

Effect of ceramic filler materials on abrasive wear performance of glass/epoxy composites

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Abstract

When creating polymer-based composites, plain weave fabrics and micron-sized fillers offer bidirectional strength and reduced voids/inhomogeneity. The aim of the present investigations, is effect of ceramic filler materials on abrasive wear performance of Glass/Epoxy Composites. These were studied during three body abrasive wear with and without ceramic fillers (, , graphite, and fly ash cenospheres). In experiments, loads of 20 N and 40 N were applied at various abrading distances of 500 m, 1000 m, 1500 m, and 2000 m. According to the results of sand abrasive wear test, the specific wear rates of G-E based composites are sensitive to fibre and filler/matrix adhesion. Under all tribo-test settings, the SWR for all particulate G-E composites decreases in the following order: G-E > Gr/G-E > /G-E > /G-E > fly ash cenosphere/G-E. Furthermore, the specific wear rate of the fly ash cenosphere filled G-E composites was found to be lower than the G-E and other filler materials filled G-E composites. There was 38.7% reduction in the specific wear rate at 40 N, 2000 m in fly ash cenosphere filled G-E composite. As per the evidence of scanning electron microscope images of worn-out surfaces, mechanisms such as ploughing, fibre breakage, fibre pull-out, fibre thinning, and a network of micro-cracks caused the wear in composites

KEYWORDS: Bidirectional glass-epoxy composites; Ceramic fillers; Three-body abrasive wear; Wear volume; Specific wear rate

1. INTRODUCTION

A recent study found that glass fibers have been used as strengthening agent with epoxy matrix material for structural applications (Megahed et al. 2018). Some advantages include high specific characteristics, low cost, bidirectional strength, and simplicity of handling. They are employed in the building and automotive industries due to its superior mechanical qualities, low cost, and ease of fabrication (Nayak et al. 2019). Gears, bearings, and sleeves are just a few examples of mechanical components that frequently make use of polymers and their mono and hybrid composites. This is a prominent class of man-made composite materials for tribo-engineering, where tribo-performance in non-lubricated settings is a key material selection characteristic (Darshan et al. 2022). Fiber and particulate-reinforced epoxy composite materials have suitable tribological characteristics ((Kiran et al. 2018), (Negawo et al. 2021), (Gafsi et al. 2021; Dass et al. 2017). The number of research articles on epoxy as a matrix material with glass fibres and ceramic fillers for improving the qualities in mechanical and abrasion resistance has increased over the past ten years ((Darshan et al. 2021), (Darshan et al. 2022), (Darshan et al. 2022; Namdev et al. 2022; Darshan et al. 2019; Shivakumar et al. 2019; Muralidhara et al. 2020)). Wind turbine blades were made of polymer composite materials that had glass fibre reinforcement (Darshan et al. 2022).

Table 1: Summary of the wear behaviour of micron sized particulates reinforced composites.

Composite	Fabrication	Loading of filler	Output
MoS2 and Al2O3 fillers + CF-epoxy	Hand lay-up	5, and 10 wt. % each	Inclusion of MoS2 and Al2O3 composites separately improved the two-body abrasive wear resistance.
Graphite and alumina + GF-epoxy	Hand lay-up	2.5, 5 and 7.5 wt. %	Alumina filled GF-epoxy composite enhanced the wear resistance, while graphite filler worsens the wear resistance of the GF-epoxy
Cenospheres +Polyester	Open mould casting	10 wt. %	Submicron size cenospheres decreased the CoF and specific wear rate.
Cenospheres + vinyl ester	Open mould casting	10 wt. %	Submicron size cenospheres contributed to increase in the wear resistance
SiC, Al2O3, and ZnO particulates +novolac epoxy	Open mould casting	10 wt. % each	All micron size fillers show improved wear resistance and reduced CoF.
Graphite + epoxy	Open mould casting	10 wt. % (20 μ) 5 wt. % -(10 μ)	5 wt. % graphite reduced the CoF and enhanced the wear resistance.
Nano-Al2O3 +chopped carbon fiber + epoxy	Open mould casting	1, 2, 4 and 6 wt. % CF 4 wt. % CF + 1, 2, 3 and 4 wt. % Nano-Al2O3	CFs are very effective in reducing CoF Specific wear rate decreased by releasing a quantity of lubricant film on the counterface.
Nano-Al2O3, nano-SiO2, nano-zirconia, gypsum micro-filler +Monomer resin BisGMA	Open mould casting	1, 2, 3 and 4 wt. % each	Addition of 3 wt. % of silane treated nano-silica in the dental composite evidenced effective for enhancing the wear resistance.
Nano-SiO2 and carbon nanotubes + carbon-epoxy	Vacuum infusion process	0.1, 0.5 and 0.9 wt. % each	Both nano-particles improved friction coefficient and wear rates of carbon-epoxy
Glass fiber + epoxy	Hand lay-up	10 to 50 wt. % Short GF 10 to 50 wt. % Woven GF	Short GF-epoxy composites were found to exhibit higher wear resistance than that of the bidirectional GF-epoxy composites
E-glass fabric+ epoxy composites with and without graphite filler	Hand lay-up	2.5, 5 and 7.5 wt. %	Experimental result showed the following trend for abrasive wear rate: graphite filled GF-epoxy composites>GF-epoxy
SiC particulate + GF-epoxy	Hand lay-up	2.5, 5 and 7.5 wt. %	Experimental results showed the positive impact of SiC fillers, which enhanced the abrasive wear resistance of GF-epoxy composites

Several research looked at the use of micron-sized fillers to improve the abrasion resistance of polymer composites reinforced with glass fibre materials ((Kiran et al. 2018), (Negawo et al. 2021), (Gafsi et al. 2021; Dass et al. 2017; Kumar et al. 2018)). According to research by Hemanth et al., the specific wear rate of TCE + PTFE composite composites is high, but it can be decreased by adding micron-sized fillers (silicon carbide, pine bark dust) to the TCE + PTFE composite (Manjunath et al. 2016). (Sharma et al. 2020) investigated whether adding fly ash improved the abrasion resistance of epoxy composites bonded with glass fibre. (Ibrahim et al. 2016) investigated the three-body abrasive wear behaviour of epoxy composites reinforced with carbon fabric. They found that incorporating micron-sized SiC particles into the same increases its resistance to abrasion. The effects of TiO₂ and ZnO on the use of bidirectional glass reinforced polyester composites were examined by (Ibrahim et al. 2016). -filled hybrid composites outperformed ZnO-filled hybrid composites in testing, the researchers found. The thermo-mechanical and wear characteristics of woven glass fibre composites that have silicon carbide incorporated were studied by (Suresha et al. 2021). The results showed a rising or falling trend as well as important components in each analysis. There was also discussion of the trend and key factors affecting the decrease in specific wear rate. Most recent literatures ((Kiran et al. 2018), (Negawo et al. 2021), (Gafsi et al. 2021; Dass et al. 2017; Kumar et al. 2018; Ayatollahi et al. 2019; Qian et al.



2019)) on micro and nano sized fillers are provided in Table 1. Hence, this study aimed to illustrate how different micron-sized fillers, including silicon dioxide, alumina, graphite, and fly ash cenosphere particulates, affected the behaviour of three-bodies of abrasive wear, in particular the specific wear rate of bidirectional glass fabric reinforced epoxy composites. For different abrading distances with a constant applied load and rubber wheel speed, the wear volume as well as specific wear rate was computed.

Natural fibre composites are biodegradable and are low cost than synthetic fibre composites. These natural fibres are easily available and best suited for manufacturing, making some researchers focus on reinforcements specifications for better-reinforced polymer composite (Miyoshi et al. 2019). Over the past few years, till now researchers are performed to substitute synthetic with natural fibers. These natural fibres have better qualities like high specific mechanical properties, renewable and biodegradable with low cost (Ibrahim et al. 2016). These natural fiber-reinforced polymer composites have better tri-biological properties than synthetic fibre material (Ibrahim et al. 2016). Even industrial applications like bearings, flooring materials, and brake pads require friction coefficient and Wear resistance (Ibrahim et al. 2015). The demand for polymer composite reinforced natural fibres has attained attention as these have excellent environmental properties, which are affordable and easy to manufacture than synthetic fibres ((Shalwan et al. 2021), (Ibrahim et al. 2015)). Due to these excellent properties, polymer composites are used in the construction, automobile and furniture industries (Zagho et al. 2018).

These natural polymer composites are distinguished by their unique low density and cost properties, flexible processing equipment, and best mechanical properties with high strength, chemically resistant than synthetic fibres ((Alajmi et al. 2022), (Darshan et al. 2021)). For a polymer composite matrix, a better option than synthetic fibre would be natural fibres like sisal, coir, date palm corn, and silk for better reinforcement polymer composite in the current situation (Darshan et al. 2022). There is an increase in research on natural fiber-reinforced composites in both mechanical and tri-biological applications. ((Darshan et al. 2022), (Namdev et al. 2022) and (Vinod et al. 2018)). These natural fiber-reinforced composite polymers can enhance their performance in tensile, impact, Wear, flexural, friction and other mechanical and tri-biological applications ((Darshan et al. 2016), (Namdev et al. 2023) and (Namdev et al. 2022)).

Research is being carried out on the effect of fibre materials, additives and their further modifications, and their content percentages on polymer composites' mechanical and tri-biological properties (Yan et al. 2020). There is still a debate between many scholars' research on the relationship between mechanical and tri-biological performances of material ((Chira et al. 2016), (Namdev et al. 2021) and (Shivakumar et al. 2020)). However, carbon has specific selective effects on mechanical performance, while frictional properties are more favourable (Srivastava et al. 2019). (Kumar et al. 2020) Investigated coir epoxy composite with various ratios and stated that the wear resistance of coir fibre mainly focuses on their dust particle size and normal load applied. He also stated that the wear mechanism had been dominated by reinforcement due to high coir dust loading (Kumar et al. 2020).

These natural fibre composites had many desirable properties, like yielding low-density material relative to composite properties. These are low in cost, and processing has also been a renewable resource. had researched rice husk-reinforced epoxy composite and found better results on abrasive wear loss by suitable treatment ((Scedil et al. 2019) and (Muralidhara et al. 2020)). Palm and mangos dry leaves also improve tri biological properties of polymer composites ((Darshan et al. 2019) and (Tahir et al. 2016)).

Our work proposes coir and sisal fibres with reinforced polymer composites to improve their wear and friction behaviour for proposed composite materials. Three orientations, parallel, anti-parallel and normal, are tested for polymeric composite under different loads from 5 to 60 N and are applied through Various Grade papers and Time Intervals to find the abrasiveness of developed composites

2. MATERIALS AND METHODS

2.1 Materials

Used materials are plain weave woven glass fibres weighing 360 g/m² (E-glass) with fibre diameters ranging from 10 to 13 µm. LAPOX L12 epoxy resin and K-6 hardener in a 100:12 weight ratio. Both materials were purchased by Nycil CCRD Limited, Nigeria. Micron sized ceramic particles namely SiO₂, Al₂O₃, graphite (Gr), and fly ash cenosphere were collected from commercially available sources and used without further treatment. The average particle sizes of Al₂O₃, graphite, fly ash cenosphere and silica were 20 µm, 25 µm, 32 µm and 25 µm respectively. The hand lay-up method was used to create G-E composite laminates (200 mm × 200 mm × 10 mm) with and without ceramic fillers as listed in Table 2, which were then vacuum-bagged.

- Initially number of glass fibre layers required (55 wt. %) to achieve laminate thickness of 10 mm were cut for the



dimension of 200 mm × 200 mm.

- Epoxy matrix along with hardener (35 wt. %) and micro sized fillers were mixed together thoroughly.
- First layer of the glass fibre was placed on the flat surface pre-cleaned with acetone.
- Epoxy mixture was then coated over the first layer with the help of a hand brush and thereafter second layer of the fabric was placed on the first layer.
- This process of applying the epoxy mixture and placing of new glass fibre layer was continued till desired thickness of 10 mm was measured.
- Air trapped between the layers of glass fibres were removed by placing the fabricated laminate in vacuum bag for 90 minutes duration.
- This was followed by curing the laminates at 120 °C for 120 min.

Table 2: Composite materials designations

Composites	Alumina (wt.%)	Fly ash (wt.%)	Graphite (wt.%)	Silica (wt.%)
G-E	-	-	-	-
Alumina G-E	10	-	-	-
Fly ash G-E	-	10	-	-
Graphite G-E	-	-	10	-
Silica G-E	-	-	-	10

Table 3: Water jet machining parameters

Parameter	Magnitude
Water pressure	200 MPa
Abrasive flow rate	300 g/min
Transverse speed	125 mm/min
Stand-off distance	1.5 mm

Laminates were then cut into the size of 75 mm x 25 mm x 10 mm for abrasion test with the help of water jet machining using cutting parameters provided in Table 3. 2.1 Three-body abrasion test A diagrammatic representation of a Rubber wheel test rig is shown in Figure 1 and its specifications are provided in Table 4. The test samples are first weighed with a weighing balance machine (Make: Sartorius BSA224S-CW, Least Count: 0.0001 g) and their initial mass were noted (m_i).

Table 4: Specifications of rubber wheel test rig

Parameter	Magnitude
Wheel diameter	228 mm
Rubber wheel thickness	12.7 mm
Wheel speed	200 rpm
Rubber hardness	60 Shore-D
Abrasive sand size	100-200 μ m
Abrasive flow rate	350 g/min

The specimen is then put in the test setup's specimen holder, which is located across from the rubber wheel. The loads are then applied. The machine is then run by giving the test samples the required number of rotations, which causes abrasive sand particles to flow clockwise between the rubber wheel and the test sample. At that point, the test sample is being abraded as the wheel rotating at 200 rpm presses up against it and the sand flows downwards via nozzle at the rate of 350 g/min. The machine stops running after the specified number of revolutions, and the test sample is removed from the sample holder and weighed once more (m_f). This weight is then compared with the sample's initial weight (m_i), to find the wear mass loss ($\Delta m = m_i - m_f$) and specific wear rate (SWR, also known as wear factor). The wear tests were conducted with two applied weights (20 N and 40 N), four abrading distances (500 m, 1000 m, 1500 m, and 2000 m), and a constant speed of 200 rpm.

The calculation of the SWR or wear factor (K_s) is done as per ASTM G40 standard using the following equation:

$$K_s = \frac{\Delta V}{P \times D} (m^3/Nm) \quad (1.0)$$

where, ΔV represents the wear volume loss in m^3 which is obtained by dividing the wear mass loss (Δm in gram) by the density (ρ in g/m^3) of corresponding composite samples i.e. $\Delta V = \Delta m / \rho$ as per ASTM G65; P represents the applied normal load in Newton and D represents the abrading distance in meters. The involved wear mechanisms of the selected abraded test samples were examined using a scanning electron microscope (SEM, Make: JEOL, JSM-IT300 series with magnification of x5-x300000).



3. RESULTS AND DISCUSSION

3.1 Effect of filler materials on wear volume

Wear volume loss versus abrading distance for G-E composites filled with various filler materials are shown in Figures 1 and 2 for applied normal loads of 20 N and 40 N, respectively. Compared to metals, polymer composites offer very less resistance to abrasion [40]. Hence, as recommended by ASTM G65 standard, light load variation from 20 N to 40 N was adopted for the conduction of wear tests.

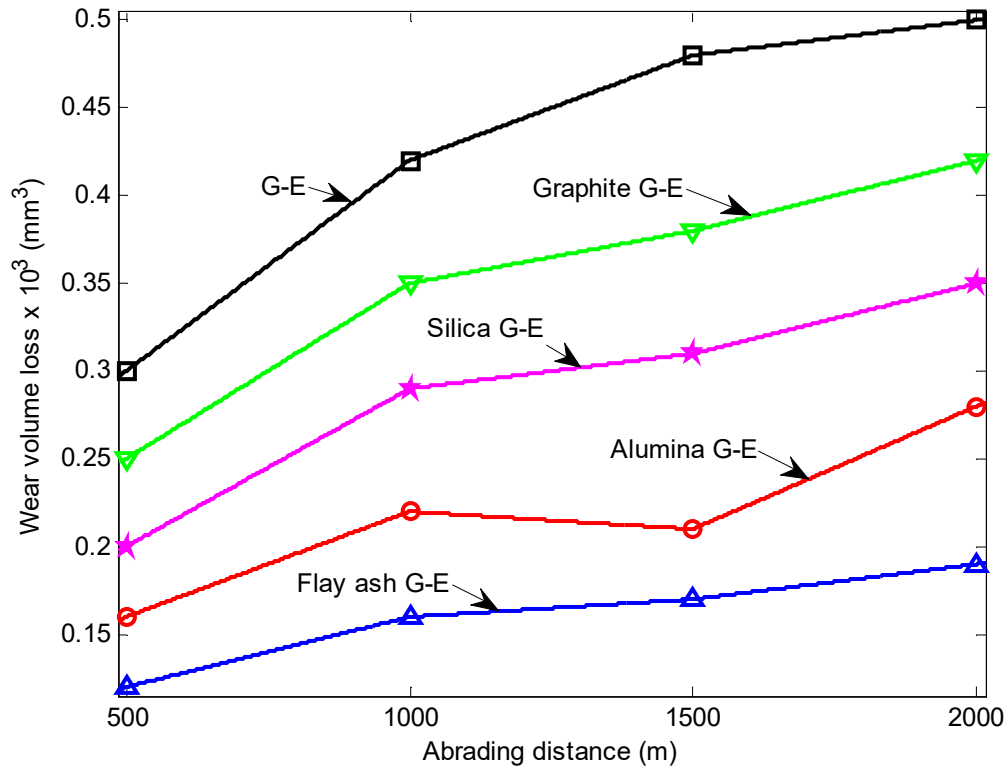


Figure 1: Wear volume loss as a function of abrading distance of filled G-E composites at 20 N.

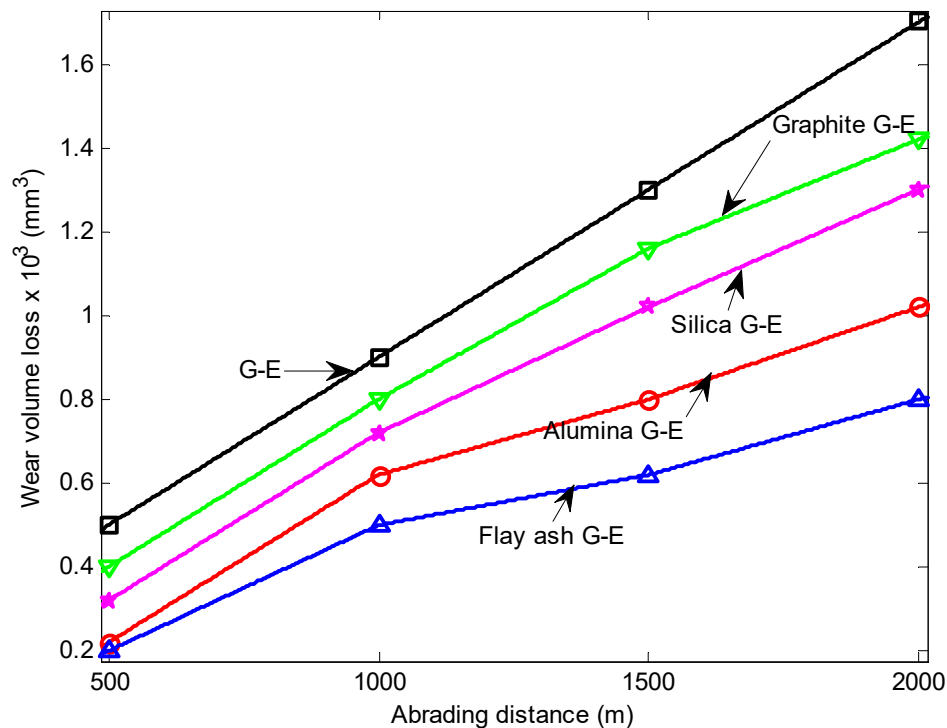


Figure 2. Wear volume loss as a function of abrading distance of filled G-E composites at 40 N



In the case of particulate filled G-E composites, fly ash cenosphere filled G-E showed lower wear volume performance. For almost all composite materials, wear volume has shown a saturation level after 1500 m abrading distance. The results in Figures 1 and 2 suggested that the ranking order of the abrasive wear performance of the composite materials changed on the abrading distance and applied normal load. Such variation in the abrasive wear performance depending on the abrading distance has also been reported. Between 500 m and 2000 m of abrading distance were recorded while holding some tribo variables constant (sliding speed: 200 rpm, abrasive size: 225 μm). The figures 2 and 3 demonstrate that with increase in abrading distance, the wear volume steadily increases for all composites having the lowest wear volume loss at the lowest abrading distance of 500 m and the maximum wear volume loss at the highest abrading distance of 2000 m. Among all filled composites, fly ash cenosphere/GE composites had the lowest wear volume loss of $0.128 \times 10^3 \text{ mm}^3$ at 20 N and 500 m abrading distance, while G-E epoxy composites had the highest wear volume loss. At applied loads of 20 N and 40 N, G-E composite with Al_2O_3 had the second-lowest wear volume loss and SiO_2 /G-E composites had the third-lowest wear volume loss as depicted in Figures 1 and 2 respectively.

3.2 Effect of filler materials on specific wear rate

Specific wear rate (SWR) versus abrading distance of G-E and their filler filled G-E composites are depicted in Figures 3 and 4. Figures 3 and 4 show an impact on SWR for Al_2O_3 , fly ash cenospheres, SiO_2 , and Gr particles filled G-E composites at 20 N and 40 N applied loads, respectively. At 20 N, the SWR gradually decreased as the abrading distance was increased, with the lowest SWR ($0.232 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$) for fly ash filled glass fabric reinforced epoxy composite at the highest abrading distance of 2000 m and the highest SWR ($3 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$) for G-E composite at the smallest abrading distance of 500 m (Figure 4) at 20 N. The SWR of G-E composite varies between $3.386 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$ and $2.113 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$ with a load application of 40 N and at abrading distances of 500 m and 2000 m, respectively. Fly ash filled G-E composite has SWR values that range from $2.12 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$ to $1.21 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$ respectively. Al_2O_3 filled G-E composite has SWR values that range from $2.45 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$ to $1.43 \times 10^{-11} \text{ m}^3 \text{N}^{-1} \text{m}^{-1}$, respectively.

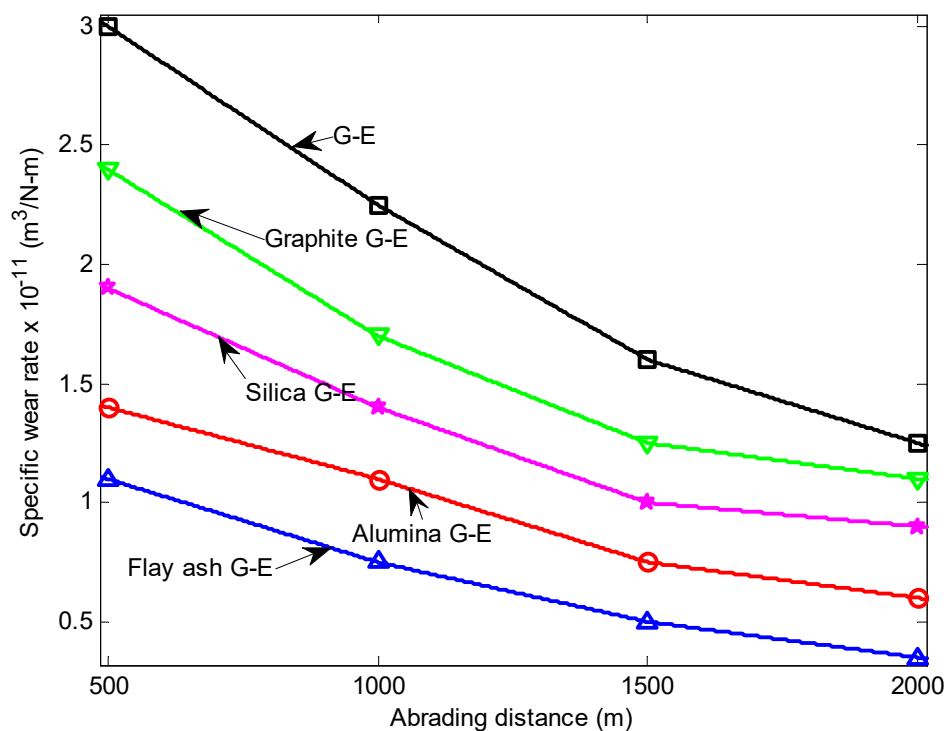


Figure 3: SWR as a function of abrading distance for filled G-E composites at 20N

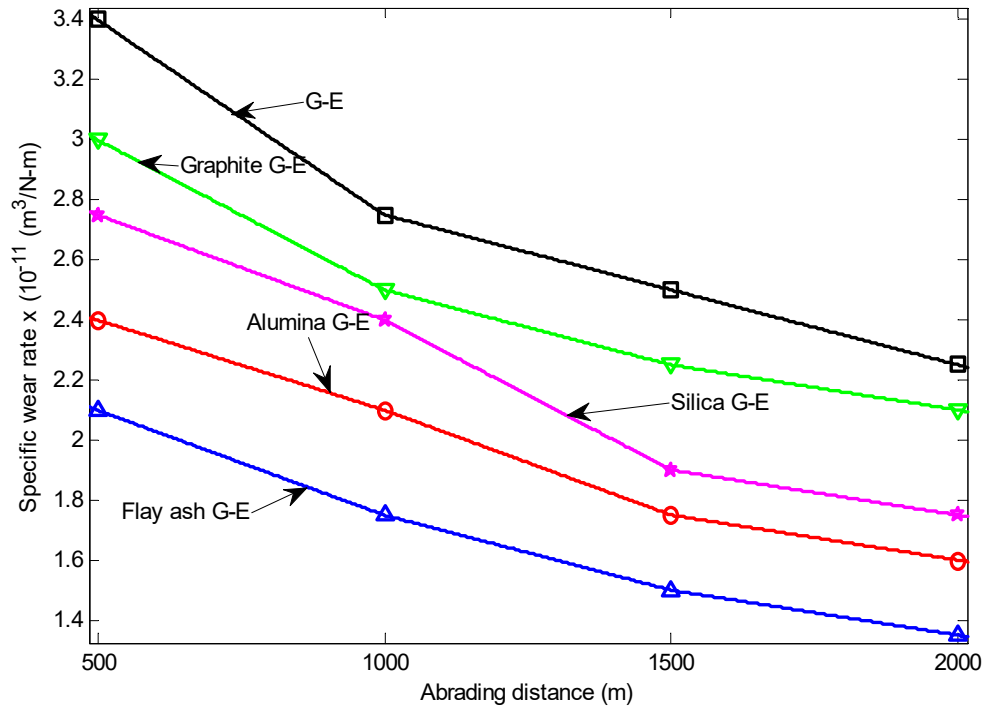


Figure 4: SWR as a function of abrading distance for filled G-E composites at 40 N.

Furthermore, $\text{SiO}_2/\text{G-E}$ composites have SWR values that range from $2.72 \times 10^{-11} \text{ m}^3\text{N}^{-1}\text{m}^{-1}$ to $1.61 \times 10^{-11} \text{ m}^3\text{N}^{-1}\text{m}^{-1}$, respectively. Gr filled G-E has SWR values that range from $2.99 \times 10^{-11} \text{ m}^3\text{N}^{-1}\text{m}^{-1}$ to $1.88 \times 10^{-11} \text{ m}^3\text{N}^{-1}\text{m}^{-1}$, respectively. The applied load of 40 N showed the same trend. Therefore, it can be inferred from the data that the SWR decreases as the abrading distance rises. The maximum SWR for G-E composites has been observed, as illustrated in Figures 6 and 7, when compared to filled G-E composite materials at 500 m abrading distance with 20 N and 40 N applied loads. Fly ash/G-E composite showed the least SWR as compared to other G-E and other filled G-E composites. The SWR in the descending order is as follows: $\text{G-E} > \text{Gr/G-E} > \text{SiO}_2/\text{G-E} > \text{Al}_2\text{O}_3/\text{G-E} > \text{Fly ash/G-E}$. When the different filler materials were added to G-E, it appeared better abrasion resistance. Therefore, it may be concluded that the SWR is decreased by the addition of fillers.

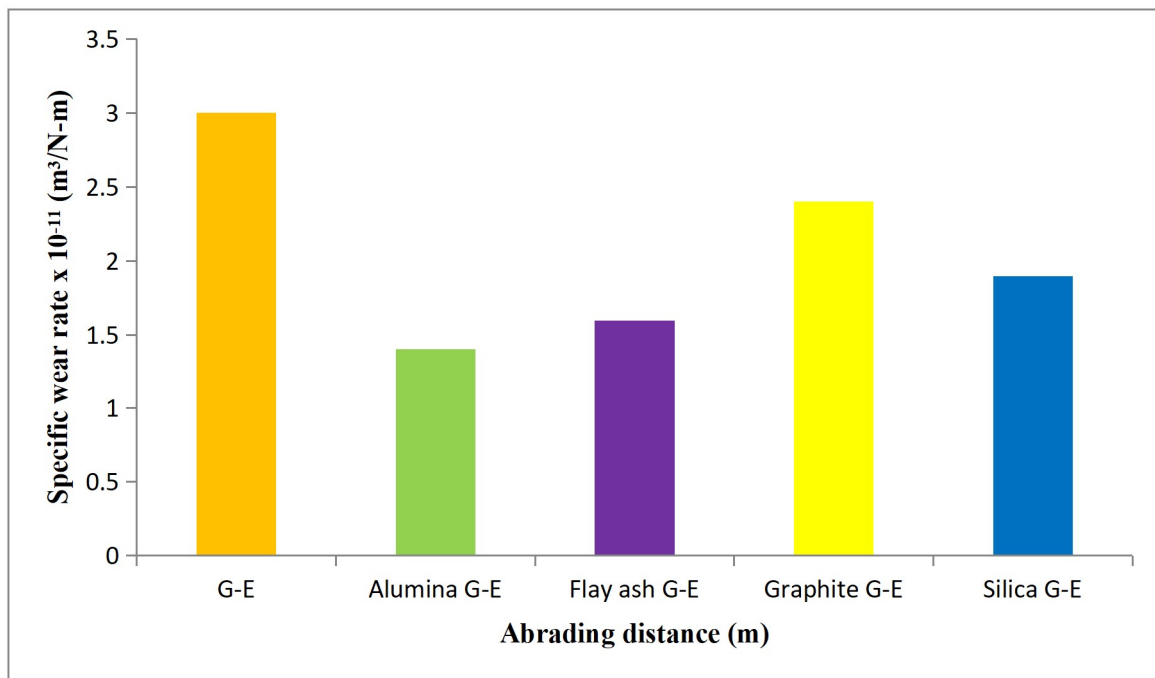


Figure 5: SWR of filled G-E composites at 500m and 20N.

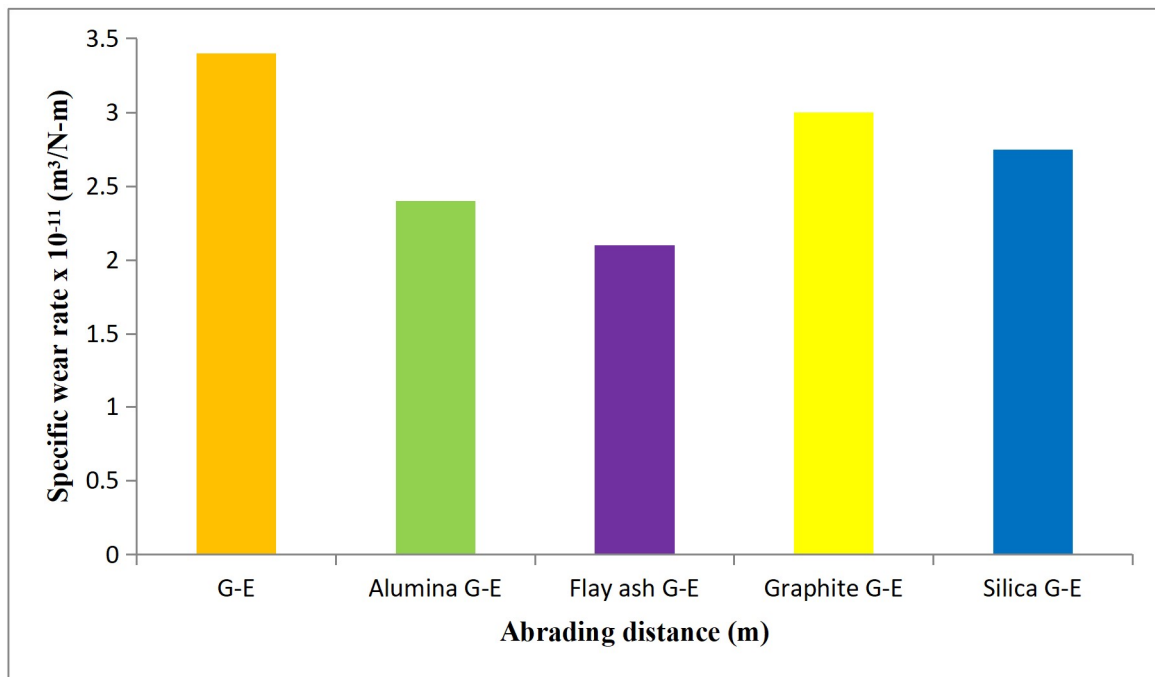


Figure 6: SWR of filled G-E composites at 500m and 40N.

3.3 Internal surface topography of filled G-E composites

Abrasive wear can be affected by several factors like the characteristic motion, surface properties and abrasion properties. Furthermore, abrasion mechanisms can be affected by range of particles size, particle, and surface component properties, contact pressure and velocity of the rubber wheel. The surface deformation depends on the constituents in the final composite. The worn-out composite surfaces were gold sputtered by using the evaporation process with current 15 mA and voltage 1 kV for 10 minutes duration. The gold sputtering process was done to get the conductive coating of 750 Å over the worn surfaces, which is the prerequisite to get good quality SEM images. As illustrated in Figure 8, G-E composite was tested at a normal load application of 40N and a worn surface at 2000 m. Figure 7 demonstrates that under a high applied load (40 N), the damage was more pronounced in the top/bottom resinous regions, with significant fibre degradation in the middle region. It is only possible to discern pitting (denoted by the letter "P") in the resinous areas and a network of micro cracks (denoted by the letter "M") in the vicinity of the bridging glass fibres. Only a few broken fibres were being dragged out, and the clean fibres looked to be intact in the abrading direction with a stepped appearance of glass fibres (marked "SA").

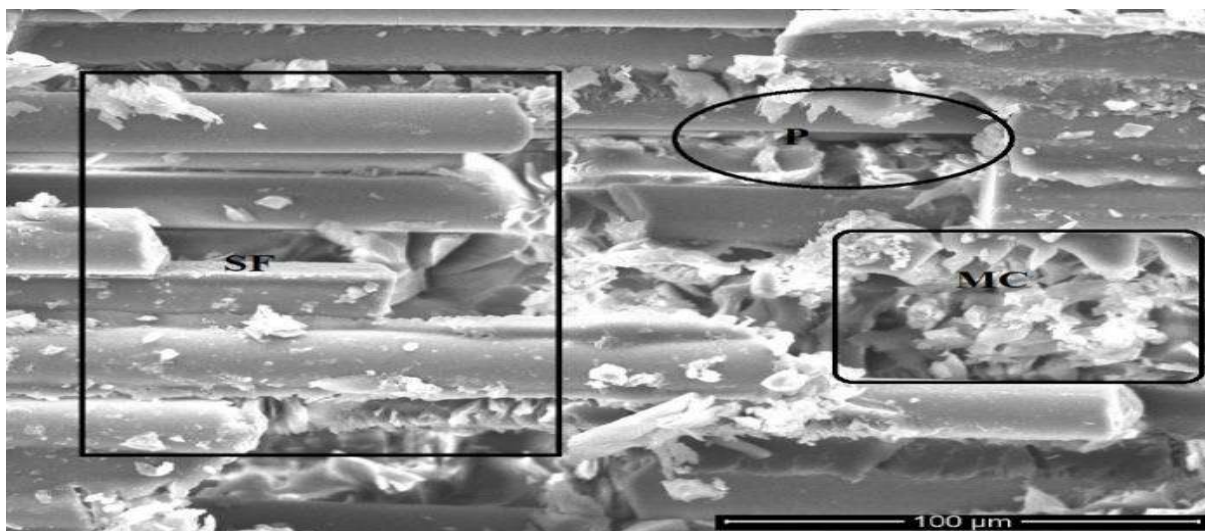


Figure 7: Internal surface topography of G-E composite.

3.4 Internal surface topography of Gr/G-E composites

Figure 9 depicts the wear-out surface of a Gr/GE composite that was tested at a load application of 40 N and 2000 m abrading distance. Figure 8 demonstrates that the epoxy graphite/matrix and fibre areas were both damaged at a high applied load (40 N).

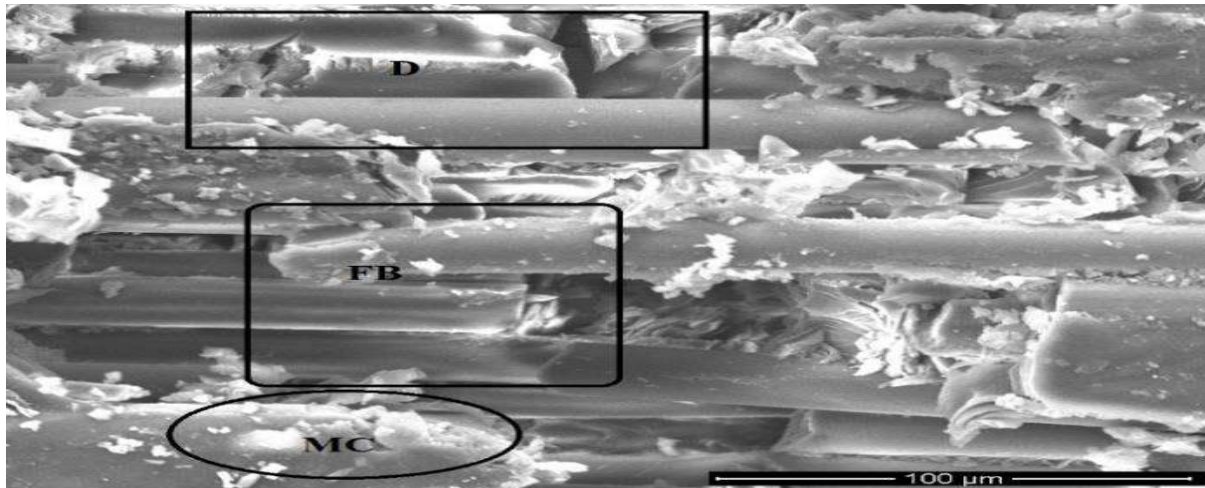


Figure 8; Internal surface topography of Gr/G-E composite.

Delamination (marked "D"), fibre breaking ("FB"), silica sand particles adhered to the epoxy matrix, and micro cracks of epoxy matrix ("MC") all happened. In addition, as shown in Figure 9, breakage occurred in the layered fabric, with broken fibres appearing to be worn-out, and a resinous layer of epoxy matrix with graphite particle pull-out occurred in the matrix/fabric interface region.

3.5 Internal surface topography of SiO₂/G-E composites

Figure 9 depicts the wear-out surface of the SiO₂/ G-E composite that was evaluated at a 40 N load and 2000 m abrading distance. Figure 9's observations of a wear-out surface under higher applied load (40 N) show that the damage was most obvious in the fibrous region, where a large amount of the resinous region near the layers of glass fabrics had been lost. The particles were then encouraged to attack the fibres and cause damage as a result. Additionally, as depicted in Figure 10, the stacked fibers fractured, resulting in the appearance of a steeped layer of broken fibres (designated "SA" in Figure 9) and a resinous layer of epoxy matrix with pull-out of silicon dioxide particles (designated "PO" in Figure 9).

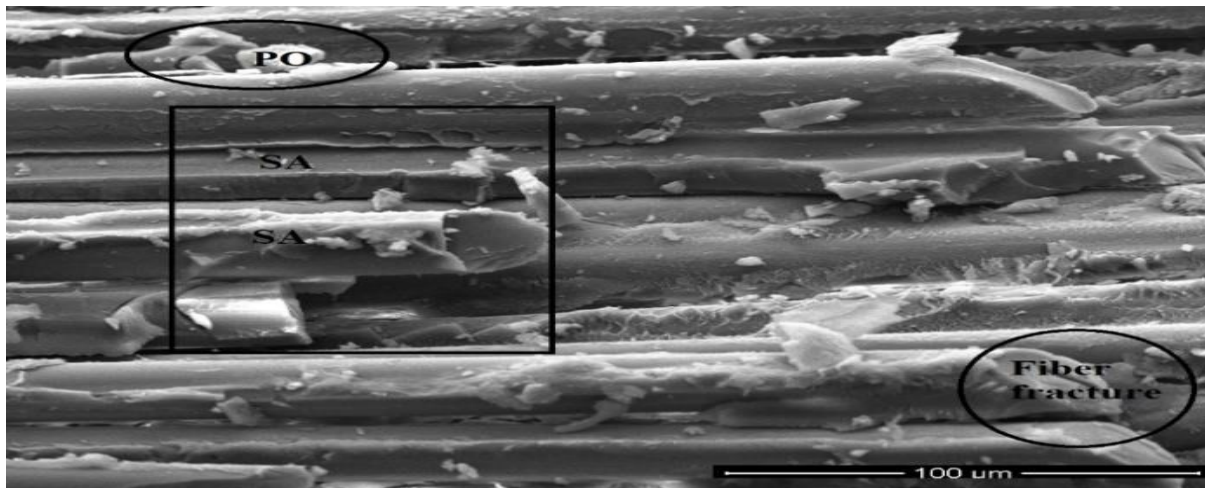


Figure 9: Internal surface topography of SiO₂/G-E composite.

3.6 Internal surface topography of Al₂O₃/G-E composites

The wear behaviour of tribo-materials is sharply affected by the type, shape and size of the ceramic fillers. The presence of ceramic fillers like SiO₂ and Al₂O₃ in G-E composites changed the material surface characteristics by reducing voids and enhancing the structural integrity which resulted in increased abrasion resistance. Figure 10 depicts the wear-out surface of Al₂O₃ filled G-E composite tested at 40N applied normal load and 2000 m. The figure shows consistent thin resinous layer removal (marked "R") and strong bonding at the interface, which minimizes damage to the epoxy/ Al₂O₃ and glass fibres on the abraded composite surface.

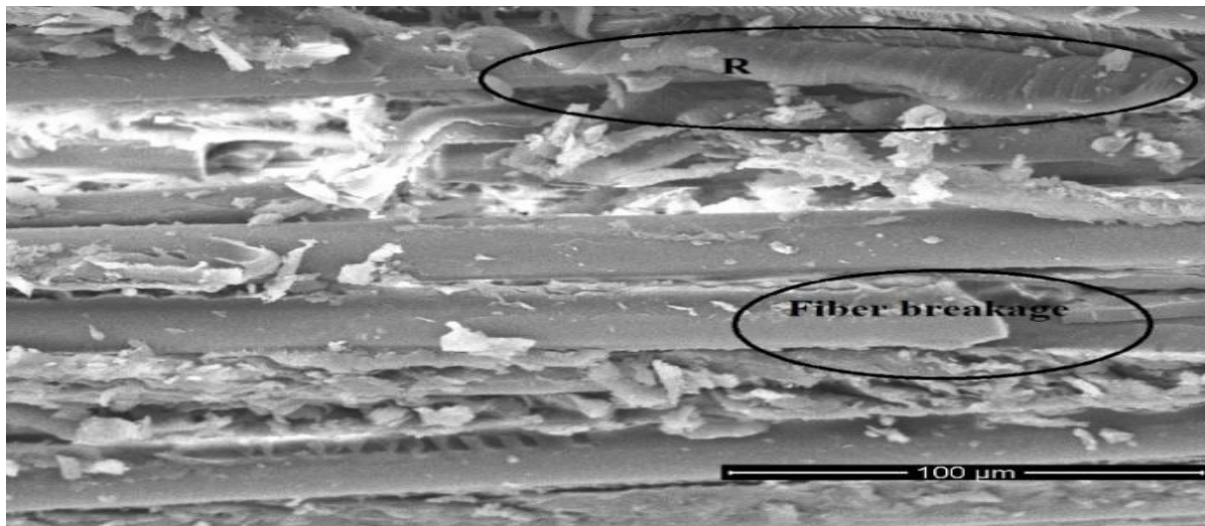


Figure 10: Internal surface topography of $\text{Al}_2\text{O}_3/\text{G-E}$ composite

This indicates that the silica sand fragments were not able to stick to the composite. When comparing the photomicrographs of G-E, Gr/G-E, and $\text{SiO}_2/\text{G-E}$ composites from Figure 11, it could be inferred that there was only a very small amount of material present that caused less damage to the glass fibres, supporting the wear data.

3.7 Internal surface topography of fly ash/G-E composite

Figure 11 depicts the worn surface of a fly ash filled G-E composite that was tested at a load application of 40N and 2000 m abrading distance. Less damage to the epoxy/fly ash and glass fibres on the abraded composite surface is seen in the image, i.e., uniform thin resinous layer removal (marked "R" in the picture) and strong bonding at the fiber/matrix interface. This indicates that silica sand fragments were not able to stick to composite.

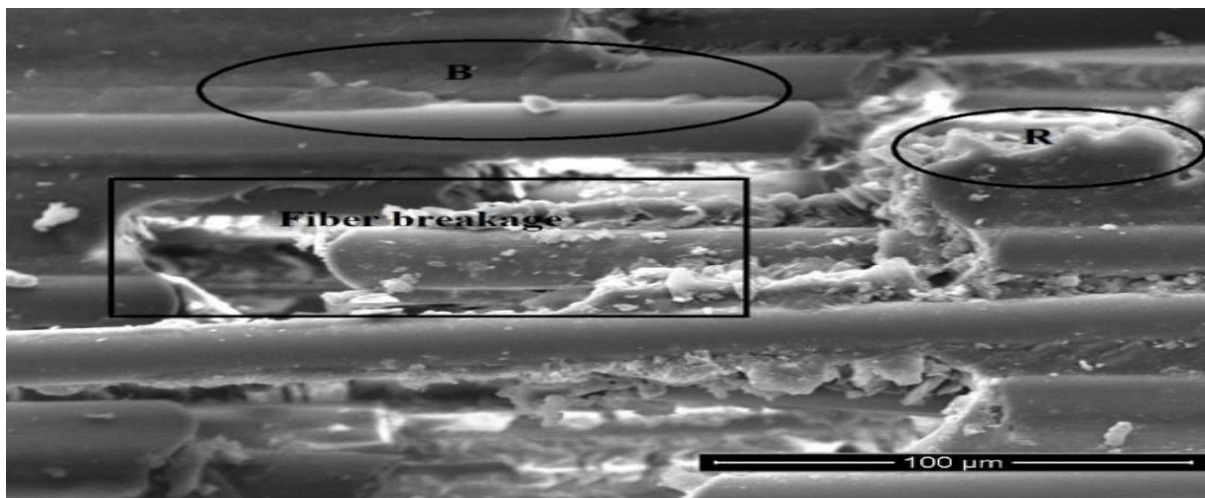


Figure 11: Internal surface topography of Fly ash/G-E composite.

Additionally, larger pieces of epoxy/fly ash particles were discovered on the surface, and the fibres seemed to be fractured but not debonded (indicated as "B"). This was accompanied in some places by little and large cracks, twisted grooves, and pitting. When comparing the photomicrographs of the unfilled Gr, SiO_2 and Al_2O_3 added G-E composites from Figure 12, it is reasonable to infer that there was only a very little amount of material, supporting the least specific wear rate, with less damage to both the matrix/fly ash and glass fibres.

4. CONCLUSION

In this investigation, G-E composites with and without ceramic fillers were made using by hand lay-up method followed by vacuum bagging. Three-body abrasive wear tests produced the following noteworthy results. Incorporation of fly ash cenosphere, SiO_2 , and Gr micron-sized fillers into G-E composite revealed good performance in abrasive wear mode. The following factors were observed to be important in controlling the wear performance of the composites. (i) All the fillers (irrespective of shape and size) used in the present work enhanced the epoxy matrix phase's interfacial bonding. (ii) The applied load and abrading distance. (iii) The extent of modification

of the composite surface which reduced the wear rate in longer abrading distance run.

Under all trio-test settings, the SWR for all particulate G-E composites decreases in the following order: G-E > Gr/G-E > /G-E > /G-E > fly ash cenosphere/G-E.

Photomicrographs show various wear mechanisms of G-E with and without filler. The wear mechanisms involved are ploughing, fibre breakage, fibre pull-out, fibre thinning, and a network of microcracks. The fly ash cenosphere proved to be more wear resistant than , and graphite.

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