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Enhancing wear resistance in Al-7075 composites through conventional mixing and casting techniques

Kumaraswamy Jayappa [a], Kyathasandra Chikkanna Anil [b], Zulfiqar A. Khan [c,*]

[a] Dept. of Mechanical Engineering, R. L. Jalappa Institute of Technology, Doddaballapur, Bengalore Rural, Karnataka, India
[b] Dept. of Industrial Engineering and Management, Siddaganga Institute of Technology, Tumakuru, Karnataka, India
[c] Bournemouth University, Nano Corr, Energy and Modelling (NCEM) Research Group, Department of Design and Engineering, Poole, Dorset, BH12 5BB, UK

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ABSTRACT

Aluminium 7075 alloy composite are highly sought after materials because of their superior strength, light weight and exhibiting enhanced tribological characteristics. An electric resistance furnace and the metal die process were used to develop this aluminium (Al 7075) alloy hybrid composites, with reinforcing provided by E-glass short fibres and aluminium oxide (Al_2O_3) particulates. The Al 7075 alloy composites have been cast by employing stirring technique at various weight percentages of E-glass short fibres (2 %, 4 %, 6 %, and 8 %) and Al_2O_3 particles (3 %, 6 %, 9 %, and 12 %). Microscopic examination demonstrates that Al_2O_3 particle distribution within Aluminium matrix has been uniform. Hardness of the in-situ Al–Al_2O_3-E-glass-based composites rose by 10.58 %, 22.35 %, 50.58 %, and 41.17 % in comparison to its base alloy. Tensile strength of the 2 to 8 wt% E-glass with 3–12 wt% Al_2O_3 stir-cast composites increased by 9.08 %, 15.91 %, 19.09 %, and 7.27 % when compared with the aluminium matrix, whereas ductility reduced by 8.9 %, 12.5 %, 18.75 %, and 25 %. An experiment on wear rate was carried out using a pin-on-disk benchtop test equipment. The examination was performed at varying weights and sliding speeds, and the resulted demonstrated that composite materials exhibit higher wear resistance than Al matrix. Furthermore, the presence of Al_2O_3 and E-glass resulted in lower wear loss across all applied loads and sliding velocities. Lower wear rates in these composites were attributed to hardness and the interfacial bonding between the Al alloy and the in-situ reinforcement.

1. Introduction

The 7075-aluminum alloy finds extensive usage in defence and aerospace applications due to its exceptional mechanical properties and impressive strength. Comprising zinc, magnesium, copper, and trace quantities of other metals, this alloy is amenable to heating processes. Because of its composition, the alloy has a remarkable strength-to-weight ratio, making it ideal for lightweight structures such as aircraft and spacecraft. Hybrid composites have become more attractive material solutions in recent year. These hybrid composite combine qualities of several materials to produce innovative materials with improved properties. The use of aluminium alloy 7075 in conjunction with other substances, such as carbon fibres, aramid fibres, and ceramic matrix composites, is one of the most promising areas of research in this subject. Hybrid composites provide a one-of-a-kind mix of desirable features, including high strength, low weight, and better thermal and electrical properties. One famous example is the insertion of carbon fibres into the aluminium alloy 7075, which improves stiffness and strength while maintaining high-temperature resistance. Likewise, combining aluminium alloy 7075 with aramid fibres improves impact resistance and toughness. Furthermore, ceramic matrix composites have exceptional electrical and thermal properties [1]. Exploring the usage of aluminium alloy 7075 in hybrid composites is an attractive research subject with the potential to produce unique materials with improved properties for a variety of applications. This effort could result in unique goods that outperform conventional ones in terms of strength, weight, durability and aluminium alloy 7075 can be age hardened. However, as the industrial sector expands, traditional production procedures for critical components are increasingly unable to satisfy modern industry's demands [2]. Hybrid aluminium composites have developed as a feasible solution to this problem. These composites have improved mechanical properties and can be produced at a lower cost, allowing them to meet the industry's requirements. The primary load-bearing components in these composites are the reinforcements, which

* Corresponding author.
E-mail address: zkhan@bournemouth.ac.uk (Z.A. Khan).

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Table 1
Al 7075 configuration.

Element	Zn	Mg	Ti	Al	Fe	Mn	Cr	Si	Cu
Composition %	5.6	2.5	0.2	Bal.	0.5	0.3	0.23	0.4	1.6

Table 2
Selected materials [21].

Materials	Modulus of elasticity (GPa)	Density (g/ cm^3)	Tensile strength (MPa)	Brinell hardness (BHN)
E-glass	730	2.54	1900	88.7
Alumina	380	3.95	2500	88
Al 7075	71.7	2.81	572	150

transfer to the reinforcement from the base alloy matrix, thereby enhancing materials strength. The process of inhibiting dislocations, on the other hand, is what leads to the reinforcement of dispersal mechanisms. The creation of research papers in this sector, beginning with its genesis, as well as monitoring the improvements noticed in the current and impending stages of this material, has enabled a comprehensive assessment of the entire history of metal matrix composites (MMCs) [3,4]. Jufu Jiang and Ying Wang discovered that spheroidal grains amount was increased within semisolid slurries as stirring time was increased for Al 7075 alloy with nano-sized silicon carbide composites [5]. Bhowmik and his colleagues' research group investigated composites made of Al with a 5 % weight fraction of TiB_2 and Al 7075 with a 5 % weight proportion of SiC using the stir casting method. The porosity of stir-cast composites is decreased due to the equivalent dispersion of particulates inside the Al. This result can be ascribed to the proper amount of time and speed spent stirring, in addition to maintaining a constant pouring temperature and rate of cooling during the solidification process [6]. Madeva Nagaral and colleagues report that when Al2024 alloy is reinforced using B4C composite, the carbide is distributed uniformly inside the base matrix alloy and no surface gaps are visible in optical micrographs [7]. When G. Ramesh and associates looked at the Al 7075 alloy's wetting properties, they saw that porosity formed around the silicon carbide particles and that the matrix alloy and reinforcing components bonded well [8]. In a further investigation, Natrayan and Senthil Kumar used the AA6061 alloy and strengthened it with 5 % Al_2O_3 and 5 % SiC by using squeeze casting procedures. They presented their results, emphasising that a sliding track length of 1200 m, an applied load of 20 N and a sliding velocity of 1 m per second were the ideal process parameters for reducing wear loss and the coefficient of friction (CoF) [9]. S. Gopalakrishnan and N. Murugan discovered parallel grooves and scratches while studying the abrasion effects on AA6061 alloy reinforced with TiC composite in the sliding direction [10]. Pitchayyapillai et al. determined that 100 m/min cutting speed of, with a 1.5 mm cut depth and 0.1 mm/rev rate of feed were optimum parameters to minimise surface roughness during CNC to turn Al6061/MoS_2/Al_2O_3 hybrid composite [11]. Hanumanthe Gowda and P. Rajendra Prasad investigated a stir casting-produced hybrid composite of A356/rice husk ash/Al_2O_3. They discovered that A356 alloy reinforced with 4 wt percent of each reinforcement (RHA and Al_2O_3) and subjected to double ageing with strain had higher ultimate tensile strength than A356 alloy alone and single-aged A356 composite. The addition of up to 4 % weight percent RHA and Al_2O_3 to the A356 alloy increased its UTS [12]. Yogananda et al. studies wear properties of Al-8011 reinforced alloy incorporating E-glass short fibres and fly ash particles. Pin-on-Disc test rig was deployed to calculate wear loss in composite. An increase in wear loss had been observed with increasing applied load over composite. Loss in wear was decreased with a higher proportion of reinforcement [13]. The introduction of contemporary technology has increased the demands placed on materials. Therefore, in order to overcome the constraints of the materials that are now available for diverse industries, it is important that new materials be developed. Materials with improved resistance to wear, high specific strength, and stability at elevated temperatures have become increasingly desirable in the last few decades. Composite materials are created by combining fibres, whiskers, and particles with metals, polymers, and ceramics to enhance the characteristics of traditional materials. Because of their remarkable mechanical qualities, fiber-reinforced metal matrix composites (MMCs) stand out among them as a potential option for application in the automotive and aerospace sectors, among other sectors. An overview of fibre reinforced MMCs is given in this paper, along with an examination of their uses, manufacturing procedures, and mechanical properties. This paper also provides an explanation of the single fibre push-out test, which was created previously to analyse these fiber-reinforced MMCs' fiber-matrix interface characteristics quantitatively [20]. The stir casting procedure was effectively used in this study to manufacture hybrid composites made up of multiple components. Standard specimens were machined, and individual specimen components were subjected to a battery of characterisation tests. Hybrid composites with Al 7075 alloy as the matrix and Al_2O_3 (3, 6, 9, and 12) particulates of 100 μm in size and E-glass (2, 4, 6, and 8) short fibres ranging from 2 to 3 mm in length can be made using the stir casting technique.

2. Materials & fabrication details

This study includes the selection of the base material and reinforcement, the evaluation of the properties of the chosen materials, the fabrication of the hybrid composite, the preparation of specimens, the analysis of their microstructure, experimental investigations on hardness, porosity, tensile strength and density. Assessment of the wear behaviour exhibited by the composite specimens. The impact of particulates/fibres on mechanical and wear mechanisms has been investigated using SEM, EDS and XRD investigations.

2.1. *Materials selected*

Aluminium alloy 7075, which is also recognized as Al 7075, represents a heat-treatable metal alloy known for its remarkable strength. It consists predominantly of aluminium, with zinc serving as the principal alloying component. The inclusion of zinc significantly boosts the alloy's strength and hardness. Owing to its lightweight nature and exceptional strength, Al 7075 finds extensive use in a diverse array of aerospace applications [23,24].

E-Glass fibres are renowned for their outstanding strength-to-weight ratio, delivering substantial structural integrity while remaining lightweight. This quality renders them a favoured selection in scenarios where weight is a critical factor, notably in the aerospace and automotive sectors. Additionally, E-Glass fibres possess a remarkable resistance to corrosion, rendering them an excellent choice for deployments in environments susceptible to moisture, chemicals, or severe weather conditions. They exhibit exceptional durability, showing no signs of rusting or degradation when exposed to moisture, which underscores their suitability for applications in construction and maritime settings. Furthermore, E-Glass fibres boast superior mechanical properties, including high tensile strength, stiffness, and resistance to creep. These attributes position them as an ideal choice for reinforcement within composite materials, such as fiberglass composites, that find application in the construction of boats, aircraft, and various structural components [25,26].

The matrix material for composite preparation was a pure aluminium

Table 3
Parameter used in wear characteristics.

Sl. No.	Parameter	
1.	Pin diameter	8 mm
2.	Load	10, 20, 30 & 40 N
3.	Humidity	60 %
4.	Slidng Velocity	1.5 m/s
5.	Speed	100, 200, 300 and 400 rpm
6.	Test duration	5 Min. 30 sec
7.	Sliding distance	3000 m
8.	Track diameter	140 mm

Fig. 1. Casting flow chart of the hybrid composites.

base alloy (7075). Alumina (Al_2O_3) and E-glass were used as reinforcing materials in this investigation. A hybrid composite with varied amounts of 3–12 wt% Al_2O_3 particulates (40 μm) and 2 to 8 wt% E-glass short fibres (diameter 20 μm) was generated using a two-stage stirring of the metal die process. Tables 1 and 2 show the composition and properties of Al 7075, alumina, and E-glass (see Table 3).

2.2. Method of casting

The Al 7075 alloy ingots are placed into the furnace to melt, yielding an approximate amount. The melt is subsequently subjected to 750 °C temperature measurement using a thermocouple. Degassers (Solid hexachloroethane-C2Cl6) are injected into the melt after it reaches the correct temperature to aid the process. Vortices are generated using a zirconia-coated chromium steel stirrer, ensuring effective mixing. While immersed to a depth comparable to 60 % of the molten material's height, the impeller maintains a constant speed of 250 rpm. Once the vortex is formed, the warmed reinforcements (Al_2O_3 and E-glass) are introduced to the melt in two stages, with a constant feed rate maintained throughout.

The procedure divides the total weight of the reinforcing mixture into two equivalent fractions to ensure equitable dispersion of microparticles in the melt and prevent particle clustering. At each stage, vigorous stirring is used both before and after the addition of alumina particles. The melt is continuously churned with a cast iron stirrer as it is discharged into a warmed die throughout the process. The resulting hybrid composite samples are 15 mm in diameter with a length of 120 mm. The same process has been used to create Al 7075 composites containing 2–8 % E-glass fibres and 3–12 % Al_2O_3.

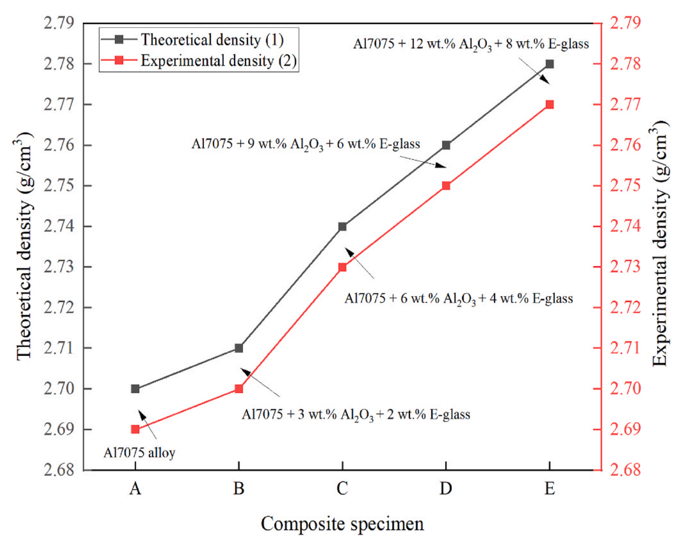

Fig. 3. Density of hybrid composite.

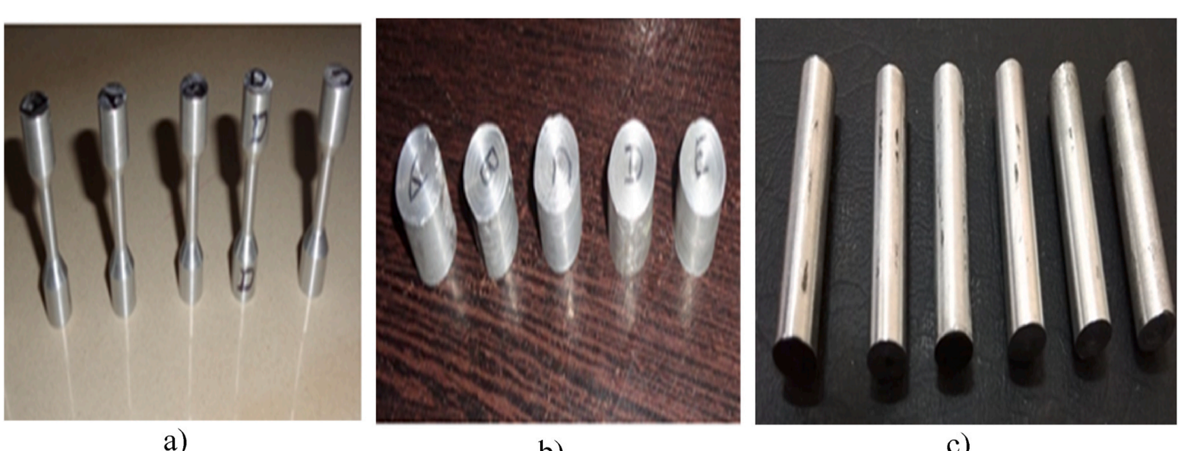

Fig. 2. Tensile, hardness and wear test hybrid composite specimens.

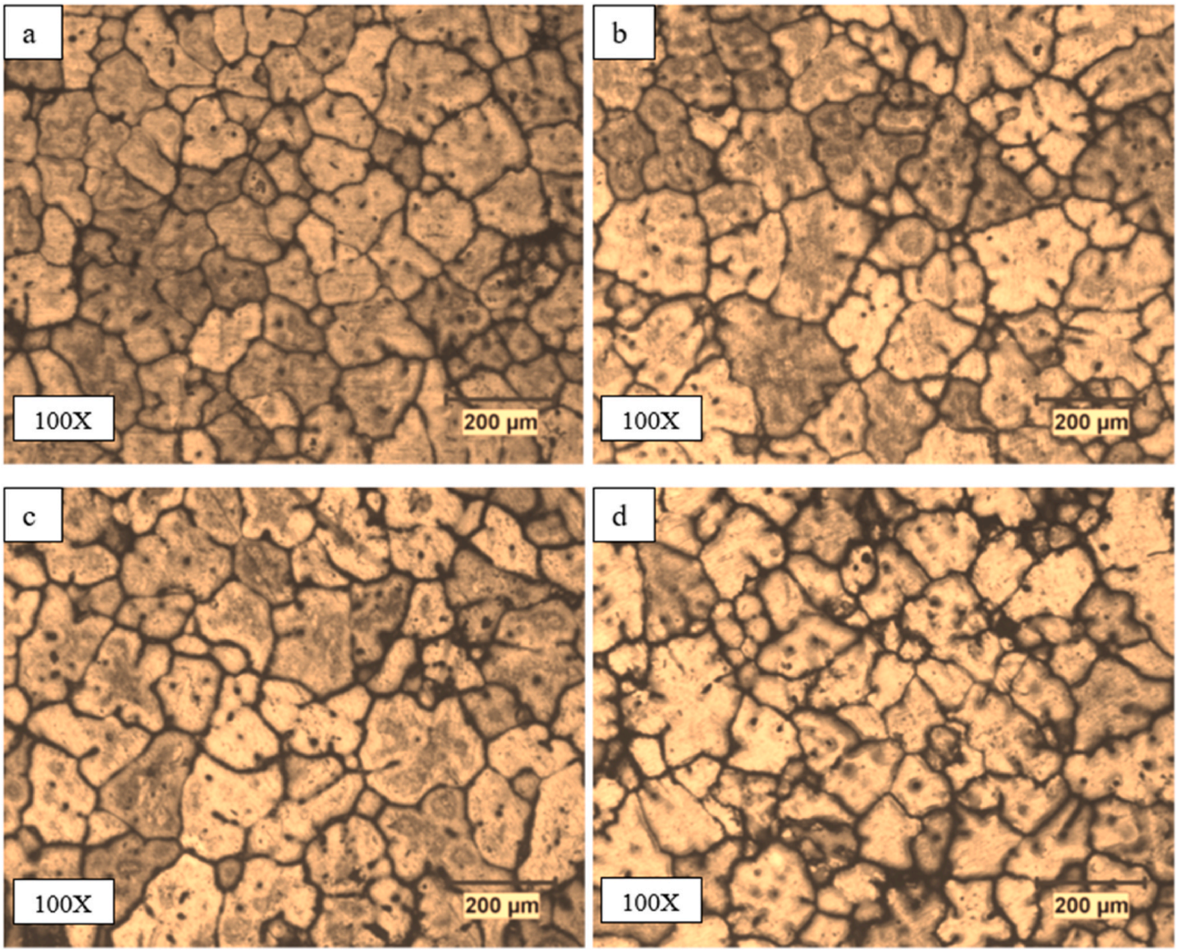

Fig. 4. Metallographic images of a) Al 7075 alloy, b) Al 7075 alloy +2 wt % E-glass +3 wt % Al_2O_3, c) Al 7075 alloy +6 wt % E-glass +9 wt % Al_2O_3 and c) Al 7075 alloy +8 wt % E-glass +12 wt % Al_2O_3.

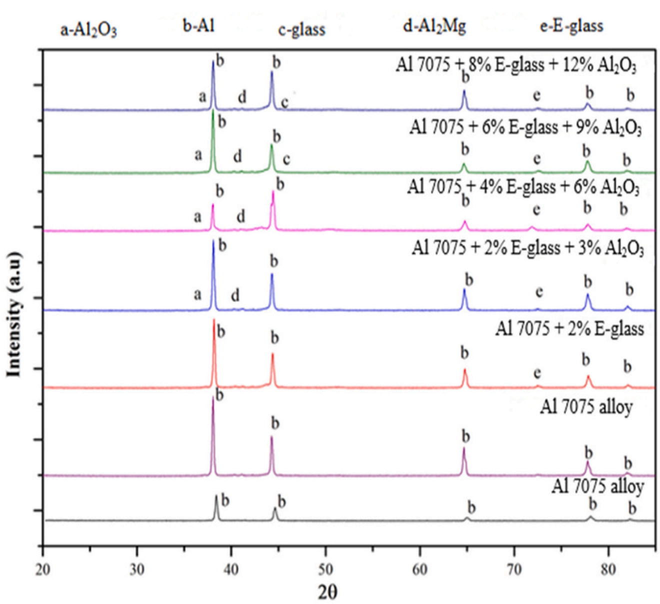

Fig. 5. XRD examination composites.

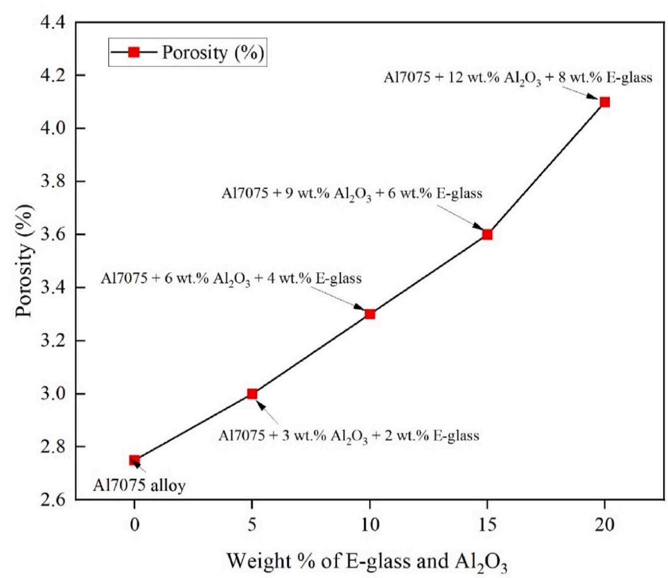

Fig. 6. Influence of reinforcement on porosity of composite.

2.3. Testing of hybrid composite

The polished composite specimens were made in line with ASTM E3-11 specifications using a Kroll reagent (see Fig. 1). An optical metallurgical microscope, the NIKON-ECLIPSE LV 150 from Japan, was used to study the even distribution of particles within the composite.

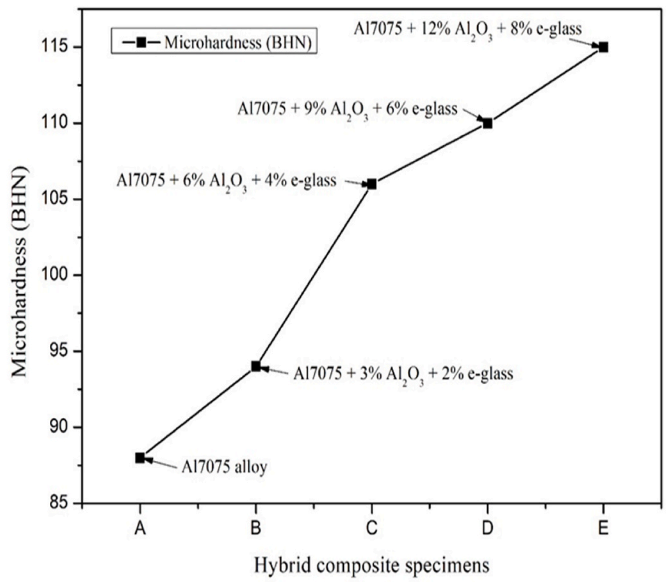

Fig. 7. Al 7075 hybrid composite alloy hardness.

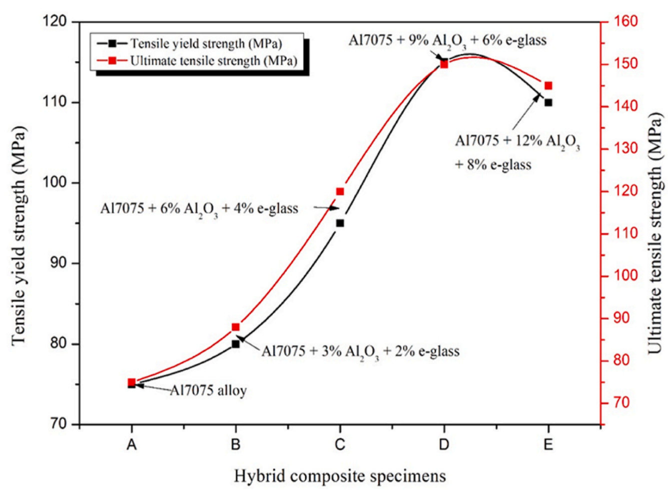

Fig. 8. Tensile and yield strength of Al 7075 alloy hybrid composite.

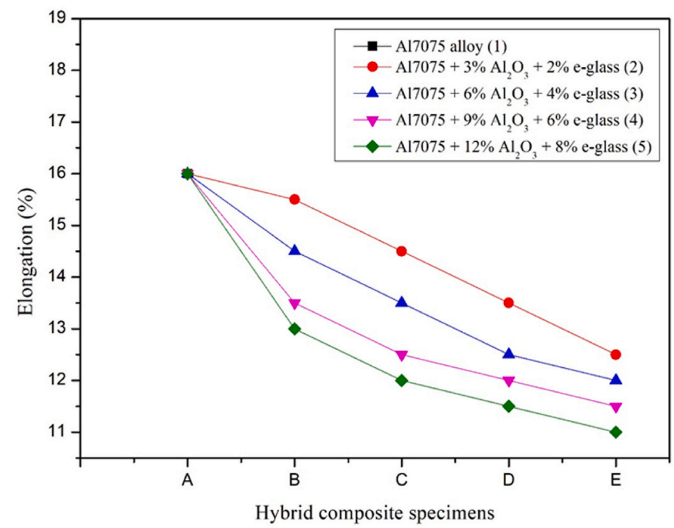

Fig. 9. Elongation of Al 7075 hybrid composites.

Tensile testing was conducted using a 400 kN maximum capacity Universal Testing Machine (UTM). The tensile test samples were created and assembled in compliance with ASTM E8 specifications, as seen in Fig. 2a. The maximum tensile strength was ascertained using an electronic tensometer, a TUE-C-400. The hardness test was conducted using a Brinell hardness machine in compliance with ASTM E8M-16a requirements. As seen in Fig. 2b, the samples ready for hardness testing had dimensions of 20 mm by 15 mm (diameter by length). Furthermore, as shown in Fig. 2c, worn samples were produced in compliance with ASTM G99 (Model: WTE 165 and Version-EV00), with specimen dimensions of 30 mm in length and 10 mm in diameter.

3. Results and discussions

A study of wear characteristics, mechanical parameters and microstructure of as cast Al 7075 alloy and its Al 7075/Alumina/E-glass composites have been conducted. Alumina particles (3 %, 6 %, 9 %, and 12 %) and E-glass (2 %, 4 %, 6 %, and 8 %) in various weight percentages were used. We also performed a study to determine the sorts of fractures in both the as-cast material and its composites. SEM examination was also performed on the worn-out surfaces and tensile fracture specimens.

3.1. Density analysis

A substance's density is a physical attribute that closely reflects its properties. The Archimedes principle was used to calculate the densities of unreinforced composite sample A and reinforced hybrid composite specimens B, C, D, and E. Fig. 3 compares the experimental density acquired by the Archimedes principle of AMCs to the theoretical density produced by the mixing rule. The results show that adding E-glass short fibers to Al 7075 alloy increases MMC density. However, as the weight % of alumina (Al_2O_3) reinforcement in Al/E-glass composites is increased, the density of the MMCs gradually increases. This is because the Al_2O_3 composite material has a higher density. The density of composites using Al+ 8 wt% E-glass +12 wt% Al_2O_3 increased by 3 % comparing with Al 7075 matrix alloy.

Incorporation of low-density E-glass in hybrid MMCs is critical in limiting the Al_2O_3 reinforcement, resulting in a more modest increase in MMC density. Fig. 3 depicts the congruence of theoretical and observed densities. Although there was a little difference between the observed and theoretical densities, this confirmed the even distribution of reinforcement (Alumina/E-glass) and might be attributable to the presence of pores inside the material. Fibers and particles increased volume proportion has led to an increase in composites density.

3.2. Study of microstructure

Aluminum oxide, E-glass fibers, and the microstructure of the aluminum 7075 alloy collaborate to form a complex blend of materials that synergistically yield the desired strength, durability, and resistance to corrosion. The high-strength aluminum 7075 alloy is renowned for its mechanical properties and finds extensive use in high-performance applications within the automotive and aerospace industries. The alloy's characteristics are further enhanced through the incorporation of reinforcements such as E-glass fibers and aluminum oxide. The alloy's homogeneous dispersion of aluminium oxide particles offers remarkable corrosion resistance by serving as a shield between the aluminium and the environment. These particles also serve as strengthening agents, bolstering the alloy's overall toughness. In contrast, E-glass fibers effectively reinforce the material by introducing short, randomly positioned strands that boost both its strength and rigidity. Additionally, these fibers play a significant role in inhibiting crack propagation, thereby enhancing the alloy's resistance to damage. Fig. 4 a–d showcase metallographic images of Al 7075 materials fortified with E-glass short

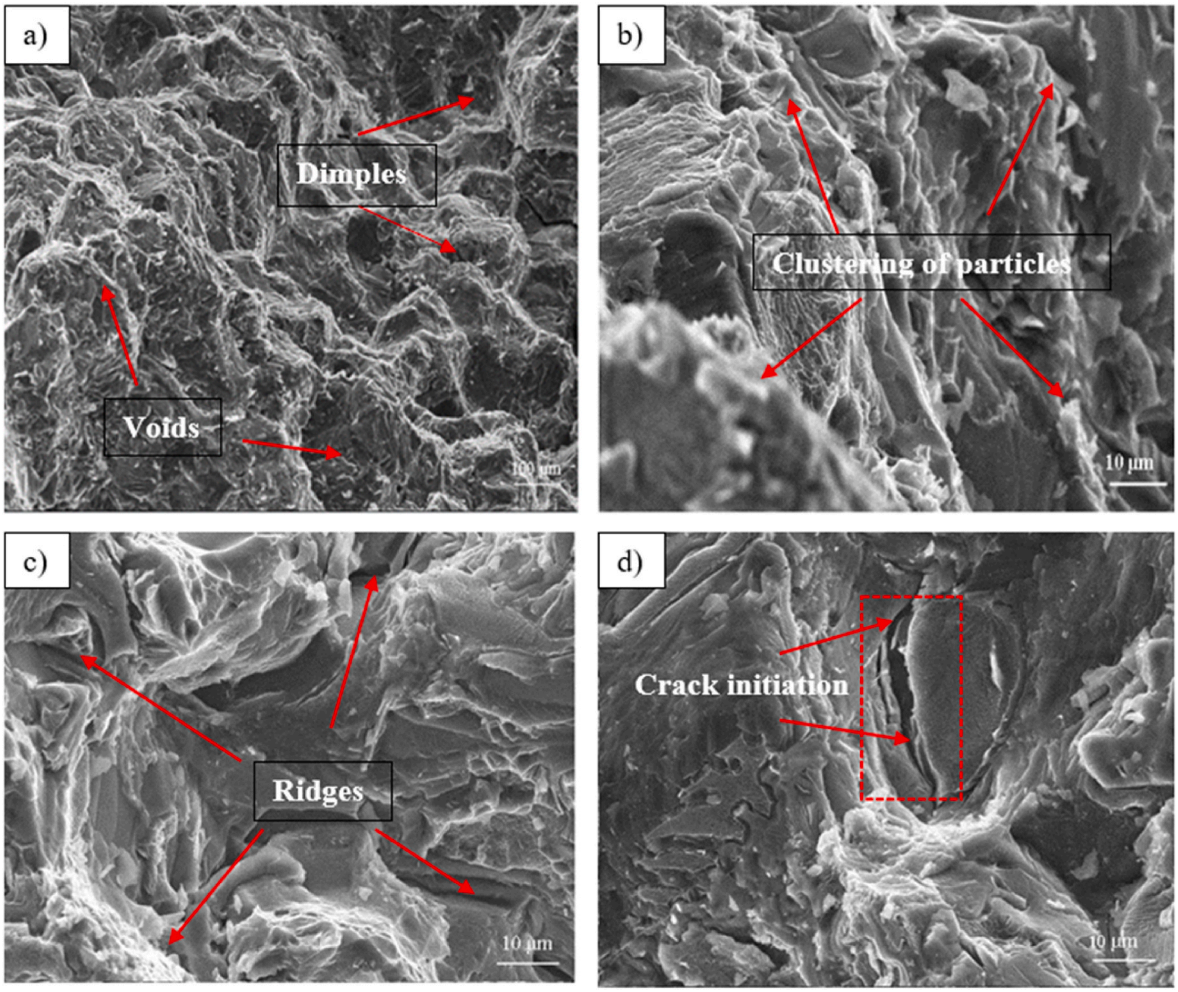

Fig. 10. SEM of a) Al 7075 alloy, b) Al + 2 wt % E-glass +3 wt % Al_2O_3, c) Al+ 6 wt % E-glass +9 wt % Al_2O_3 and d) Al+ 8 wt % E-glass +12 wt % Al_2O_3.

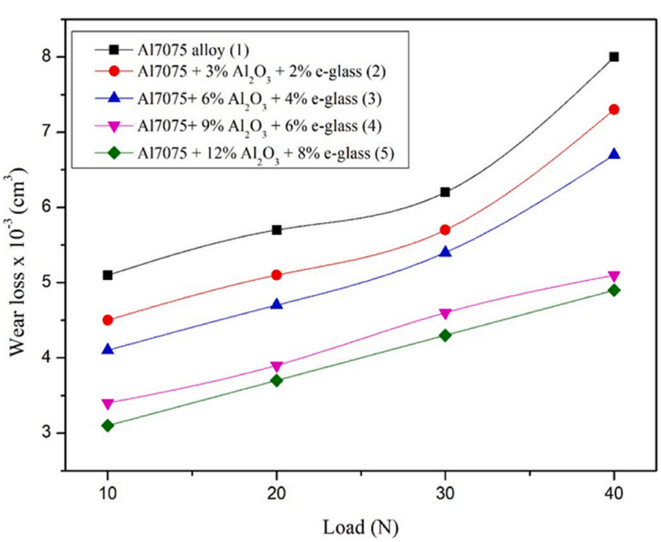

Fig. 11. Wear loss of Al 7075 alloy hybrid composite at varying load.

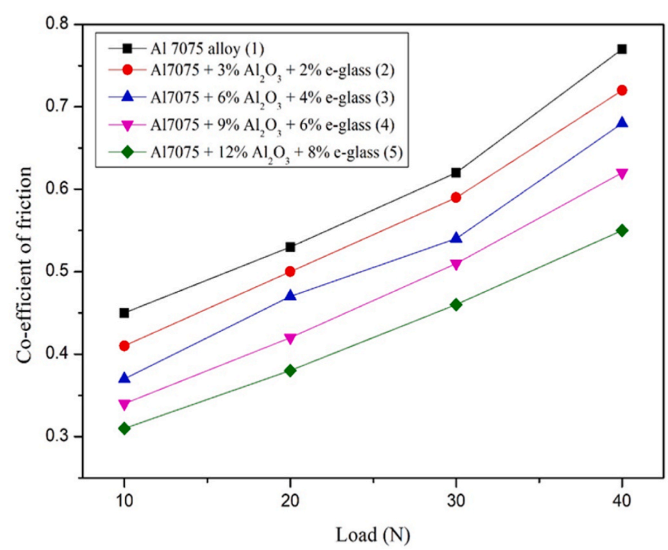

Fig. 12. COF of hybrid composite at varying load.

fibers and Al_2O_3 particles without undergoing heat treatment.

Fig. 4a displays the microstructure of the pure Al 7075 alloy. Many factors, including as variations in the thermal conductivity between the molten material and particles, restrictions on dendritic particle expansion, and disruptions in dendritic growth, influence the morphology of dendrites throughout the casting process. It is essential to emphasize that in its unfortified state, the Al 7075 alloy micrograph reveals an absence of particles. Nevertheless, it is important to acknowledge that heat treatment can be applied to enhance the alloy's properties,

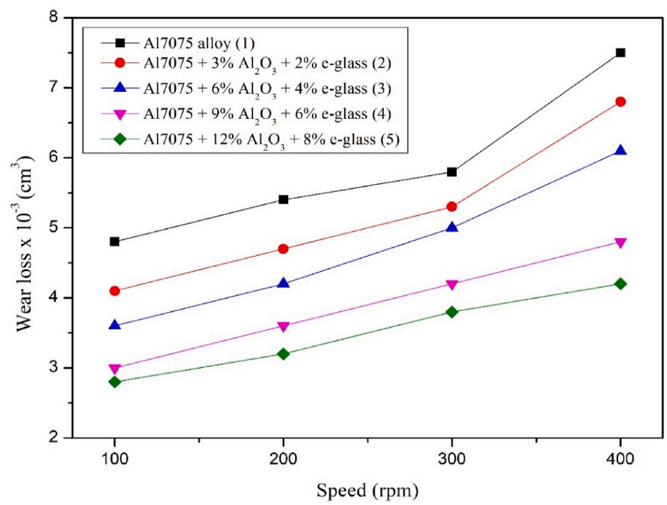

Fig. 13. Wear loss of hybrid composite at varying speed.

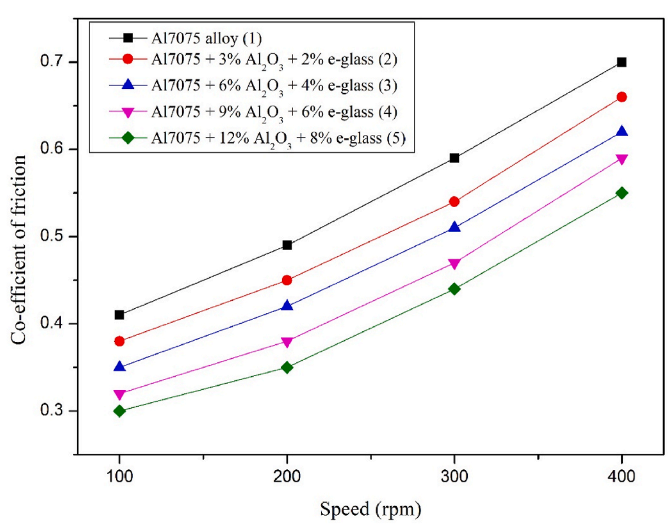

Fig. 14. COF of hybrid composite at varying speed.

primarily because zinc plays a key role as an alloying element. Fig. 4b–d illustrate the uniform distribution of E-glass fibers and alumina particles used in creating hybrid composites. The enhanced reinforcing qualities observed in the Al 7075 alloy composites are vividly demonstrated through the microphotographs. Notably, Fig. 4c illustrates how the addition of 6 % E-glass and 9 % alumina particles, applied twice to the Al 7075 matrix, significantly enhances the composite's microstructure. The initial stage of the stirring process reveals visible agglomeration during the initial 5-min period. However, as time progresses and the stirring speed remains constant, the agglomeration dissipates. This phenomenon is the result of a persistently high stirring speed, which makes it easier for reinforcements to disperse uniformly throughout the matrix and creates noticeable turbulence. The results of the X-ray analysis, which was performed to identify the phases present in hybrid composite samples with varying concentrations of Al_2O_3 and E-glass, are shown in Fig. 5. Every study's XRD patterns reveal the presence of prominent peaks related to Al, Al_2O_3, and E-glass. The combination of E-glass and a trace amount of Al_2O_3 results in the formation of many intermetallic composite phases. The peaks at identical 2-degree angles are discernible for all reinforcement weight %, although their intensities differ. With an increase in the weight % of reinforcement, there is a gradual rise in porosity levels, as demonstrated in Fig. 6. The SEM & XRD analysis reveals that the incorporation of E-glass and Al_2O_3 reinforcements results in a composite with a notable oxide concentration. While the porosity in the hybrid composite remains under 5 %, and it is within the preferred range, some instances of agglomeration have been observed in the composite. The primary factors contributing to the gradual increase in porosity levels, particularly in the core region, include inadequate degasification and extended pouring times.

3.3. Micro-hardness

In Fig. 7, the as-cast Al alloy matrix and Al alloy hybrid composites reinforced with E-glass and alumina particles varied weight percentages of (2 %, 4 %, 6 %, and 8 % wt.%) are shown along with their hardness characteristics. The graph shows that adding more E-glass short fibres and alumina particles to base alloy Al 7075 results in increased alloy hardness. The cast Al 7075 alloy has a starting hardness of 88 BHN. However, Al 7075 alloy matrix's hardness has been improved by adding various E-glass and alumina particles. Al 7075 alloy reinforced composites having 8 % E-glass and 12 % alumina particles had a maximum hardness of 112 BHN. These two kinds of short fibres and particles are added to the Al alloy, increasing its hardness by up to 27.2 %. When loaded, these E-glass and alumina particles function as surface deformation barriers [14]. The increased hardness is a result of better interfacial bonding between the base alloy Al 7075 and the E-glass and alumina particles.

3.4. Tensile strength

Fig. 8 displays the ultimate tensile strength (UTS) and yield strength (YS) of the Al 7075 alloy E-glass and alumina composites. The strength of the Al 7075 alloy is 90 MPa when it is first cast. Furthermore, adding varying percentages of alumina (3, 6, and 9) and E-glass (2, 4, and 6) to the Al alloy improves its UTS and YS. The composite with the highest ultimate tensile and yield strengths, measuring 150 N/mm^2 and 89 N/mm^2, respectively, among these composites is the one containing 6 % E-glass and 9 % alumina. When short fibres and particles are added, there is a notable rise of 66.6 % in UTS and 48 % in YS. The extra particles' high strength, which effectively inhibits plastic deformation, is primarily responsible for this notable strength increase. Throughout the composites manufacturing process, preheating the reinforcing particles increases their interfacial strength and promotes greater dispersion. Because the hard phases of the composite resist plastic deformation, when an external load is applied, both the reinforcement and the matrix can effectively support the full load. The reinforcement (7106/C) and matrix (23.2016/C) have different average thermal expansion coefficients, which results in a significant number of dislocations surrounding the fibres and particles in the material during solidification. As such, there is an increase in the energy of the particle-dislocation interactions [15,16]. The reason for the little decrease in tensile strength observed in composites with 8 % E-glass and 12 % Al_2O_3 can be traced back to the use of an excessive number of reinforcements, which leads to an inadequate and weak link between the matrix and reinforcements. As seen in Fig. 10d, this causes micro voids and cracks to emerge, which speeds up the propagation of cracks. Additionally, a higher percentage of reinforcements increases the hardness of the composites, reducing their ductility, as illustrated in Fig. 9. This decrease in ductility promotes trans granular crack propagation and early-stage failure.

Fig. 9 is showing elongation of an Al 7075 hybrid composite and highlights the various weight proportions of alumina and E-glass. It is clear how E-glass and alumina expansion affect the malleability of Al 7075 amalgams. The Al 7075 combination becomes less malleable when hard particles are present. Notably, the as-cast Al 7075 composite, which contains 2 % E-glass and 3 % alumina, had a 12.5 % extension rate. Al 7075 composite durability decreases with E-glass short fibres weight percent increase from 2 to 8 wt% and that of alumina from 3 to 12 wt%. The least ductile hybrid composites were those reinforced with

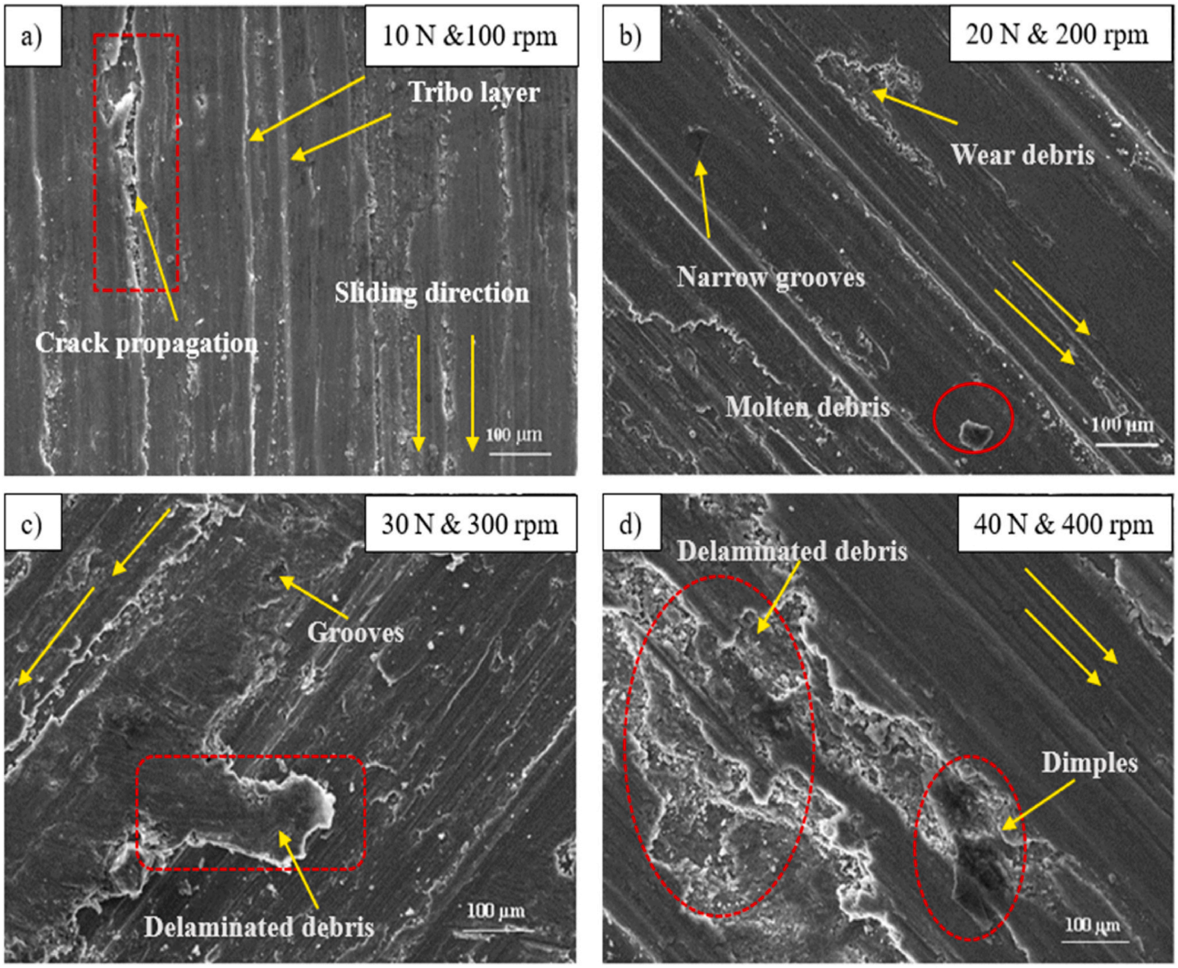

Fig. 15. Worn-out surfaces SEM of Al 7075 alloy.

8 % E-glass and 12 % alumina. decrease in elongation is underpinned by deteriorating sensitive framework induced by insertion of hard particles. Their use might be restricted in terms of conduction, though.

3.5. Tensile fractured surface study

Composite fracture is attributed to both the reinforcement amount and distribution, including manufacturing conditions. In turn failure in aluminium composites is driven by particle debonding, and fracture and matrix failure. Fig. 10(a–d) show the SEM fracture surface examination of Al 7075 composites. The as-cast matrix alloys' tensile fracture behaviour is shown in Fig. 10a, which also shows bigger voids, grooves, and grains that have undergone significant plastic deformation. The tensile cracked surfaces of Al 7075 alloys with different compositions, such as two weight % E-glass and three weight % alumina hybrid composites and six weight % E-glass and nine weight % hybrid alumina composites, are shown in Fig. 10(b–d). The tensile behaviour of the Al 7075 alloy changed with the addition of mica particles and short fibres. The fracture of the Al 7075 alloy becomes more brittle as the particle content rises. A brittle and ductile mix-mode failure mechanisms at the transient failure approach is demonstrated by the composites. Impending interfacial propagation of crack as a response to increasing applied stress has been elucidated by making use of normalised debonding driving force [17]. Micro voids are first formed in the inter-dendritic zones which then lead to solidification. Researchers have discovered reinforcing particles and their tiny clusters within these micro gaps. It is anticipated that this incident will accelerate brittle composite failure, which will eventually result in composite rupture. Particle cracking is a serious possibility when the particles and matrix develop a tight bond. Numerous dislocations cause significant stress concentrations, which in turn encourage particle disintegration and start cracks [18]. The composites undergo significantly less elongation in comparison with the unreinforced metals as result.

3.6. Wear characteristics

Critical factors such as wear rate and friction coefficient affect the performance of hybrid composites. By tracking the weight loss over time, it is possible to calculate the wear rate, which is the amount of material lost as a result of friction and abrasion. High wear rates may compromise the composite's strength and toughness. The resistance to motion between two contacting surfaces is measured by the friction coefficient. Increased friction coefficients contribute to composite becoming more brittle and impair its ability to move or function. Both wear rate and friction coefficient of the composite is affected by both the particular material choices made and the procedures used in its design and manufacture. By creating hybrid composites with low wear rates and low coefficients of friction, researchers are actively working to improve performance and durability. In order to further optimise the properties of hybrid composites, it is also possible to apply fillers or coatings to reduce the rate of wear and friction coefficient.

Cast metal, alumina particles, and E-glass fabricated hybrid composites wear rate and friction behaviour are shown in Figs. 11–14. Info graphs evidence that when E-glass an increase in weight percentage from 2 to 8 and an increase from 3 to 12 wt percent in the amount of alumina particles relative to the base matrix, result in significant wear

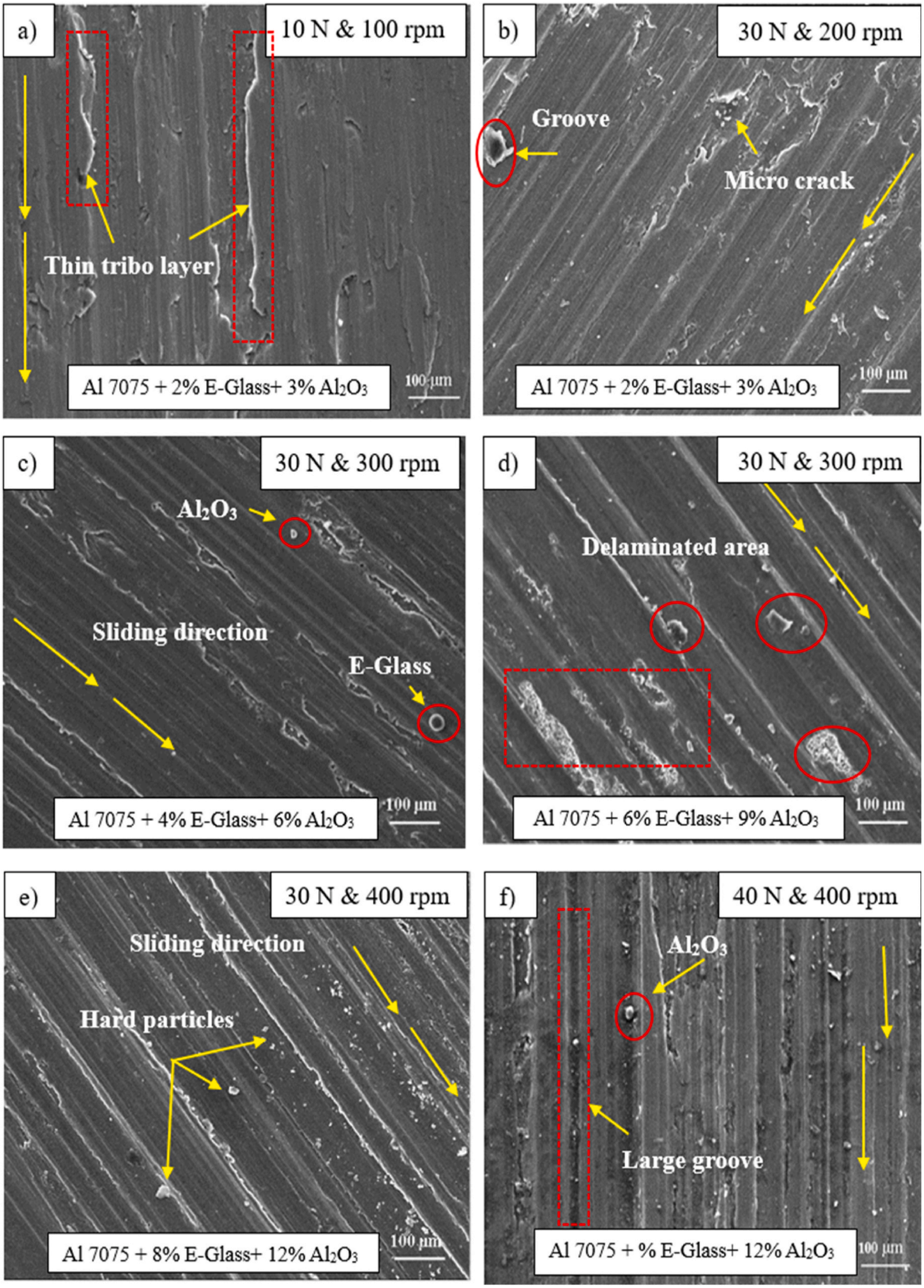

Fig. 16. Worn-out surfaces SEM of hybrid composites.

loss decreases. It has been noted that over a 3000 m sliding distance at 40 N of pressure and 500 rpm, there is an increase in the coefficient of friction accompanied with a drop in the weight percentage of the particles. Increased wear resistance that particles offer, providing resistance to plastic deformation under diverse situations, is what is responsible for their substantial presence on the worn specimen surface. Because it is softer than composites reinforced with short fibres and particles, Al 7075 alloy suffers more wear loss over time. However, the Al matrix is protected by the E-glass/alumina particle combination from material loss brought on by excessive hardness.

Researchers [24,25] are particularly interested in the degraded surfaces of hybrid composites made of aluminium alloy 7075 reinforced with e-glass fibres and aluminium oxide particles. Friction and abrasion are two types of mechanical stress that cause these surfaces to gradually deteriorate. The examination of a surface morphology, surface roughness, and chemical makeup can be used to identify worn-out surfaces. Scanning Electron Microscopy (SEM) is used for examining changes in morphology of worn-out surfaces including particle size, shape, and distribution. While profilometry has been in use to quantify surface roughness including waviness, and other pertinent features. X-ray diffraction (XRD) was employed to examining chemical constituents of worn-out interfaces. These analytical methods make it possible to identify and measure the chemical components that are present on the surface by numeric methods. The wear process parameters are tabulated in Tabe 3.

3.7. *Worn-out surfaces analysis*

Worn Al 7075 interfaces and its E-glass and alumina particles composites show several types of wear that various materials experience. Aluminium can flow viscously through the Al 7075 alloy matrix's smoother surface, forming it into a pin while sliding. This results in considerable material loss and plastic deformation of the sample's surface. Fig. 15(a–d) shows the Al 7075 alloy's worn surface, which is marked by micro pitting, grooves, and a fractured within oxide layer, all these phenomena contribute to significant wear loss. While Fig. 16(a–f) shows fewer grooves and voids which demonstrate enhanced resistance to wear. Al 7075 alloy matrix exhibits deterioration in ductility. Tensile loading induced fractured surfaces in the hybrid composites show brittle fracture, while those in the Al 7075 alloy show ductile mode failure, as shown in Fig. 16(a–d). The Al 7075 alloy's wear resistance is enhanced when reinforcements are included which results in a corresponding fall in friction coefficient. Wear surfaces in as-cast alloys show more pronounced grooves and surface cracks than composites do [19].

Based on the results of the experiments, it has been discovered that hybrid composites made of aluminium 7075 alloy, E-glass fibres, and aluminium oxide particles display superior wear-out surfaces to the base alloy. Both wear rate and friction coefficient have been significantly reduced by these hybrid composites. Furthermore, the hybrid composites wear resistance is increased by the addition of E-glass fibres and aluminium oxide particles, which increases surface roughness. Studying the worn-out surfaces of hybrid composites made of the aluminium 7075 alloy and reinforced with E-glass fibres and aluminium oxide particles is therefore essential for understanding the performance of the materials and developing the creation of new and improved composites.

4. Conclusions

The results that have been drawn are as follows.

- The hybrid composite's microstructural examination shows a regular distribution of reinforcement in the form of fibers and particles, as well as a solid link between the reinforcement (Al_2O_3/E-glass) and the matrix Al 7075.
- The hybrid composite materials density increased compared to non-reinforced Al 7075 alloy after integrating the Al_2O_3/E-glass reinforced composites.
- XRD patterns were also utilized to distinguish between the various phases and elements present in the alumina and E-glass particles. The increased hardness and tensile qualities of the material result from these reinforcements, albeit at the cost of reduced ductility in the underlying Al 7075 alloy matrix.
- The developed composites have shown increases in hardness, tensile strength, and yield strength of 31.42 %, 36.70 %, and 33.99 %, respectively, as compared to the matrix material.
- Hybrid composite's percentage elongation decreased by 55.5 % as compared with matrix alloy. The hybrid composites' tensile-damaged surfaces showed brittle fracture, whereas the Al 7075 alloy showed ductile mode failure.
- The wear rate was inadvertently influenced by the inclusions of alumina particles and the E-glass fibers. Because the added reinforcement minimised distortion in the cast specimens, a higher volume % of reinforcement produced less wear.
- Wear rates of hybrid composites were 37.25 %, 35.08 %, 30.6 %, and 38.75 % which are lower than those of Al 7075 alloy at loads.
- An increase in sliding speed from 100 rpm to 400 rpm induced wear rate increase up by 30 %. Since higher sliding speeds raise the temperature of the sliding surface, allowing E-glass fibers and Al_2O_3 particles to escape from the surface layer, this clearly shows a direct correlation between sliding speed and wear rate.
- Micrographs of worn interfaces can be utilized for analyzing wear characteristics of hybrid composites, which exhibit traits like ploughing, delamination, and wear tracks.
- Both mechanical and wear properties of Al 7075 alloy have been significantly improved (32 %–35 %) by adding alumina particles and E-glass fibers to the matrix. Particularly ideal applications for these composite materials include fixed frames, bicycle stands, cylinder stands, and sports equipment.

Declaration of competing interest

We confirm that there is no known conflict of interest.

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