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Study on the Wear Behaviour of Aluminium foam Reinforced Glass Fibre Epoxy Composites

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Abstract: *Hand layup was used to fabricate the glass fibre reinforced aluminium foam epoxy composites in this study. On the manufactured materials, dry sliding wear experiments were performed. The effect of wearprocess parameters such asapplying load (kg), speed (m/s), and sliding distance (m) on specific wear rate (Ws) was investigatedand the obtained results were compared with neat glass fibre reinforced epoxy composite in this work. The outcome of these results showed that specific wear rate (Ws) of glassfibre epoxy composite containing aluminium foam decreased as compared with neat glass fibre reinforced polymer composites. Experimental results showed that a minimum wear rate of 10.1 µm was attained for the sliding velocity (1.5 m/s), Applied load (2 kg), and sliding distance (1000 m) in the fabricated composite laminates. It was observed thatthe resistance to wear in glass fibre reinforced aluminium foam composite was mainly due to the bond strength between aluminium foam and epoxy.*

Keywords*: polymer composite, epoxy resin, wear rate, glass fibre, aluminium foam*

1. Introduction

Due to light weight, specific thickness, better energy absorption, metal foams are suitable for applications in automotive, aerospace and ship building industries where safety is important aspects [1]. Now days fibre composite materials are widely used in automotive, aerospace solar arrays, cryogenic tanks, automobile body panels. Due to their signifigant mechanical properties and lightweight structure, aluminum foam glass fiber reinforced plastics sandwich composites have been increasingly utilized in the shipbuilding, automotive, and aerospace industries for their striking mechanical and physical properties. In aircraft industries fibre metal laminates are used in upper fuselage skin panel structures. Carbon fibre reinforced composites are used for making wing panel aircraft wing boxesand stabilisers [2, 3].

In Aerospace and automotive industriesless weight with high-stiffness and strength materials are preferred. Manufacturing of automotive parts lightweight components are used for reducing 30-40% in the total vehicle weight [4]. To reduce the engine emission and increase the fuel efficiency, light weight non-ferrousaluminiumand magnesium alloys were used in transportation industries [5, 6].

In sandwich structures, adhesives are used for composing a number of individual layers. These classical sandwich structures are unsuitable for joining techniques such as ordering, welding, screwing and riveting [7]. Polymeric composite sandwich panelsconsist oflight weight porous aluminium foam core lightweight core. Due to high strength, stiffness, high energy dissipation and better vibration reduction aluminium foam composites widely used in industries. Metal plates were used as panels in structural applications in previous literary works. [8]. In nature various porous structures occurwhich

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**email: smkumar69@gmail.com, prab_er@yahoo.co.in* includes honeycomband foam like structures. Now days researchers made porous metals to extend the applications of metals, inspired by naturallyformed porous materials [9, 10]. Compared with the polymeric foams, metal foams showflexibility to recycle, good thermal stability and thermal conductivity [11].

Due to lightweight, energy absorbing capacity and vibration damping capacity, they have been used in building construction, automotive, aerospace and industrial equipment [12, 13]. They are useful as core and filler material in the fabrication of sandwich panels [14]. Despite their low mechanical strength, researchers worked to improve the mechanical properties of aluminium foams by adding fibres in them [15]. From the previous literature works, it was seen that, most current sandwich structures are based on aluminium honey comb and polymeric foams bonded with glass fibre reinforced polymeric composites. Metal foams are the material with relatively high energy absorption and low density and high energy absorption capabilities. They are categorized into two types namely open and closed cell foams [16].

Glass fibre reinforced metal foams are widely used in many applications. Friction and wear properties of glass fibre reinforced metal laminates have been studied by various of researchers. Glass fibre with aluminium foam was fabricated using hand layup process for helmet applications. From this work it was seen that weight was reduced and strength also increased in the fabricated helmet with minimized wearing property [17]. The friction and wear characteristics of glass epoxy composites filled with aluminium particulate sliding on steel were studied. Wear behaviour under dry sliding condition is presented as a function of speed (1 to 5m/s), applied load (10 to 40 N). From this work it was seen that incorporation of aluminium foam reduces wear rate as compared with to unfilled glass fibre reinforced epoxy composites [18]. Pin on disc wear test was performed on granite powder filled glass fibre reinforced epoxy resin by varying load, sliding distance and velocity. This work showed that the addition of granite powder in the glass fibre composites reduced the wear loss [19].

Sandwich panel with Al foam and fibre metal laminate consist of aluminium sheet and woven glass fibres was fabricated for investigating low velocity impact response. The effects of foam thickness and skin thickness on impact response was examined in this study. From the result it was observed that the aluminium foam in the fabricated increase the impact property [20, 21].

Friction and wear studies were carried out in aluminium (A356) foam reinforced composites filled with silicon carbide. Process parameters such as applying load, sliding speed were used as process parameters. This work concluded that aluminium foam silicon carbide composites the friction specific wear rate as compared with base alloy. For both the materials, it was noticed that as the applying load increased, the co-efficient of friction and wear rate decreased [22]. Wear studies were conducted on the fabricated aluminium syntactic foam with the process parameters of applied load (1-5kg) and sliding velocity of (2-4) m/s. From this work it was seen that the craters presented in the fabricated specimenplay important role in the friction and wear characterization [23]. Friction and wear behaviour of epoxy matrix reinforced syntactic foams filled with cenosphere was investigated. From this work it was noticed that syntactic foams have maximum wear resistance as compared with the matrix resin. Also, with increasing the applied loadthe wear rate also increased. When the filler content increased, the wear rate in the fabricated composite decreased [24].

Glass fibre aluminium foam sandwich structures offers potential for use in transport engineering such as aerospace, marine, automobile, shipbuilding industry. These fabricated composited have their interesting properties such as low weight, high energy absorbing capacity, high stiffness and strength to weight ratios, excellent thermal insulation, acoustic damping, fire retardancy, ease of manufacture and repair. With the increasing attention on the environmental consequences of the burning of fossil fuels and the expected increase in the oil price, there is a growing interest in the energy efficiency for transport industry [25].

Influence of aluminium foam on specific wear rate of glass fibre epoxy aluminium foam sandwich structure has not yet been fully understood and the work has so far been established in the development of glass fibre aluminium foam sandwich fibre metal laminates is scanty.Objective of providing aluminium foam between glass fibre skin is to reduce the wight of the samples and increase the impact resistance of the material

This current research aims

-To fabricate glass fibre reinforced aluminium foamcomposite and the effect of wear parameters specific wear rate (Ws).

-Due to its light weight and ease of mixing with fibres and resin, closed cell aluminum alloy foam was utilised in glass fibre composite.

-The effect of load (k/g), sliding speed (m/s), and sliding distance on the specific wear rate (Ws) of glass fibre reinforced aluminium foam was investigated.

2. Materials and method

2.1 Materials

Glass fibre reinforced polymer compositeand aluminium foam with various thicknesses (0.5 and 1mm) were used to fabricate the sandwichpanelin this work. In between glass fibres, a closed-cell aluminium foam material is selected as a core material. S-Glass fibre, Epoxy resin (LY556), Hardner (HY951) used for this investigation were purchased from Hayal Aerospace Ltd, Chennai. The foam panels (purchased from Nanochemazone Inc) were between 0.5 and 1mm thick, with a glass fibre skin produced during the manufacturing process.

2.2 Experimental procedure

2.2.1 Fabrication of composite panel

In this work, aluminium foam specimens were cut from big panels and being used as a sandwich between glass fibre skins. In order to make aluminium foam sandwich samples, epoxy resin was used as an adhesive agent [26]. Handlayup process was used for fabricating the composite samples. Figure 1 shows the aluminium foam used for this investigation. Figure 2 shows the fabricated aluminium foam reinforced GFRP composites. Three layers of glass fibre used for obtaining the thickness. Inbetwwen the layers of glass fibre, aluminmium foam was inserted with different thickness (0.5 and 1mm). Epoxy resin was used.

Figure 1. Aluminium foam

Figure 2. Glass fibre reinforced aluminium foam composite

2.2.2 Pin-on-disc wear test

Based on the ASTM G99, wear test apparatus illustrated in Figure 3 was used to conduct the experiment under dry sliding condition [27-29]. The composite specimens with the length of 30mm and the diameter of 8 mm were cut from the fabricated samples was used for wear testing. Wear experiment has been performed using pin-on-disc. Table 1 shows the specification of the pin-on-disc apparatus used for this investigation. Before test, the cylindrical specimen pin and stainless-steel disc were polished with abrasive paper and cleaned in acetone [30-32]. Sliding distances of 1.5, 3 to 4.5m/s, applied loads from 2 k/g to 4 k/g, contact pressure of 0.2 to 0.4 MPa and sliding distance of 1000 to 2000m/s was chosen as process parameters. After that the pre-worn composite samples were cleaned with ethanol. Aluminium foam reinforced glass fibre composites specimen is pressed against the rotating steel disc by applying the load. The glass fibre aluminium foam reinforced polymer composite specimen was kept stationary against the disc.

Figure 3. Pin-on-disc apparatus

Table 1. Pin-on disc specification

Parameter	**Operating conditions**
Temperature	Ambient conditions (28°C)
Relative humidity	60 (5±) %
Test disc Hardened steel	EN-31, hardness 62 HRC
Roughness (Ra) of EN-31	1.8 μm
Duration of rubbing (s)	500
Surface condition	Dry
Applied load (kg)	2, 3 and 4
Sliding speed (m/s)	1.5, 3 and 4.5
Sliding distance (m)	1000, 1500 and 2000
Filler loading (wt. %)	0, 5, 10
Plin material	Glass fibre reinforced aluminium foam
Pin size	30 mm x ∅ 8 mm

2.3 Experimental design

Taguchi's variable framework is used to improve a system's ruggedness and to aid in product and process design judgements. Because of its ease of adaptation and easiness, this procedure can be used to optimise process conditions [33, 34]. This method yields the preferred information from a small number of trials with varying levels. Orthogonal arrays are recommended for research design for two purposes: their small size and the reality that they appear to produce acceptable results [35]. Taguchi's scientific method was used for the four factors chosen without taking into account the interrelations among them; thus, a L_9 orthogonal array is developed for investigating the impacts of designated variables independently [36, 37].Sliding speed, applied Load, contact pressure and sliding distance are considered as independent input parameter while specific wear rate is considered as dependent output variable. Figure 4 shows the schematic representation of pin and disc used for this investigation and as per the experimental condition mentioned in the Table 2 wear experiments were conducted.

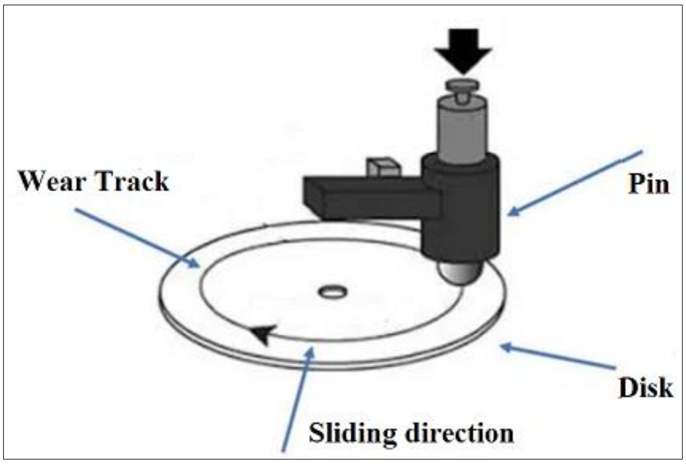


Figure 4. Schematic representation of pin and disc

Table 2. Wear test factors and their levels

S. No.	Factor	Notation	Unit	Levels		
				1	2	3
1	Sliding speed	S	m/s	1.5	3	4.5
2	Applied load	L	Kg	2	3	4
3	Contact pressure	P	MPa	0.2	0.3	0.4
4	Sliding distance	D	M	1000	1500	2000

3. Results and discussions

3.1 Wear experiment analysis

In this current study, dry sliding wear behaviour of neat glass fibre polymer composite and glass fibre reinforced aluminium foam samples have been studied in terms of specific wear rate (W_S). Three samples were tested for accuracy. The wear responses of the fabricated GFPC and aluminium foam composite materials were recorded in Table 3. Influence of pin on disc parameters on specific wear rate (W*s*) in glass fibre reinforced aluminium foam composites are presented in Figure 5 at different pin-on disc parameters.

Table 3. Wear experimental results

Pin-on disc input parameters					Specific wear rate (mm)		
Exp. No.	Sliding velocity (m/s)	Applied load (N)	Contact pressure (MPa)	Sliding distance, (m)	Neat GFRP	GFRP 0.5Al foam	GFRP lAl foam
1	1.5	2	0.2	1000	14.5	12.3	10.1
2	1.5	3	0.3	1500	17.6	15.5	13.5
3	1.5	4	0.4	2000	18.3	16.4	14.2
4	3	2	0.2	1000	17.5	15.3	13.6
5	3	3	0.3	1000	26.4	24.4	22.6
6	3	4	0.4	1500	28	26.3	24.7
7	4.5	2	0.2	1500	32.2	30.4	28.6
8	4.5	3	0.3	2000	34.4	32.1	30.3
9	4.5	4	0.4	1000	36.3	34.2	32.5

3.1.1. Effectof sliding velocity on specific wear rate

Specific wear rate of neat glass fibre and glass fibre with 0.5 mm and 1 mm aluminium foam reinforced epoxy compositeagainst the sliding velocity is shown in Figure 5. In this work specific wear rate increased with increasing the sliding velocityin neat glass epoxy and glass fibre (0.5, 1 mm) aluminium foam reinforced epoxy composite. When the sliding velocity is 1.5m/s, the specific wear rate

(Ws) obtained in the neat glass fibre epoxy composite is 14.5µm. The introduction of aluminium foam in glass fibre composite with 0.5mm thickness reduced the specific wear rate to 12.3m, and the addition of 1mm thickness reduced the wear rate even further to 10.1m. When the sliding velocity increased to 4.5m/s offered the specific wear rate of 32.2µm in glass fiber reinforced epoxy composites is reduced to 28.6µm. In glass fibre reinforced aluminium composites, the sliding velocity has a significant effect on the wear rate. When the sliding velocity is minimal, the stresses at impact are insufficient for plastic deformation to occur, and surface fatigue takes over wear rate. When the sliding velocity increases, it is possible to erodethe material to deform plastically on particle impact [38].

When the sliding velocity increased, the bonding of aluminium foam against the epoxy matrix took increased which in turn improve the wear resistance. For the maximum sliding velocity, the stress reached its fatigue limit hence increasing the removal of surface material and hence high weight lossoccurred. The aluminium foam placed between the glass fibre skins decreases the specificwear rate by generating thin layer whichin turnreduce the specific wear rate of the fabricated composite [39]. It is observed from the figure that at minimum sliding velocity both neat glass epoxy and its aluminium foamcomposites shows reduced wear rate.

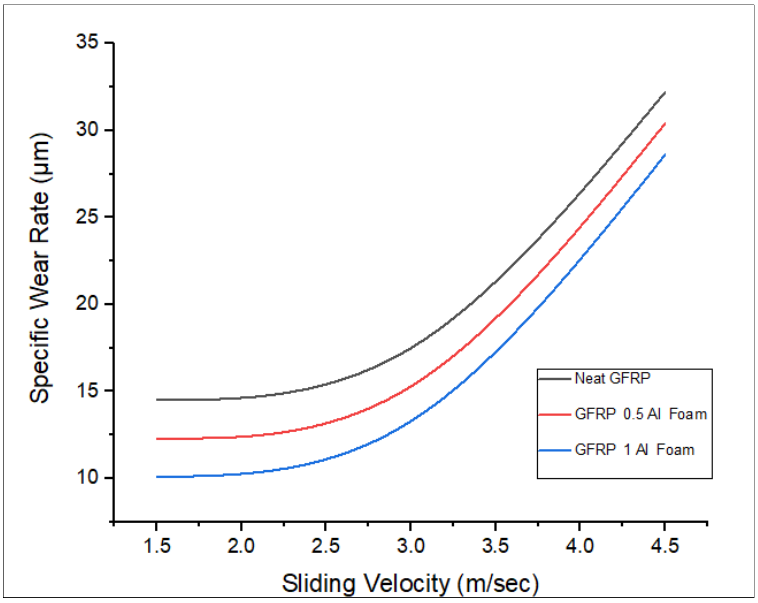


Figure 5. Influence of sliding velocity of specific wear rate in glass fibre aluminium foam composite

3.1.2. Effect of applying load on wear rate

Figure 6 explains the specific wear rate of neat glass fibre and its aluminium foam composites in contradiction of the applied load. In this investigation increasing the load increased the specific wear rate in both glass fibre epoxy and its aluminium foam composites. When the load is 2N, the specific wear rate obtained in the neat glass fibre reinforced epoxy composites is 18.3µm. Aluminum foam was incorporated into a glass fibre epoxy composite to reduce the specific wear rate. When the load is increased to 4 N the specific wear rate of 16.4µmin glass fibre and addition of 1mm thickness aluminum foam it is reduced to 14.2µm.

The specific wear rate increased with increasing the applied load, according to this research. Higher frictional heat generation at maximum load led to a large number of reverse transmission patches in the composite film, which protected the composite surface from any further damage [40].When the applying load is maximum, due to high thermo mechanical field generated by the addition of aluminium foam caused increased the deboning between the fibers and the epoxy resin matrix. Hence more fibre pull-out occurred which in turn increased the wear rate. In this investigation, wear rate decreased in glass fibre reinforced aluminium foam composites.

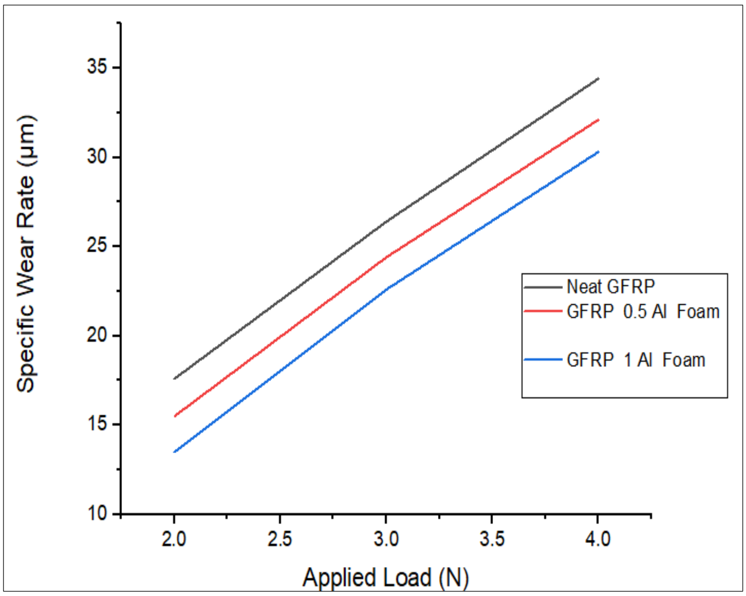


Figure 6. Influence of applied load of specific wear rate in glass fibre aluminium foam composite

3.1.3. Effect of sliding distance on wear rate

Figure 7 shows the effect of sliding distance on wear rate of neat glass fibre aluminium foam epoxy composites. In this investigation neat epoxy glass fibre composite offered the wear rate of 24µm for the sliding distance of 1000 m and it is decreased to 34.4µm for the sliding distance of 2000 m. According to this study, the specific wear rate increased as the sliding distance increased. At maximum distance, increasing frictional heat generation resulted in a significant number of reverse transmission patches in the composite film, shielding the composite surface from further damage [41].When the distance between the disc and the composite pin increased, the formation of composite shield happened between the pin and disc whichin turn resist the wear rate [42].

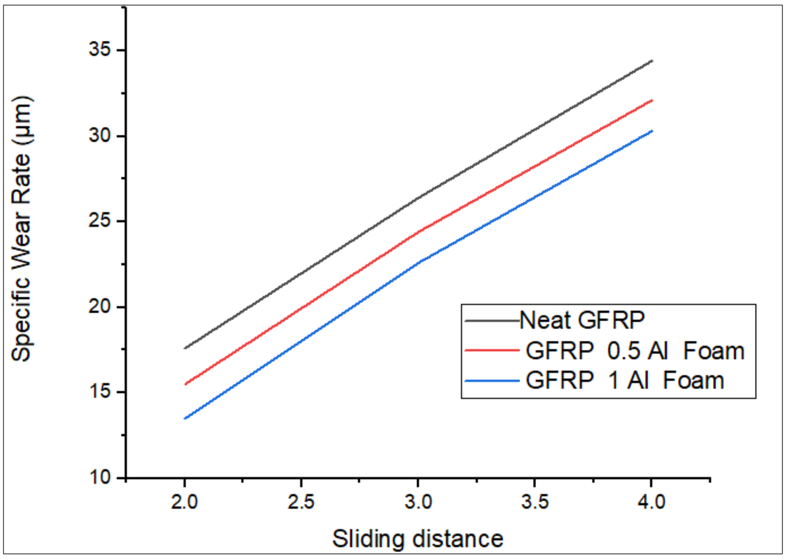


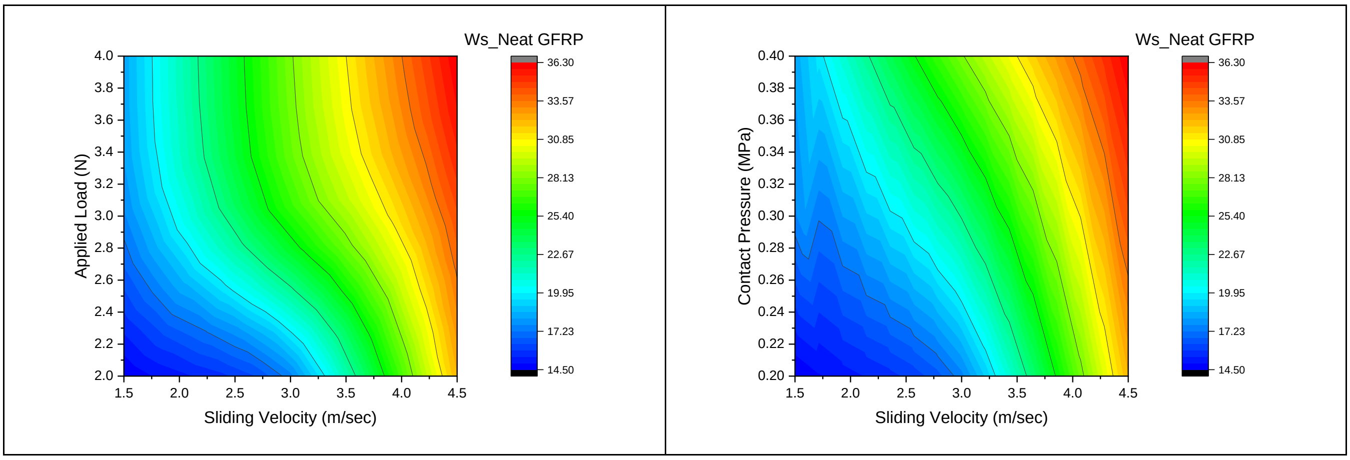
Figure 7. Influence of Sliding distance of specific wear rate in glass fibre aluminium foam composite

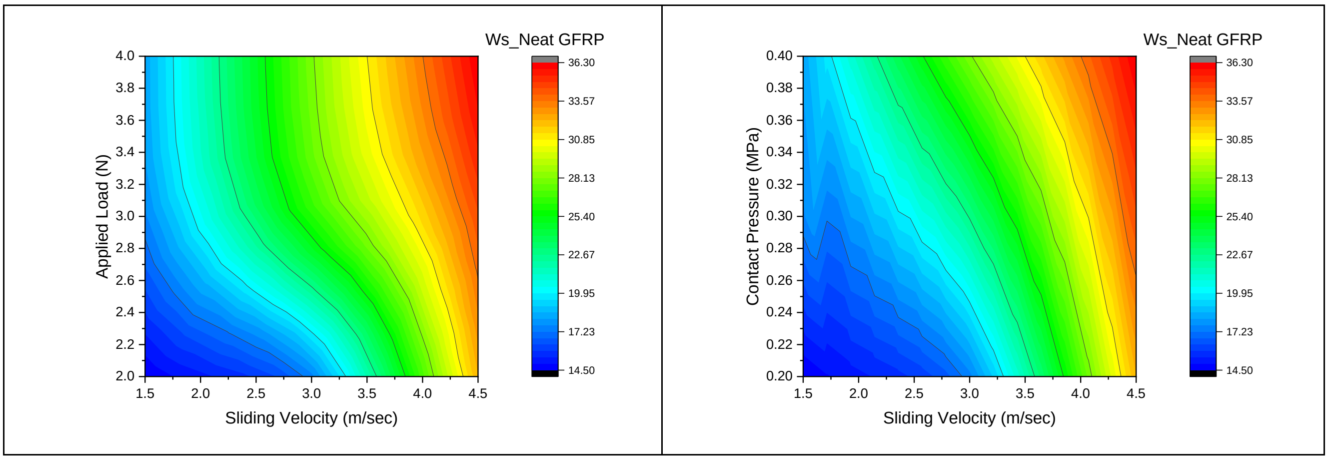
3.2. Correlation of inputs and wear rate

The relationship that exists among the considered input and the wear rate obtained from wear test for three different materials is provided as contour plots. Contour plots (also known as Level Plots) are a method of representing a 3D surface on a 2D plane. It plots two estimator variables X Y and a dependent variable Z as contours on the y-axis. These contours are also known as iso-response values or z-slices. Contour plots are used for evaluating the input data aspects as this plot investigate the relationship between three variables and to examine X and Y combinations that result in desirable outcome values. Contour plots necessitate the use of three continuous variables [43,44].

3.2.1. Correlation between inputs and Ws for neat GFRP

The contour plot drawn for the inputs and wear rate for neat GFRP is presented in Figure 8. Increasing the velocity of sliding obviously rises rate of wear but there is no effect of axial load and contact pressure over the wear rate. Higher sliding velocity produces higher wear rate due to the amount of friction developed between the sliding pairs. For lower and higher values of sliding distance the wear rate becomes low as higher sliding distance causes self-lubrication of GFRP [45, 46]. But at moderate value of sliding velocity produces a considerable amount of wear rate.





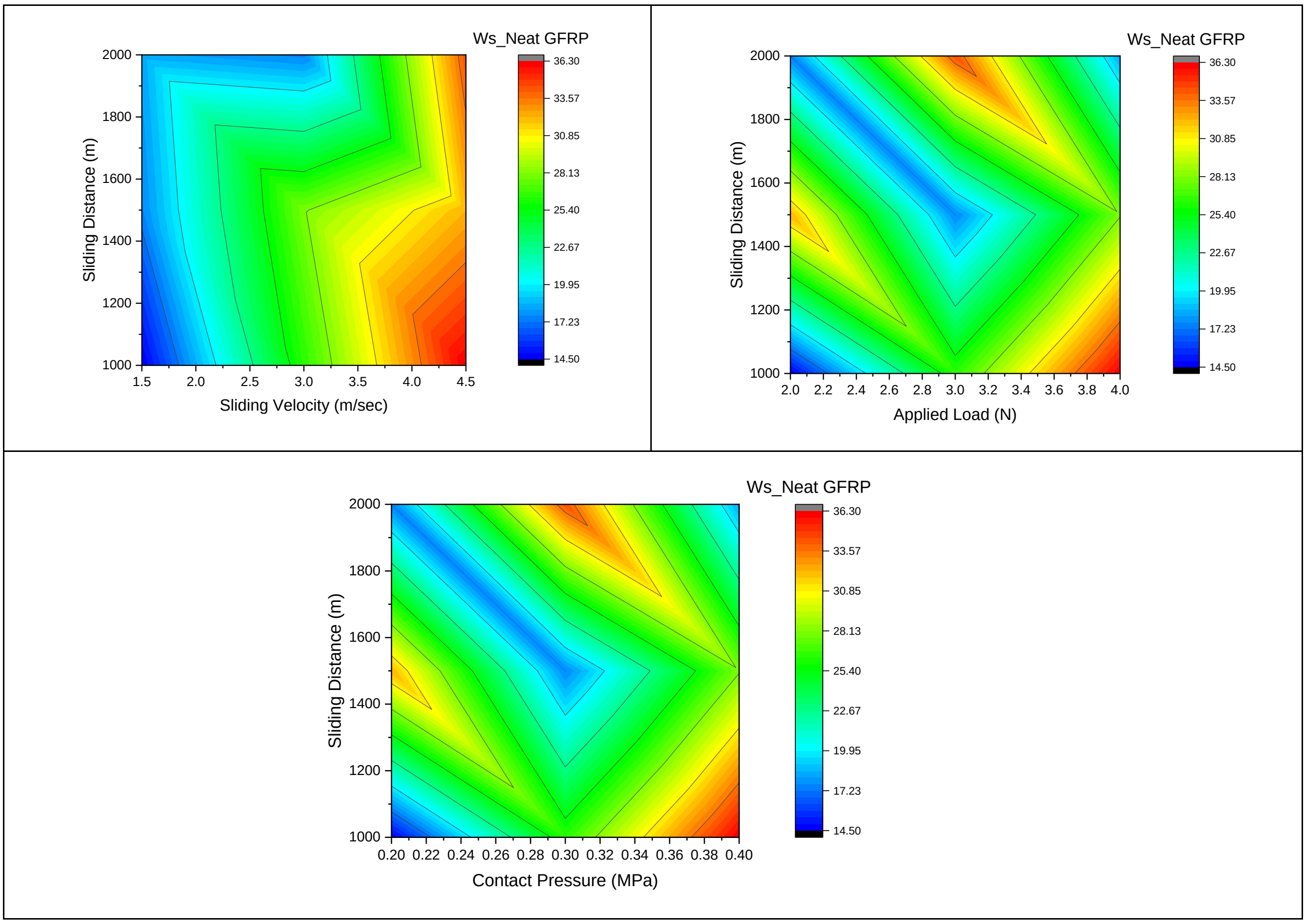
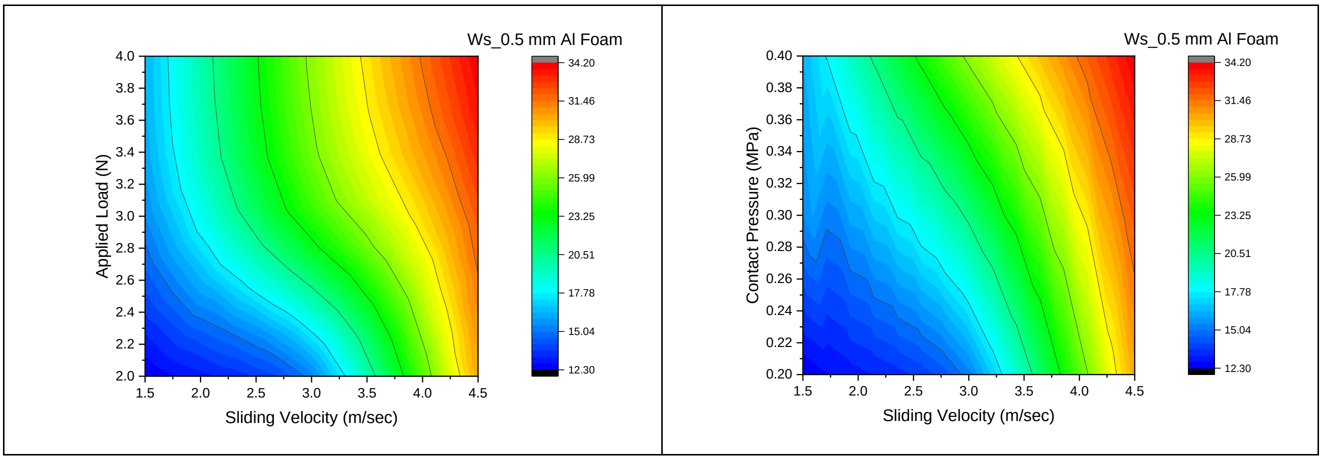


Figure 8. Correlation between inputs and Ws for neat GFRP

3.2.2. Correlation between inputs and Ws for 0.5mm Al foam added GFRP

Figure 9 presents the relationship among the input parameters and 0.5mm aluminium foam reinforced GFRP composite. From the wear performance of aluminium foam reinforced GRFP composite it is found that the reinforced foam increases the strength and toughness of the polymer composite core.



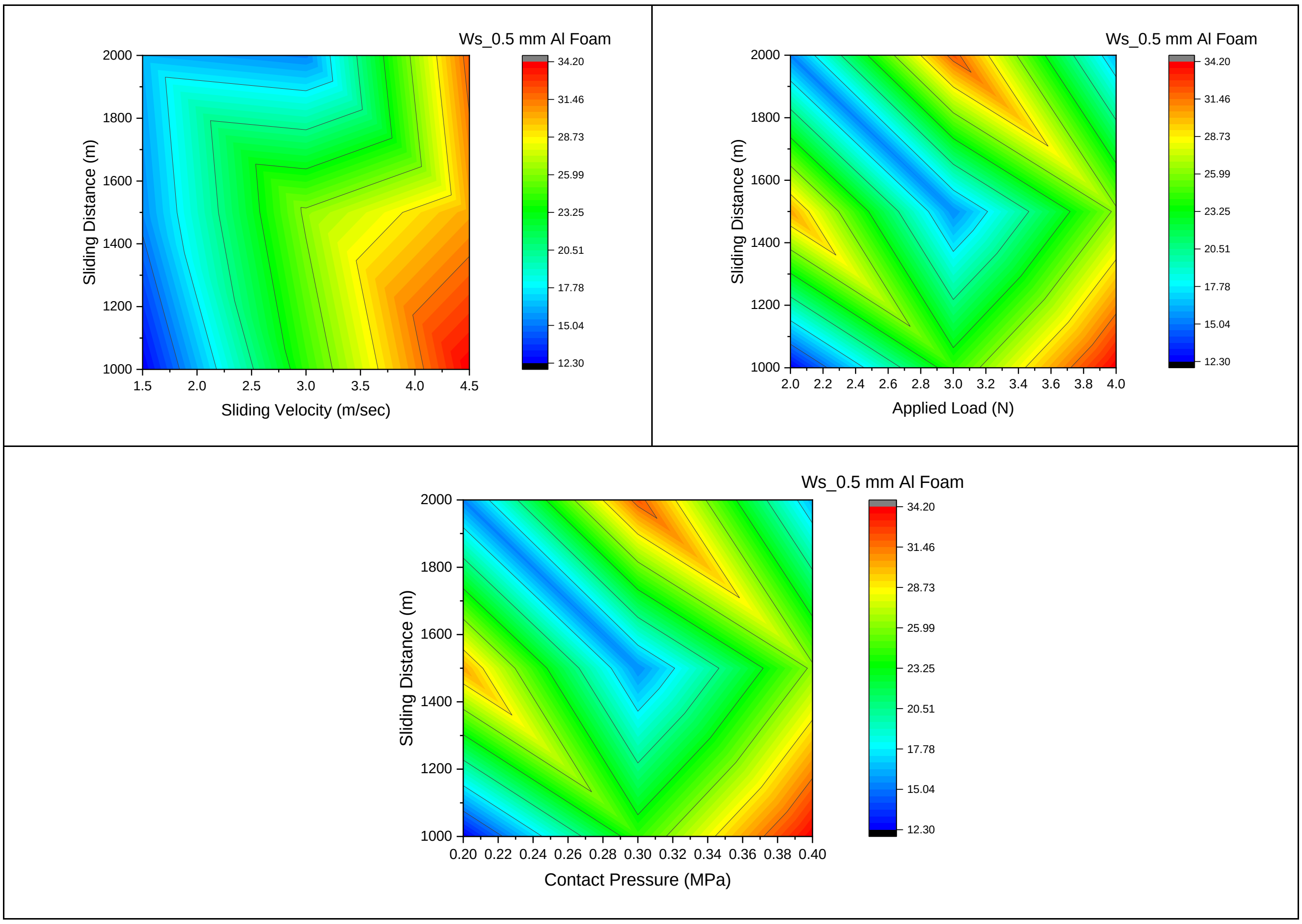


Figure 9. Correlation between inputs and Ws for 0.5mm Al foam added GFRP

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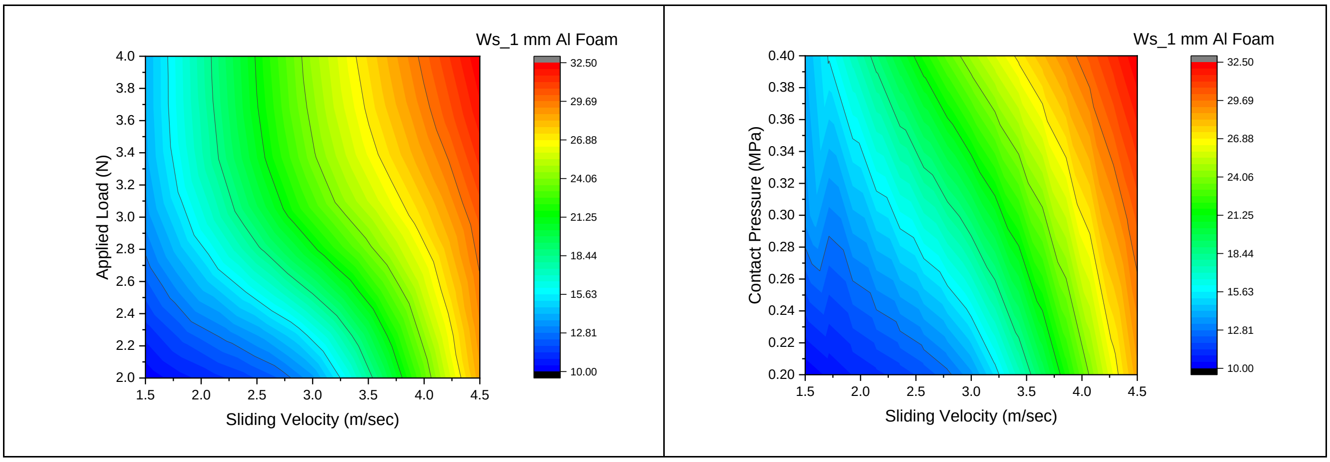
3.2.3. Correlation between inputs and Ws for 1mm Al foam added GFRP

The effects of input parameter on the wear rate of 1mm aluminium foam reinforced GFRP composite is depicted as contour plot in Figure 10. From the wear performance of aluminium foam reinforced GRFP composite it is found that the reinforced foam increases the strength and toughness of the polymer composite core. But the GFRP reinforced in epoxy alone is going to be in contact with the sliding pair and hence similar result is obtained. The influence of sliding distance and sliding velocity is higher than the axial load and contact pressure. But there is a considerable contribution of all the input parameters towards the wear rate.



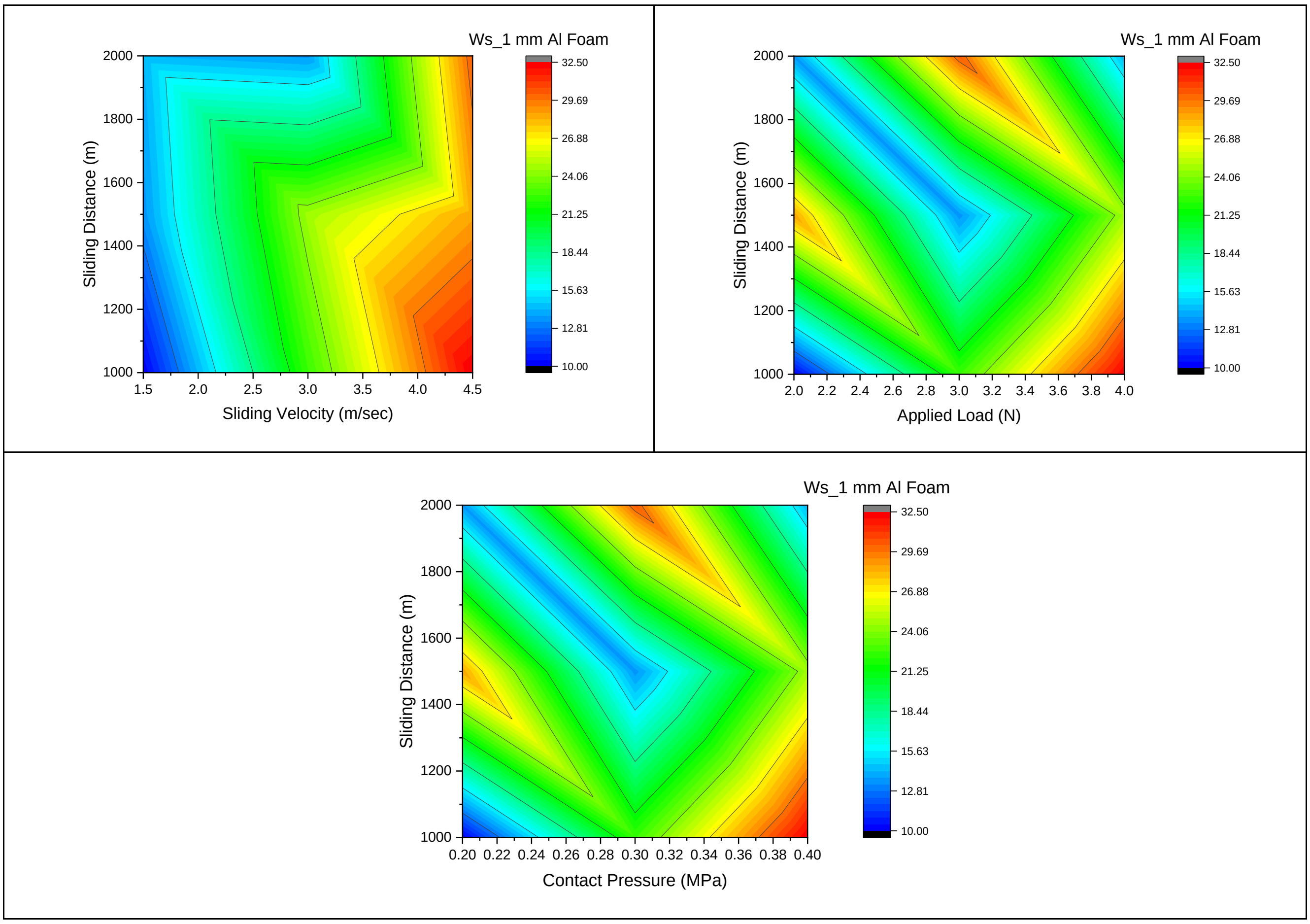


Figure 10. Correlation between inputs and Ws for 1mm Al foam added GFRP

3.3. Microstructure of worn surfaces

Worn surface feature on the fabricated glass fibre reinforced aluminium foam (0.5 and 1mm) composite is evaluated using scanning electron microscope. Figure 11a-c shows the SEM images of neat epoxy glass fiber composite, glass fibre with 0.5mm and 1mm thickness of aluminium foam for the different sliding conditions using pin-on-disc apparatus.

Figure 11a depicts the wear loss in a neat epoxy glass fibre composite when sliding speed, applied load, sliding velocity, and sliding distance are all considered with account. It can be seen in the figure that there is more debris in the matrix, fibre masking, and the resin matrix. Furthermore, increased wear-related cracks in glass fibres have really been observed [47]. And this is compared with glass fiber reinforced aluminium foam epoxy composites with 0.5mm thickness aluminium foam (Figure 11b).

It is witnessed that debris and fibre cracks is more in neat glass fibre composite as shown in Figure 11a. Further, maximum damage of fibres with the matrix precious due to wear is noticeably seen in Figure 11b. The structures like low debris creation, beginning of fibre ruptures are observed due to the adding of aluminium foam in which form a mask between glass fibres and the resin Figure 11c. In numerous regions the glass fibres still closely adhere with epoxy matrix [48]. From this investigation, it was noticed that the increase in thickness of the aluminium foam decreased the wear rate in glass fibre reinforced aluminium foam epoxy composites.

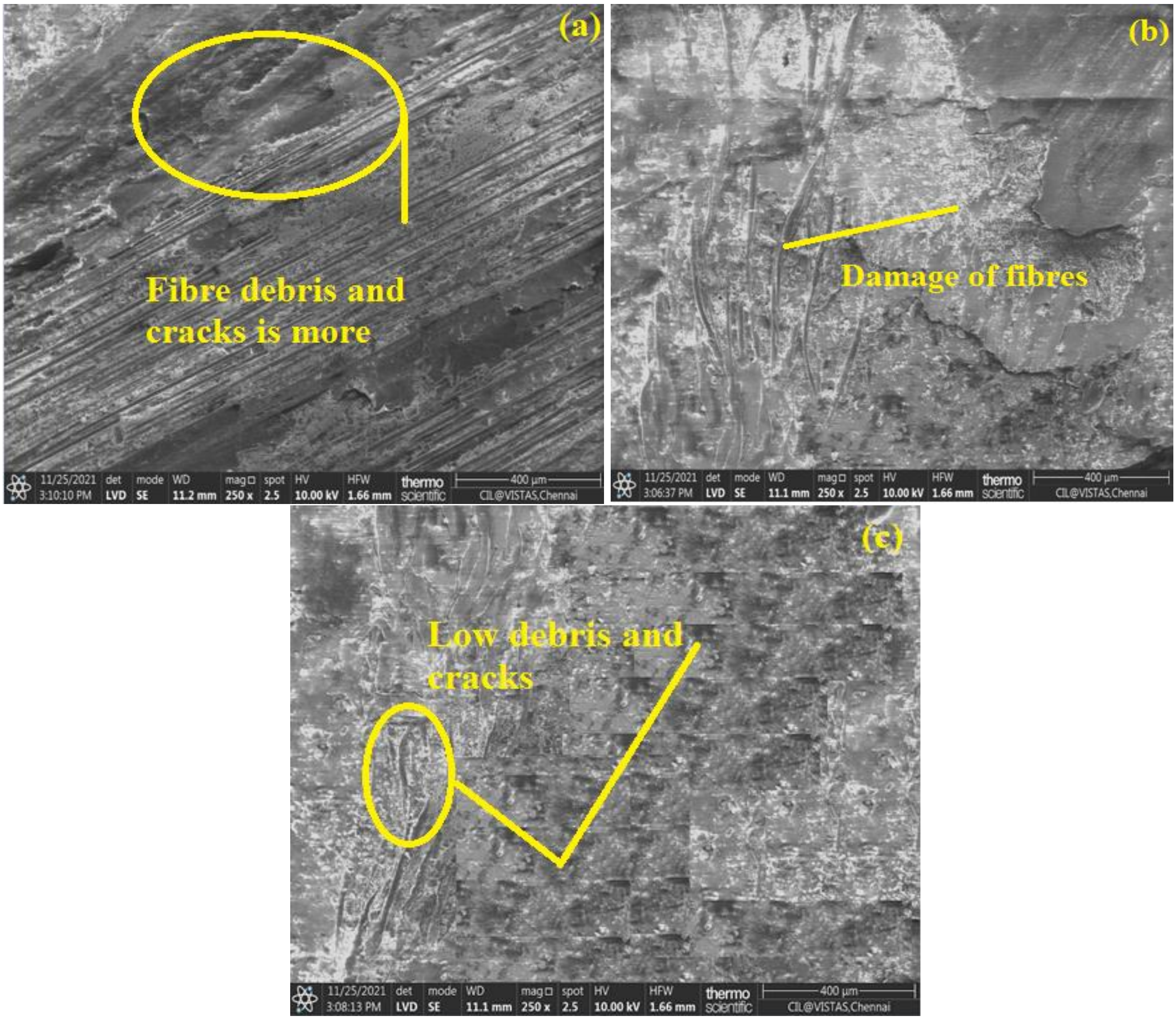


Figure 11. Microstructure of worn surfaces (a) Neat GFRP (b) GFRP 0.5 Al foam and (C) GFRP 1Al foam

4. Conclusions

An investigational study to understand the wear behaviour of neat glass fibre and aluminium foam reinforced glass fibre composites at different sliding velocity, sliding distance, applied load was conducted. From this research, the following conclusions were drawn

In this work sliding velocity and load appliedare the significant process parameters affecting the specific wear rate in glass fibre and aluminium reinforced glass fibre composite.

When the sliding speed increased wear rate also increased. At higher sliding speed, the abrasive wear mechanisms govern the interaction between the surfaces in contact.

Sliding wear behaviour of 1mm thickness aluminium foam glass fibre composites are higher as compared with neat glass fibre composites.

Aluminium foam with 1mm thickness in the glass fibre composites showed an increase in specific wear rate up to 70%.

Investigations that used a scanning electron microscope (SEM) revealed that worn surfaces indicate the removal of broken fibres from of the glass fibre matrix.

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