Tribological Behavior of Magnesium alloy (AZ91D) reinforced with Graphene (MMC) by using Pin-on-Disc

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Abstract

Recently many applications like automotive, aerospace industries are preferred like light weight and high strength materials, besides offering more resistance to wear during operation.. In this study magnesium alloy is preferred because of light weight and graphene as reinforcement to prepare metal matrix composite. Fabrication of different samples of MMC can be done by using Vacuum die casting method. Experiments are conducted on different composites like 0.5%, 1%, 1.5%. of graphene added and base metal magnesium alloy (AZ91D), load 40, 50 60 N, rotational speed 400, 500, 600 R.P.M and sliding distance 500, 600, 700 m remaining should be constant to find the investigate dry sliding tribological behaviour. Taguchi's L9 orthogonal array is used to determine the worn out of different samples by using different parameters like sliding distance, rotational speed, composite material, load and remaining parameters are constant. During wear resistance in different composition of MMC "smaller-the-better" has been considered. As a result of the observation, it can be inferred that wearing behaviour on 0.5% Gr gives less wear rate. SEM can be examined by different samples of worn out surfaces.

Keywords: *Graphene, AZ91D, Wear, Metal matrix composite,* SEM.

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1. Introduction

In the present day, metals such as magnesium alloys are widely used in industries such as metallurgy, electrical, automotive, aviation, and chemical engineering. Other things involved in this are the formation of a relationship between tensile strength (160 MPa - 360 MPa), density (1.74 g/cm^3), and modulus of elasticity (45 GPa). There is a high tensile strength and density in magnesium alloys compared to other alloys. In addition, magnesium has a high damping capacity, as well as good electrical and thermal conductivity [1-2]. The versatility, exceptional corrosion resistance, and low weight and strength of Mg alloys (example: AZ91D) make them essential for many manufacturing industries. For a wide range of future applications, including aerospace, automotive, electronics, biomedical, and sports, magnesium and its alloys are replacing steel, copper, and aluminum [3]. As a result of the addition of reinforcement material to base materials, metal matrix composites (MMC) benefit from increased physical and mechanical properties.

The unique properties of graphite cause a solid lubricant to form on the metal-graphite composite tribo surface during dry sliding. This prevents the two sliding surfaces from getting in contact with one another, reducing friction and improving wear resistance. According to a previous report, metal-ceramic composites with graphite added have been found to have improved wear resistance and reduced friction. According to Aatthisugan et al. [4], matrix composites of magnesium AZ91D and Gr exhibit a superior wear resistance. It was found that 1.5% of Gr added to AZ91D-Gr composites improved the wear resistance by significantly. Additionally, Deaquino et al. [5] observed the same phenomenon while investigating Al7075-Gr composite tribological behavior.

According to Lokesh and Mallik [6], use Taguchi technique to calculate the wear rate based on applied loads and sliding distances of stir-cast Al-3%Gr composites. According to their results, the applied load significantly affected wear rate. A significant reduction in the mechanical properties of these materials is observed when graphite is added to MMCs, even though graphite produces a remarkable wear performance [7-9].

An article by Aatthisugan et al. [4] investigated the wear properties and mechanical properties of magnesium AZ91D hybrid composites composed of boron carbide (B4C) and Gr reinforcements. In their study, they reported a significant improvement in hardness and tensile strength of the hybrid magnesium alloy by adding 1.5% B4C and 1.5% Gr. Further, Zhang et al. [10] Carbon nanotube-reinforced AZ91D magnesium matrix composites were studied in terms of mechanical and microstructural properties. It was reported by the authors that a significant improvement in yield strength and ultimate tensile strength had been recorded.

Using an ultrasonic method, Mula et al. [11] succeeded in achieving uniform reinforcement distribution in a matrix alloy made of aluminum and magnesium. Nevertheless, producing this process at a large scale is difficult and expensive. MMCs can be manufactured through a variety of manufacturing techniques, including mechanical alloying. Through this technique, reinforcing particles are uniformly dispersed over the matrix material, ensuring excellent mechanical properties and wear resistance [5]. Furthermore, Chemically non-reactive methods can be used to fabricate MMCs with high reinforcement contents [12].

As a result of vacuum die casting, different weight percentage (0.5, 1, and 1.5) of graphene nano-particles are embedded in the Mg alloy AZ91D that are used in this study to determine the wear characteristics. By using 750 grams of base metal and 0.5%, 1% and 1.5% weight (3.75, 7.5, 11.25 grams) of graphene in the reinforcing material, 300x100x15mm castings can be made.

2. Experimental Procedure

2.1 Fabrication of MMCs

By using vacuum die casting method, magnesium alloy (AZ91D) was reinforced with different percentage weight of graphene particles were used to make MMC. At a speed of 450 - 500 rpm, a mechanical stirrer is used to distribute reinforcement particles uniformly inside the matrix metal. An electric induction furnace has been heated to 400^0c in the vacuum die cast machine (fig.1). Mg alloy particles are then placed into the furnace. Magnesium is highly flammable, so argon gas is continuously supplied inside the furnace. A mechanical stirrer is used to distribute graphene particles evenly throughout the molten magnesium alloy while maintaining a temperature of $700\text{-}750^0$c. There are some defects that will occur in stir casting because of the amount of moisture in the die. Preheating the die to 300 degrees Celsius prior to filling the die with molten metal will remove defects. Once molten metal has been poured into a die measuring 300mm x 100mm x 15mm, it is allowed to solidify.

Fig. 1. Vacuum Die Casting Machine.

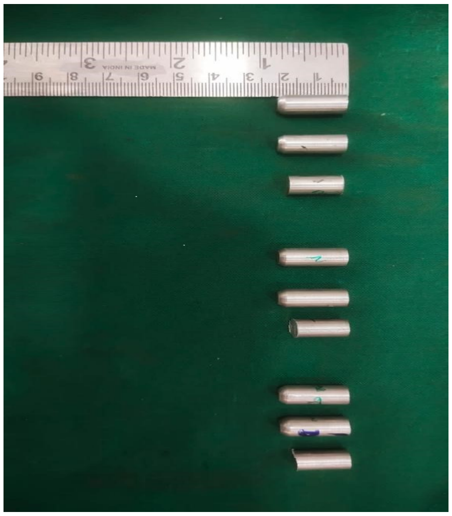


Fig. 2. Wear testing samples

2.2 Tribology Test

Using a pin-on-disc tribometer can be used for evaluating Dry sliding wear results on MMC-pin specimens. An ASTM G-99 certified collection of specimens (8ϕ x 35) were used for the wear test using the steel material E-30 as the counter-face disk. Wear tests were conducted using cylindrical pellet specimens with a diameter of 10 mm and a height of 20 mm as depicted in fig 2. Prior to performing wear tests, specimens were cleaned using ethanol solution for a period of 10 minutes. When conducting dry sliding tests, three parameters can be varied, namely composite material, sliding distance and disc rotational speed, with the rest remaining constant. Each run of the test is conducted with an electronic weighing machine (least count = 1x10-3 g) to determine the weight of the worn-out pins. An illustration of the pin-on-disc wear testing equipment used during the test can be seen in Figure 3. During the test, there was a weight loss in wear rate. As shown in Table 1, these parameters determine the operation of the machine.

3. Results and Discussion

3.1 Wear Behavior

In order to determine the wear rates of fabricated samples, a pin-on-disc tribometer was used at room temperature with a variety of loads and sliding speeds. As shown in Table 1, the wear rate varies according to the load and sliding speed. According to Figure 4(a), wear rates corresponding to sliding speed and load are shown as a graph. In figure 4 (a), the load is proportional to the wear rate. The following trigonometric expression was used to measure wear rate in (Eq. (1)) and coefficient of friction in (Eq. (2)).

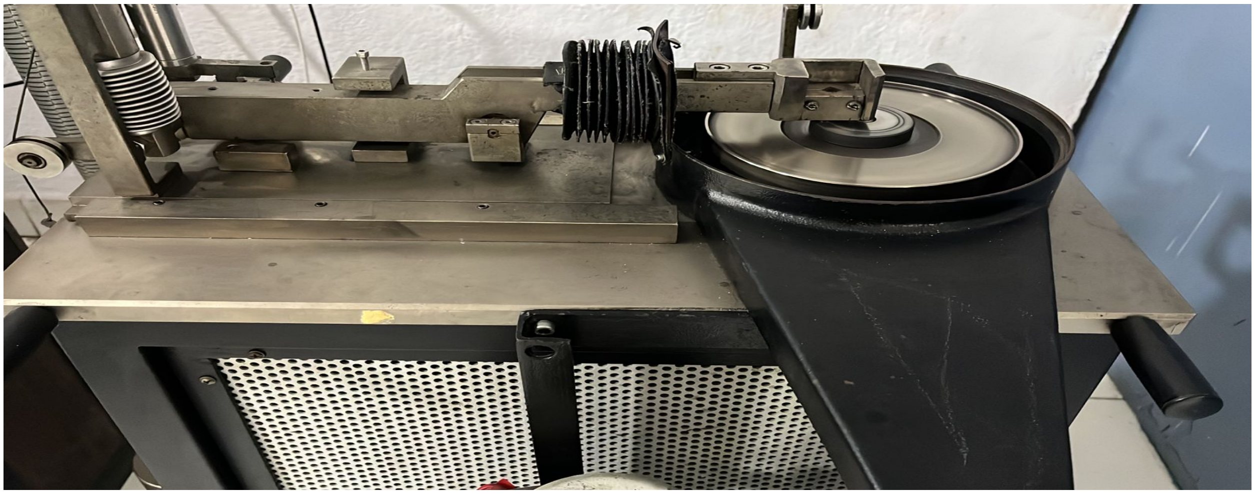


Fig. 3. Pin-on-disc machine

Table 1. L9 orthogonal array

Test Run	Applied Load (N)	Sliding Velocity (m/sce)	Sliding Distance (m)	Sliding dia (mm)	Rotational Speed (R.P.M)	MMC (%)	Time (Sec)	Co-efficient Friction (μ)	Wear Rate (mm^3/Nm) 10^{-8}
1	40	0.838	500	40	400	0.5	596.6	0.17	0.227
2	40	1.047	600	40	500	1.0	573.0	0.31	0.327
3	40	1.255	700	40	600	1.5	557.7	0.22	0.311
4	50	0.838	500	40	400	1.0	596.6	0.48	0.361
5	50	1.047	600	40	500	1.5	573.0	0.24	0.370
6	50	1.255	700	40	600	0.5	557.7	0.14	0.384
7	60	0.838	500	40	400	1.5	596.6	0.31	0.459
8	60	1.047	600	40	500	0.5	573.0	0.24	0.438
9	60	1.255	700	40	600	1.0	557.7	0.17	0.389

$$Wear\ rate = \frac{Weight\ loss\ /\ density}{Sliding\ distance \times Applied\ load} \quad (1)$$

$$Coefficient\ of\ friction = \frac{Frictional\ force}{load} \quad (2)$$

When MMCs with different percentages of graphene reinforcement are analyzed using Taguchi's L9 orthogonal array, the wear rates are significantly reduced. In sample 1 (0.5% Gr) shows a low wear rate of 0.227 with a load of 40 N and rotational speed of disk 400 R.P.M. and this wear rate value increases to 0.438 once the load increases to 60 N. Similarly, in sample 2 (1% Gr) shows a low wear rate of 0.327 with a load of 40 N and rotational speed of disk 500 R.P.M. and this wear rate value increases to 0.389 once the load increases to 60 N. Similarly, in sample 3 (1.5% Gr) shows a low wear rate of 0.311 with a load of 40 N and rotational speed of disk 600 R.P.M. and this wear rate value increases to 0.459 once the load increases to 60 N. Figure 4(b) shows a similar tendency for the wear rate based on sliding distance, as well. Also depicted in Figure 5 are the coefficient of friction and different percentage of grapheme (0.5%, 1%, and 1.5%). From the graph it shows the percentage of grapheme increases coefficient of friction also increases. Conversely, it is seen from the graph the coefficient of friction decreases at 1.5% graphene added.

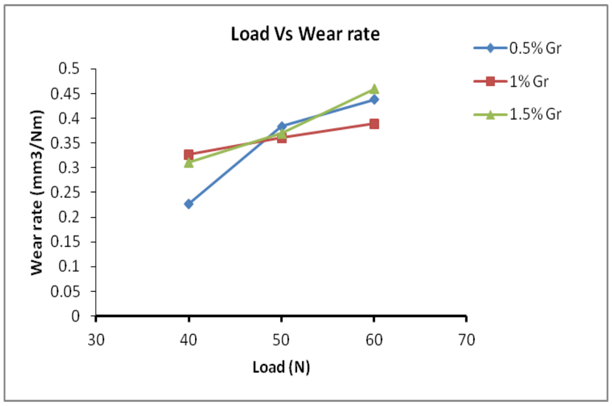


Fig. 4 (a) Load Vs Wear rate

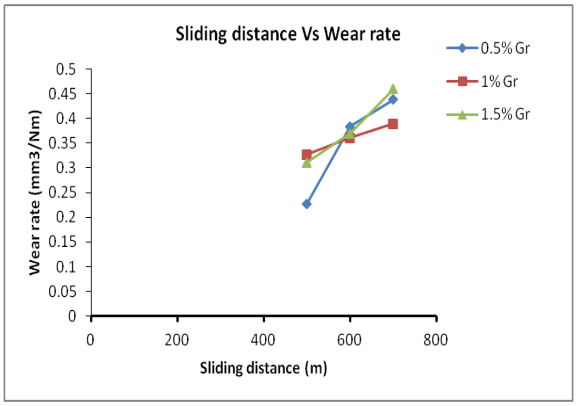


Fig. 4 (b) Sliding distance Vs Wear rate

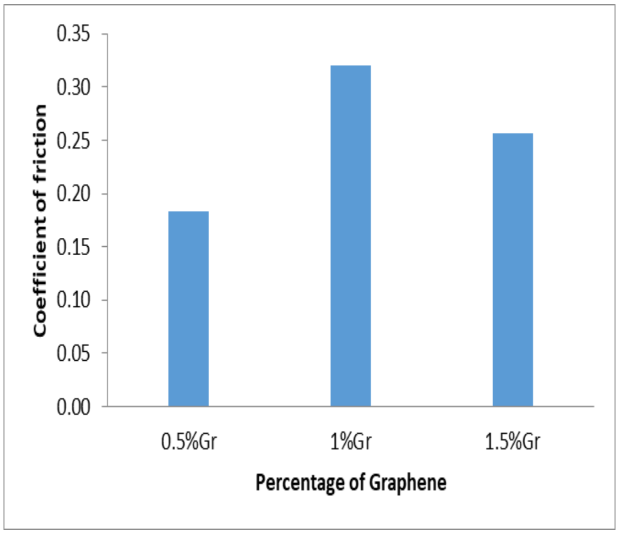
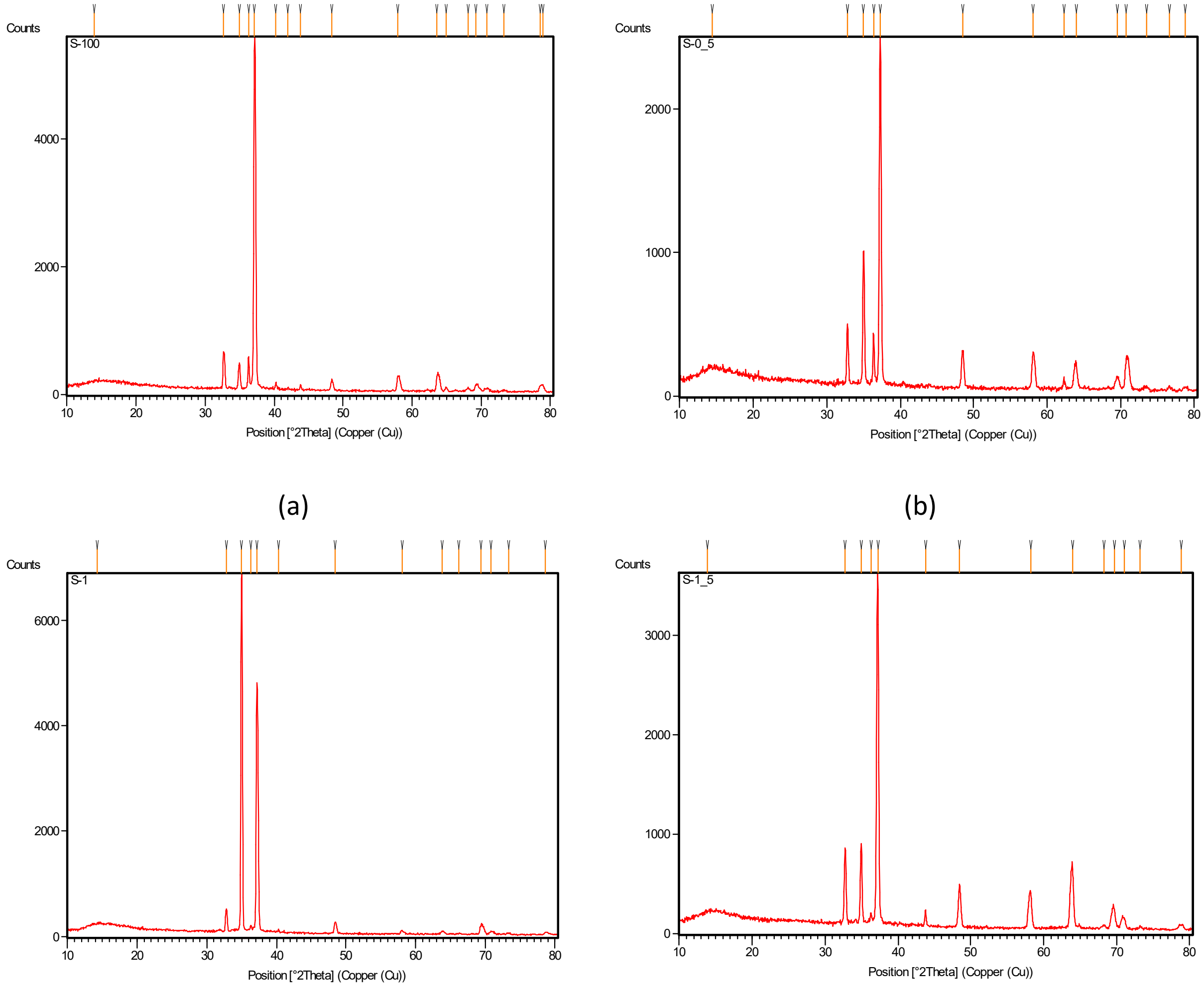


Fig.5. Percentage of Gr Vs Coefficient of friction

Fig.6. XRD Diffractometer

3.2 XRD Patterns

The macro agglomerations may contain a certain porosity that will affect the mechanical properties of the material. To examine the structural phases of all the elements and the powder mixture, X-ray diffraction (XRD) was conducted with a high-resolution X-ray diffractometer and the XRD patterns as shown in fig (6, 7). Using standard values for magnesium alloy and graphene, the Bragg angles were matched. It is evident from the XRD pattern that the powder mixture contains Mg Alloy, Gr due to high-intensity peaks in Mg Alloy and Gr.



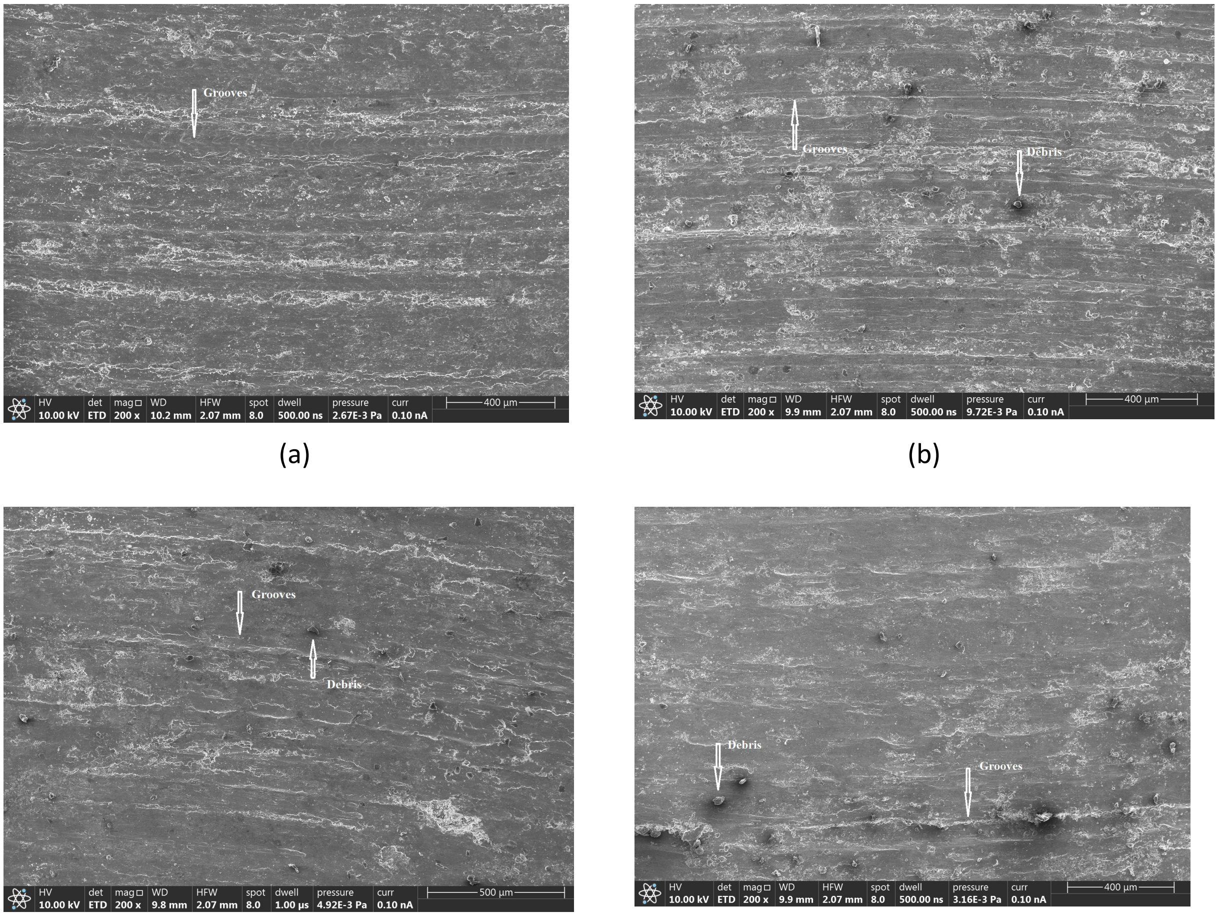
(c) (d)

Fig. 7. XRD Patterns of (a) Mg Alloy (AZ91D) (b) 0.5% Graphene (c) 1.0% Graphene (d) 1.5% Graphene

4. Microstructure of Worn Surfaces

Figure 8 shows the results of SEM examination of the worn surfaces of the MMCs to further investigate wear mechanisms. In MMCs, wear mechanisms including abrasion and delamination are evident from their morphology. As seen in all the MMCs, there are large grooves showing plastic deformation from abrasion in the sliding direction. The presence of debris also indicates that the delamination mechanism was at work. Pores evident in the MMC's tribosurface indicate deterioration caused by severe plastic deformation of the surface. These composites are characterized by a higher percentage of Gr particle reinforcement, which results in higher plastic deformation and reduced surface quality. As a result, these MMCs wear more quickly and have a higher friction coefficient. While the worn surface of the sample with 1% Gr particles (Figure 8 c) does not exhibit pores or cracks.

Furthermore, the worn surface of sample 1.5% Gr contains a smooth layer of graphite lubricating oil that uniformly covers the whole worn surface (Fig. 8 d). When compared to the base material, this MMC offers improved wear performance because of its reduced wear rate and friction coefficient. In conclusion, graphene enhances the wear behavior of the base material when added to it.



(a) (b)

(c) (d)

Fig.8. SEM images of worn out surfaces (a) Mg Alloy (AZ91D) (b) 0.5% Gr (c) 1.0% Gr (d) 1.5% Gr

5. Conclusions

This research investigated the wear behaviors of self-lubricating MMCs. Furthermore, tribological properties have improved substantially, including wear rate and friction coefficient. As a result of graphene reinforcement particles, MMCs exhibit improved tribological properties.

- The wear behavior of the three different composite materials depends on the three parameters, including the load, the sliding distance, and the rotational disk speed and remaining parameters should be constant. When compared to other MMCs, 0.5 % of graphene gives low wear rate. The load act as highly influencing parameter during worn out on the surface followed by remaining parameters like sliding distance and rotational disk speed.

- In SEM images showed clearly the worn out surfaces of different composite materials and base material, In the composite material, small grooves and debris were formed due to de-bonding of metal from the matrix, whereas no debris were formed in the base material.

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