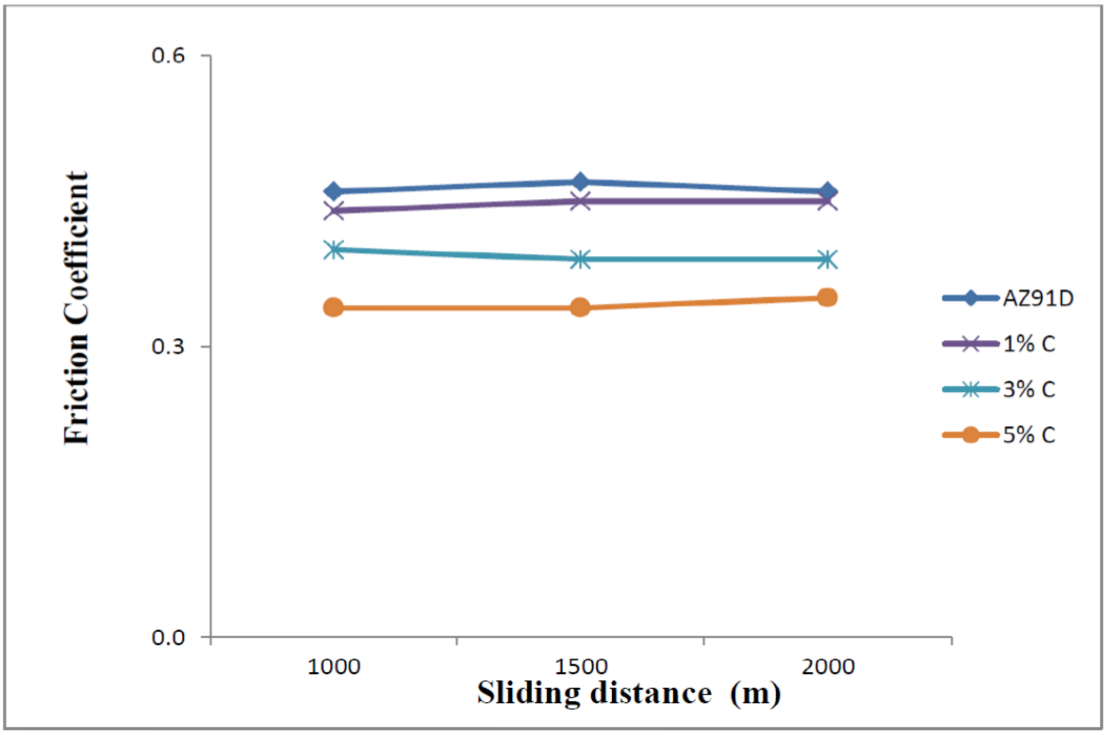


Fig. 5. Variation of co-efficient of friction with sliding distance.

Fig. 5. Additionally, compared to AZ91D alloy and AZ91D-Gr composite, the AZ91D-Gr hybrid composite has higher friction coefficients. Due to the slower temperature rise during the wear test caused by these parameters, there is less adhesion between interfaces in this composite. However, due to the increased level of graphite self-lubrication, the wear feature size in the worn surface is smaller. As a result, abrasion and delamination are the main wear mechanisms in the AZ91D-Gr hybrid composite, and adhesive wear is unlikely to occur. An important factor in determining the wear mechanism is the temperature rise on the contact surface during the wear test. By raising this temperature, the contacting specimen's yield strength declines, softening and producing adhesive wear. Due to a higher coefficient of friction at the surface, the base alloy sample's worn

surface heats up quicker than composite surfaces do. The hybrid composite's worn surface is relatively smooth with a few small grooves. However, the AZ91D-Gr composite's worn surface morphology is distinguished by tiny grooves scattered with craters.Smooth Gr particles strengthen the matrix alloy, increasing its capacity for load bearing and thermal stability while also improving the material's resistance to plastic deformation and flow. As a result, sub-surface cracks that were started by the graphite particles contributed to the wear process.

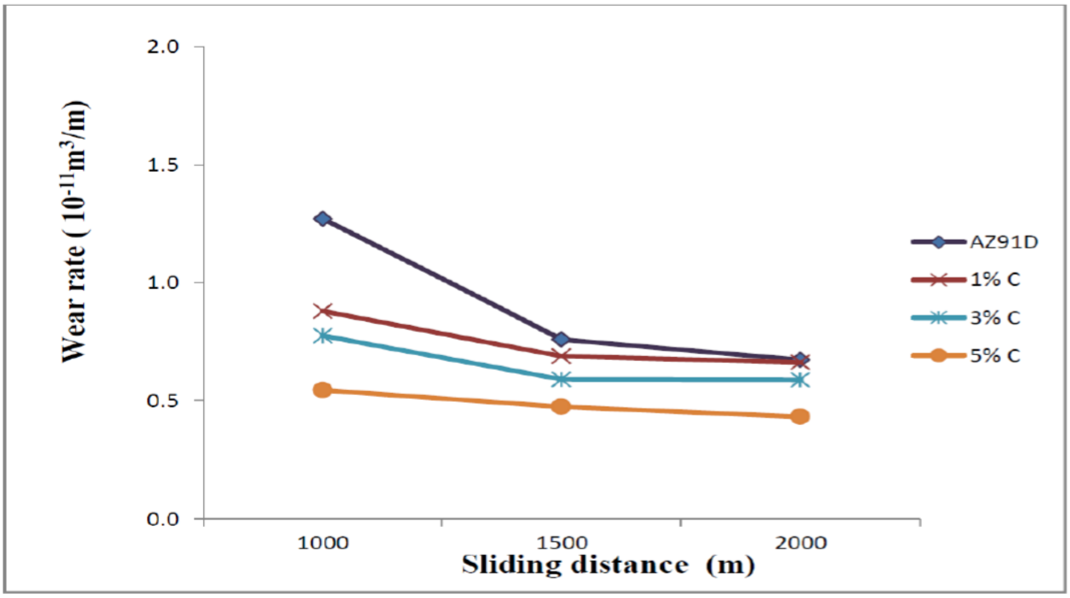


Fig. 6. Variation of wear loss with sliding distance.

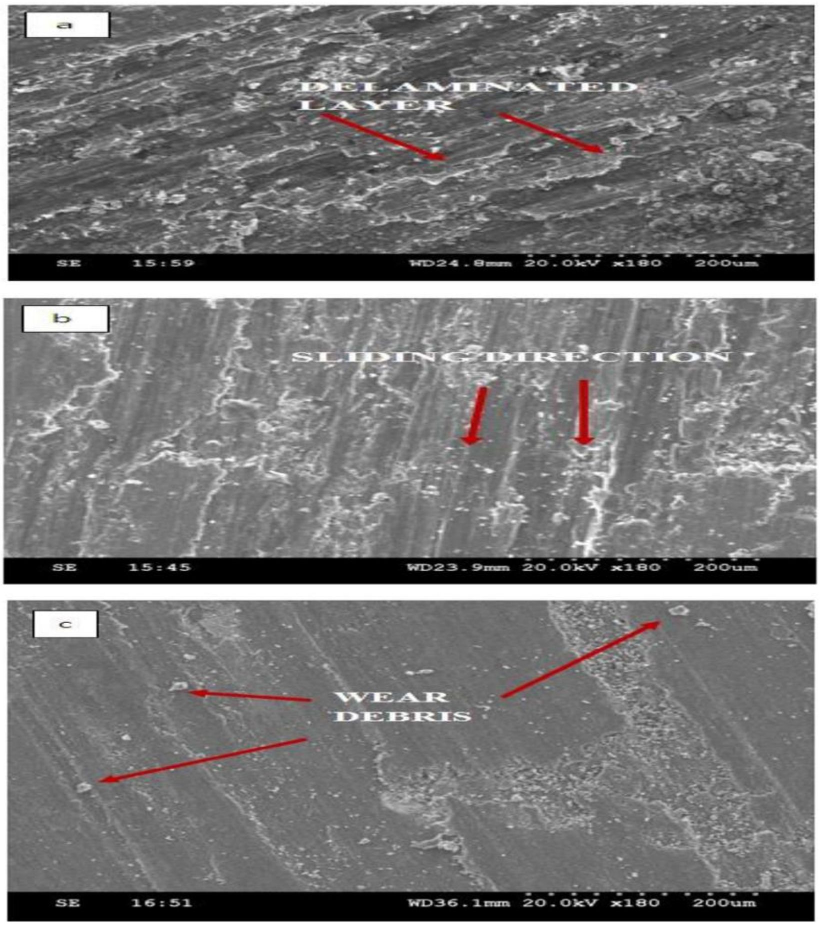


Fig. 7. SEM images of worn surface: (a) AZ91D, (b) AZ91D/1% Gr, (c) AZ91D/2%Gr.

## IV. Conclusions

- Stir casting technique has been used to develop hybrid AZ91D-Gr composite successfully. The following properties were assessed: density, porosity, hardness, ultimate tensile strength, optical microstructure, and abrasive wear. The density of AZ91D composite and hybrid composite was higher than pure AZ91D magnesium alloy. Compared to AZ91D alloy and AZ91D-Gr composite, AZ91D hybrid composite has less porosity.
- When compared to AZ91D alloy and AZ91D-Gr hybrid composite, AZ91D-Gr composite has a high hardness value. Similar to alloy and hybrid composites, composites' tensile strength decreased. This is because hybrid composites contain graphite.
- The wear resistance of the composite is increased by adding Gr reinforcement to AZ91D alloy. When compared to matrix and hybrid composite, the developed composite has demonstrated higher wear resistance and higher coefficient of friction. The wear resistance of the composite was further reduced by the hybrid addition of Gr reinforcement to AZ91D-Gr.
- The addition of graphite particles provides the composites with solid lubrication, reduces metal-to-metal contact and friction, and lowers the coefficient of friction, which lowers the temperature of the worn surface. Therefore, by adding graphite to the base alloy and composites, the likelihood of adhesive wear is reduced. However, as was already mentioned, graphite is a soft substance that lowers the hardness and mechanical qualities of composites and is ineffective at resisting the matrix's deformation during sliding.

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