Journal of Mines, Metals and Fuels, *71(12D): 202-212; 2023. DOI: 10.18311/jmmf/2023/47989*

Print ISSN : 0022-2755

Journal of Mines, Metals and Fuels

Contents available at: *www.informaticsjournals.com/index.php/jmmf*

Comparative Study of Wear Characteristics of Graphite, Silicon Carbide and Mixture of Silicon Carbide – Graphite Filled E-Glass Fiber Reinforced Vinyl Ester Composites

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Abstract

Composite materials blend unique characteristics such as stiffness, toughness and high thermal strength. The present study evaluates the tribological properties, namely abrasion and erosion wear of E-glass fabric reinforced vinyl ester composites with and without the addition of particulate fillers. The composite plates were fabricated using the hand lay-up technique. Graphite, Silicon Carbide (SiC) and a mixture of SiC-Graphite were used as particulate reinforcement and accordingly, three sets of composites were fabricated with each set containing composite plates of 3%, 6% and 9% filler content by weight. Dry Abrasion test or three body wear tests and Erosion Wear Testing were conducted to evaluate the tribological properties of the composites and the test was performed under ASTM G-65 (ASTM G65, 1994). Silica sand and quartz sand were used as abrasive media. It was concluded that the addition of particulate filler in vinyl ester composites significantly improved their wear resistance and Silicon Carbide filled composites have better resistance to wear than the other combinations which were tested.

Keywords: *Abrasion Wear, Erosion Wear, E-Glass Fibre, Graphite, Polymer Composites, Silicon Carbide, Tribology, Vinyl Ester*

1.0 Introduction

Wear leads to significant wastage of material and deteriorates the mechanical performance. Reducing the wear results in substantial cost savings. The main cause of wear and energy loss is the friction. Tribology is a field of science, which applies in operation analysis to problems of great economic significance such as reliability, maintenance, and wear of technical equipment[1-4]. Composite material consists of two or more appropriately arranged phases, having an interface separating them. It is also can be defined as a multiphase system that consists of at least two different groups of materials which are physically and chemically distinct and separated by interfaces[5]. They offered a new approach to the design of materials with tailor-made properties. These newly designed materials consist of reinforcing phases in a matrix of different materials. The applications

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of composite materials extend from commonly used materials to high-technology applications like spacecraft and marine equipment. Composite materials now form a class of advanced materials and are considered a potential material for wide use because of their unique properties such as lightweight, high strength, toughness, and stiffness[6-9]. The wear rate and friction coefficient of epoxy resin decrease significantly with an increase of graphite content above 3% weight. Graphite also enhances the surface smoothness of polymeric components[10].

A study of the wear behavior of several polymer composite materials sliding against smooth steel counterparts was conducted and the comparison of steady-state wear rates of various composite materials in three basic fibre orientations was made. There was a notable increase in the wear resistance of the matrix materials due to fibre reinforcement under the sliding wear conditions[11].

Investigation on the influence of sliding speed on friction and wear characters of un-directional aramid fiber-phenolic resin composites revealed that the frictional coefficient was stable over a wide range of sliding speed and normal pressure. The wear was insensitive to variations in the speed at higher speeds[12] Glass fibre-reinforced epoxy and unsaturated polyester composites were subjected to different aggressive environments such as water ageing, lubricating oil, heat, 5% Hydro Chloric acid, 5% oxalic acid, seawater for 7 days at room temperature. Their physical, mechanical, chemical, and thermal properties were studied. There was a significant in mechanical properties in heat ageing[13].

Filling the matrix with hard powder increases the wear resistance of composite materials at high sliding velocities and normal load[14]. The effects of working parameters were analyzed statistically. Load, grit size, and sliding speed were the parameters which were considered individually and in combination. The effect and interactions with the contacting surfaces on the wear of Polytehrmide (PEI) were studied. The pooled outcome of these parameters and their interactions with the contact surfaces had a deep impact on the wear. However, the wear depends on the ratio of glass fibres[15].

Principles and methods of manufacture of fibre composites, components and characteristics of fibres, and reinforcements are provided, which gives a good guide for the selection of materials[16]. Dynamic mechanical thermal analysis was done to investigate moisture uptake of E-glass vinyl ester composite and it was found that there was irreversible degradation through micro cracking and fibre-matrix debonding[17]. The mechanical and tribological behaviour of glass fibre-reinforced epoxy composites with and without graphite particulate filler were studied. Increasing the graphite content led to enhanced tensile strength and dimensional stability of the G-E composite. The friction and wear behaviour of the graphite-filled G-E composite systems were studied by varying the filler content (0-7.5 %wt) and sliding distance. The frictional coefficient increased directly as the sliding distance for non-filled composites. The morphological features of the worn features were studied using SEM [18].

Evaluation of the abrasive wear behaviour of bi-directional glass-fibre-epoxy composites with and without cenosphere filler was done. The results showed that worn surface features largely affected the abrasive wear of the composites. Like graphite, cenosphere particles also favourably influence the three-body abrasive wear behaviour of epoxies[19]. SiC and Graphite fillers improve tensile strength, modulus, and three body abrasive wear behaviour of epoxy/E-Glass composites, establishing their capability with both the resin and reinforcement types[20].

Composite materials find practical applications in various technical fields due to their light weight, good strength, special properties and ease of fabrication. Their growth in automotive industrial applications has a more promising future (Friedrich and Almajid, 2013)[21]. The effect of variations in sliding velocity and application of normal load. The specific wear rate increased with the applied load. The frictional coefficient decreased on increasing the normal load and sliding velocity[22].

This paper puts forth the comparison of erosion and abrasion wear behaviour of E-glass vinyl ester composites with graphite, SiC and SiC-Graphite fillers. The above properties were studied with silica and quartz sands as abrasive media.

2.0 Methodology

This study presents the assessment of the influence of friction and erosion on E-Glass woven matrix fabric

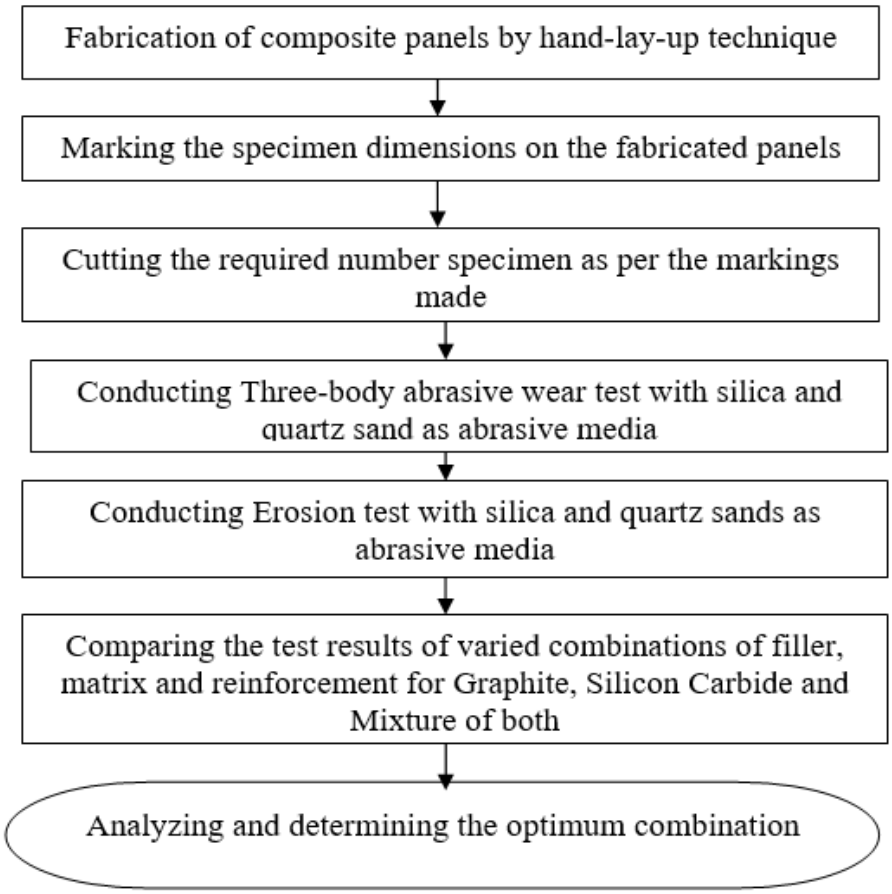


Figure 1. Methodology of the present study.

reinforced vinyl ester composites with and without the addition of particulate fillers. Graphite, Silicon Carbide (SiC) and a mixture of SiC-Graphite were used as particulate reinforcement and accordingly, three sets of composites were fabricated with each set containing composite plates of varying filler content by weight. The methodology adopted for this study is depicted in Figure 1.

2.1 Hand Lay-Up Technique

In this study, bi-directional (00/900) glass fabric-reinforced vinyl ester resin composites were considered. The laminates used were fabricated by hand lay-up technique. E-Glass woven fabric, which is compatible with vinyl ester resin, was used as reinforcement material. Hand lay-up is an open contact moulding in one-sided moulds is the lowest-cost and most common process for making fibreglass composite components and is the most widely used method of manufacturing composite components in the aircraft industry. Table 1 shows the materials used for fabrication and their respective functions.

The plate was made up of 55% glass fibre and 45% Vinyl Ester by weight. Subsequent fabrication of plates involved the addition of Silicon Carbide / Graphite/ mixture of SiC-Graphite filler in steps of 3%, 6% and 9% by weight of Vinyl Ester resin.

The initial material preparation included getting the glass fabric cut to the desired size and fourteen such fabrics went into each fabricated plate to give the desired thickness of 2.5mm. The curing additives were added in the ratio (Accelerator- Cobalt octate 1.5 wt% and Catalyst-MEKP 1.5 wt%) to the first bowl, stirred thoroughly and the first resin coat was applied on the release film which spanned an area equal to the area of the final plate.

Table 1. Materials used for fabrication and their functions

Material	Function
Vinyl Ester Resin	Matrix
E-Glass Fiber Woven Mat	Reinforcement
MEKP (Methyl Ethyl Ketone Peroxide) 1.5% by Weight of Vinyl Ester	Catalyst
DMA(Di Methyl Aniline) 0.15% of Vinyl Ester by weight of Vinyl Ester.	Promoter
Cobalt Octate 1.5 % by weight of vinyl ester	Accelerator
Silicon Carbide, Graphite and a mixture of SiC-Graphite	Fillers

Table 2. Percentage composition of vinyl ester resin, glass fibre and filler

Plate No	% Glass Fiber	% Vinyl Ester Resin	% Filler
1	55	45	No Filler
2	55	42	3% SiC
3	55	39	6% SiC
4	55	36	9% SiC
5	55	42	3% Graphite
6	55	39	6% Graphite
7	55	36	9% Graphite
8	55	42	3% SiC-Graphite
9	55	39	6% SiC-Graphite
10	55	36	9% SiC-Graphite

Fabric layers were placed over the resin coat and thorough compaction was achieved to prevent air bubble entrapment. This was followed by the application of alternate layers of resin and reinforcement. The mold was closed by placing the top slab which compressed the lay-up to the desired thickness of 2.5mm. Curing was allowed for 6-8 hours before it was retrieved from the mould. The above steps were repeated to fabricate ten plates, with the percentage composition of vinyl ester, glass fibre and filler as shown in Table 2.

2.2 Three Body Abrasive – Wear Test

The specimen sizes required for various tests were marked on the fabricated plates. After curing, the fabricated composite was cut to a specimen size of 75mm x 26mm and tested for its tribological properties as per ASTM G-65 [1]. Figure 2 the test specimen dimensions and the picture of the abrasion test specimen.

The tribological behaviour of glass fibre-polyester composites without fillers was studied using a dry sand abrasive tester. The three body wear test was conducted

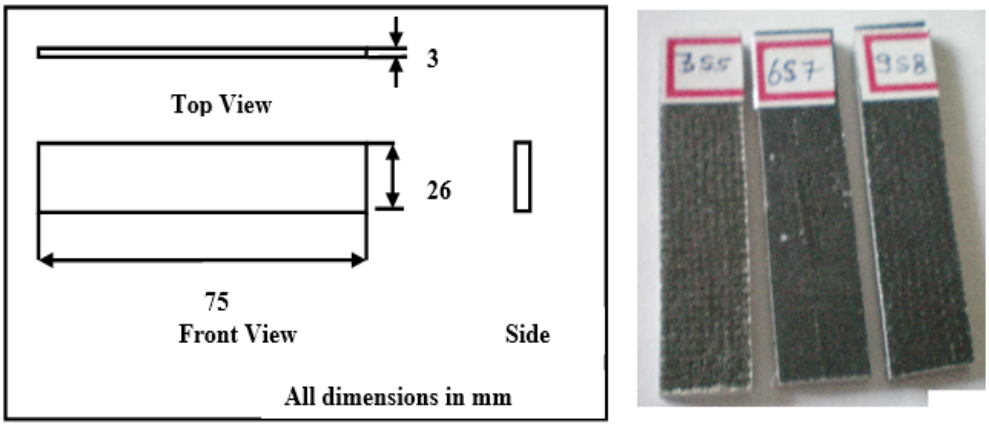


Figure 2. Specimen dimensions and cut specimen for abrasion test.

on silicon carbide, graphite and a mixture of SiC-Graphite filled glass-reinforced Vinyl ester composites. The testing parameters were: Load applied = 22 N, sliding velocities = 2.357 m/s, abrading distance = 270m, 540m, 810m, 1080m, wheel diameter = 225mm. The rate of sand flow through the nozzle was set between 300g/min (0.66lb/min) and 400g/min (0.88 lb/min). The wear loss in grams was calculated by finding the difference between the final and initial weights.

2.3 Erosion Test

The erosion wears behavior of glass fibre-polyester composites with an outfielder was studied using a dry sand/air jet as per ASTM G65. The specimen diagram is shown in Figure 3. The erosion test was conducted on silicon carbide, graphite and a mixture of SiC-Graphite filled glass-reinforced vinyl ester composites. The test parameters selected were: Jet Pressure = 1.6 bar, Flow Rate of Sand = 19 m/s, Time of test = 5 minutes, Angle between the jet direction and plane of specimen width 90°, 75°, 60°, 45°, 30°. The wear in grams was calculated by finding the difference between the final and initial weights.

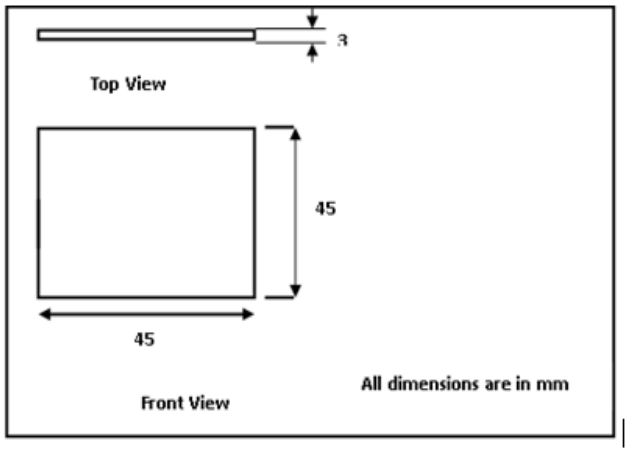


Figure 3. Erosion test specimen.

The time taken for the jet to create a hole in the specimen was determined which was the limiting time for the test. The constant time of 5 minutes was fixed for all specimens in this experiment. Experiments were conducted with inclination angles of 90°, 75°, 60°, 45°, 30°. The final weight was recorded and the weight loss was determined in each case.

3.0 Experimentation, Results and Discussions

3.1 Three-Body Abrasion Test

3.1.1 Silicon Carbide Filled Composites

Table 3 and Figure 4 depict the wear (g) of Silicon carbide composites with abrading distances using silica sand (size 200-250μm) and quartz sand as abrasives. Glass fibre-Vinyl ester composites with 3% SiC filler show quite large wear compared to composites with 6% and 9% SiC filler.

Table 3. Wear in grams for Silicon Carbide e-glass fibre reinforced vinyl ester composites

Sand Used	Abrading Distance, m	Wear, g			
		Without Filler	3% SiC Filler	6%SiC Filler	9%SiC Filler
Silica	270	0.35	0.2	0.19	**0.12**
	540	0.52	0.36	0.24	**0.21**
	810	0.6	0.48	0.43	**0.35**
	1080	0.72	0.44	0.42	**0.4**
Quartz	270	0.52	0.33	0.28	**0.24**
	540	0.71	0.47	0.42	**0.39**
	810	0.82	0.63	0.59	**0.55**
	1080	0.93	0.61	0.59	**0.53**

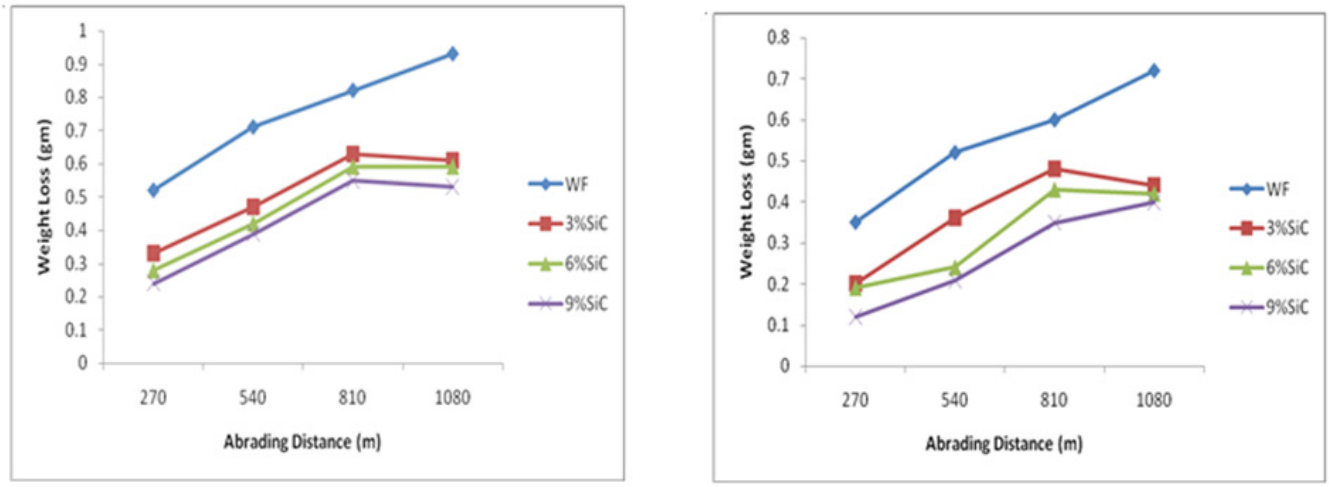


Figure 4. Variation of wear loss with abrading distances for silicon carbide-filled composites using silica sand and quartz sand.

Similarly, tests were carried out for specimens with Quartz sand at a load of 22N and wear loss was recorded at different abrading distances. By changing the sand from Silica to Quartz weight loss of Silicon Carbide (9%) filled Fibre Reinforced Plastic (FRP) increased from 0.40g to 0.53g at 1080m abrading distance.

Irrespective of the type of sample used there is nearly a linear trend of weight loss and it was also observed that the wear resistance of the Silicon carbide-filled FRP increases with an increase in filler content (Figure 4). The wear resistance is maximum with 9% Silicon carbide content.

3.1.2 Graphite Filled Composites

Wear loss(g) of graphite-filled composites with abrading distances for 22N load with Silica sand and Quartz sand were recorded. Silica and Quartz sands with particle sizes varying from 200-250μm were used as abrasives. Figure 5 illustrates that composites with 3% graphite filler have comparatively better wear resistance than other combinations.

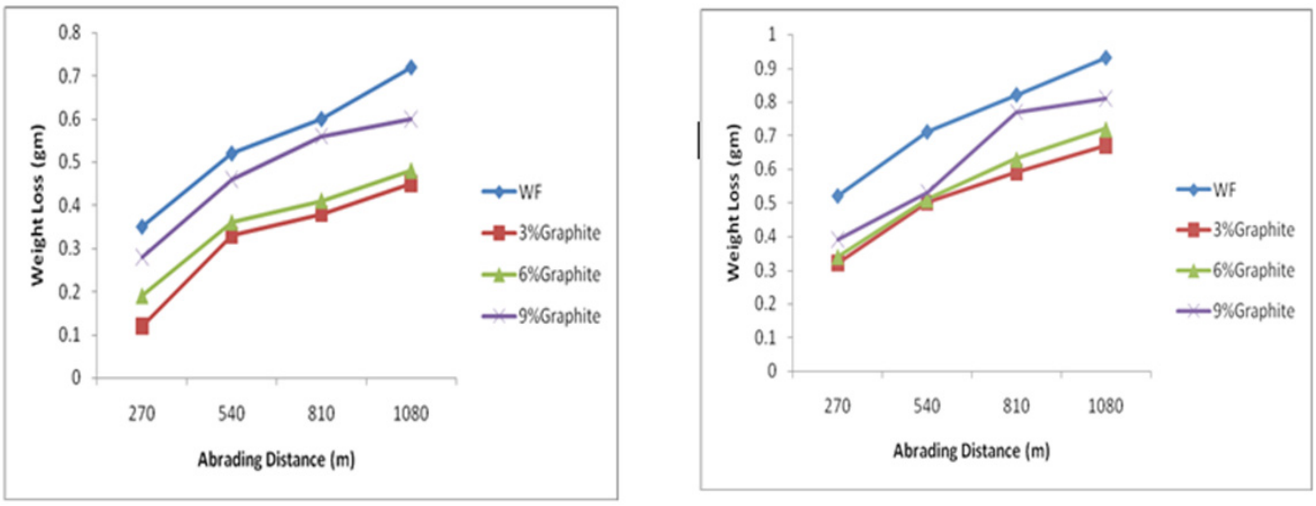


Figure 5. Variation of wear loss with abrading distances for graphite-filled composites using Silica Sand and quartz sand.

3.1.3 *Mixture of Silicon Carbide-Graphite Filled Composites*

Wear loss(g) of the mixture of SiC-Graphite filled composites with abrading distances for 22N load with Silica sand and Quartz sand were recorded. Silica and Quartz sands with particle sizes varying from 200-250μm were used as abrasives. It can be seen from Figure 6 that 6% SiC-Graphite filled composites show a lower loss compared to other compositions.

3.1.4 *Comparison among 3% Graphite, 9% SiC and 6% SiC-Graphite Filled Composites*

A comparison of wear loss for 3%Graphite, 9%SiC and 6% SiC-Graphite filled composites with abrading distances for 22 N load with silica sand and quartz sand was made. Figure 7 shows that 9% SiC-filled composites show a lower loss compared to other compositions.

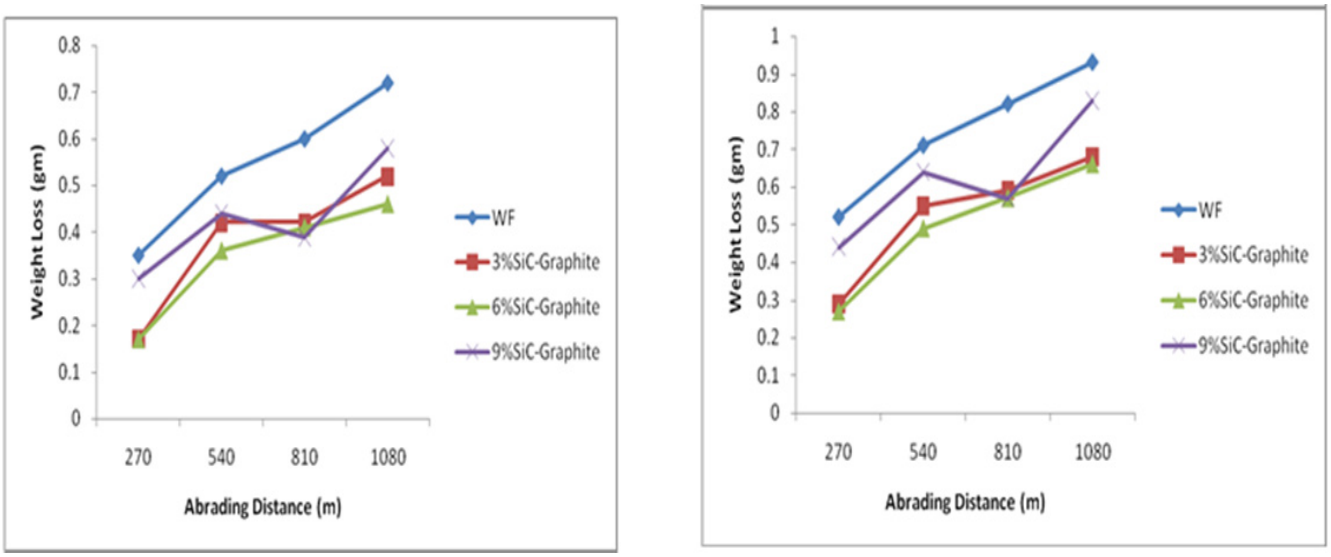


Figure 6. Variation of wear loss with abrading distances for Sic-Graphite filled composites using Silica Sand and quartz sand.

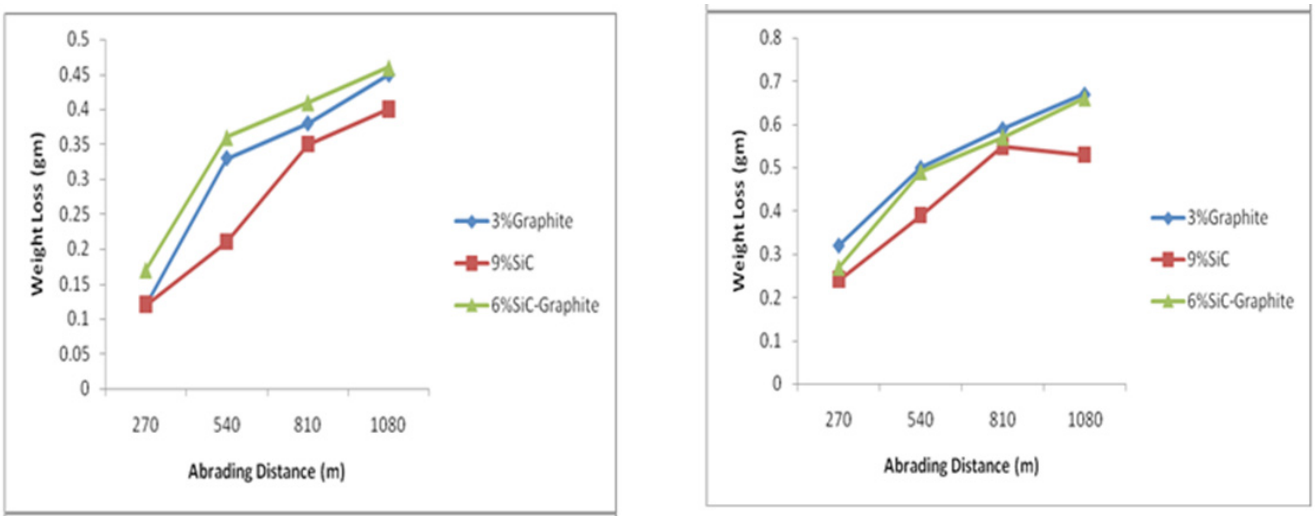


Figure 7. Variation of wear loss with abrading distances for 3%Graphite, 9%SiC and 6%SiC-Graphite filled composites using Silica sand and Quartz sand.

3.2 Erosion Test

3.2.1 Silicon Carbide Filled Composites

From Figure 8 it is observed that 3% SiC-filled composites have better erosion resistance than other combinations.

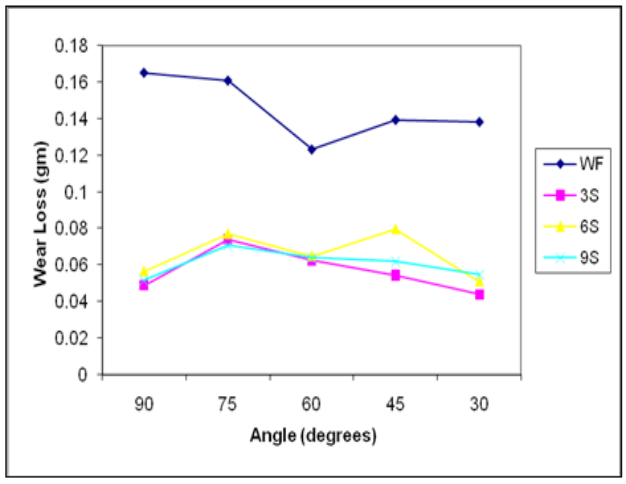


Figure 8. Comparison of erosion wear loss with varying angles for Silicon carbide-filled composites with Silica sand.

3.2.2 Graphite- Filled Composites

Figure 9 shows that 3% graphite-filled composites have improved resistance than other combinations.

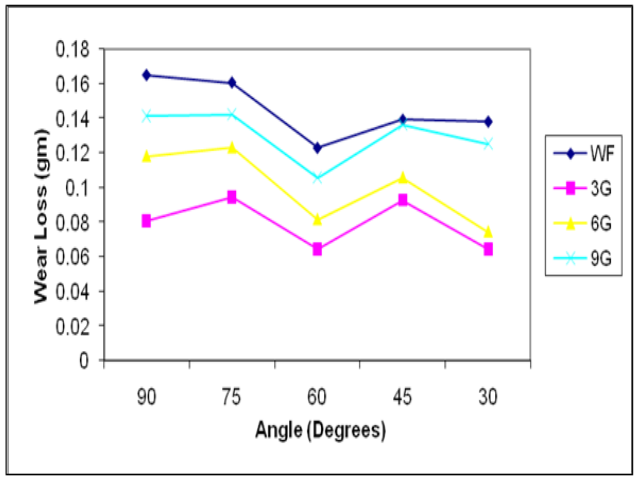


Figure 9. Comparison of erosion wear loss with varying angles for graphite-filled composites with Silica sand.

The erosion wear is maximum at a 75° angle between the direction of jet flow and the specimen width.

3.2.3 SiC-graphite-filled composites

Figure 10 it can be seen that 3% SiC-Graphite filled composites have better erosion resistance than other combinations. The erosion wear is maximum at a 75° angle between the direction of jet flow and the specimen width.

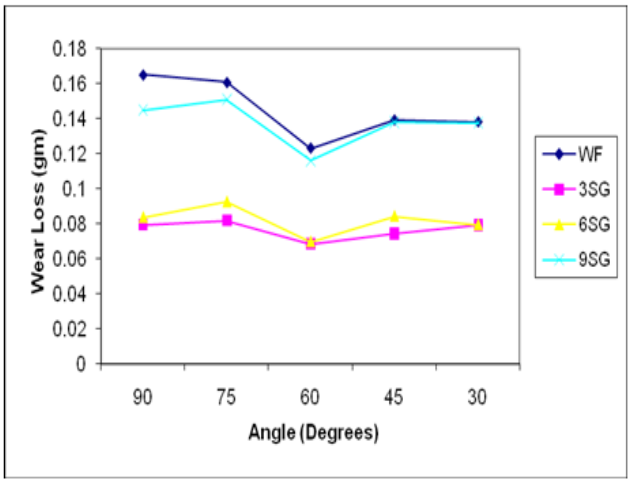


Figure 10. Comparison of erosion wear loss with varying angles for SiC-Graphite filled composites with Silica sand.

3.2.4 Comparison of Erosion Wear among 3% Sic, 3% Graphite and 3% SiC-Graphite Composites

It is evident from Figure 11 that 3% SiC-filled composites have better erosion resistance than other combinations. The erosion wear is maximum at a 75° angle between the direction of jet flow and the specimen width.

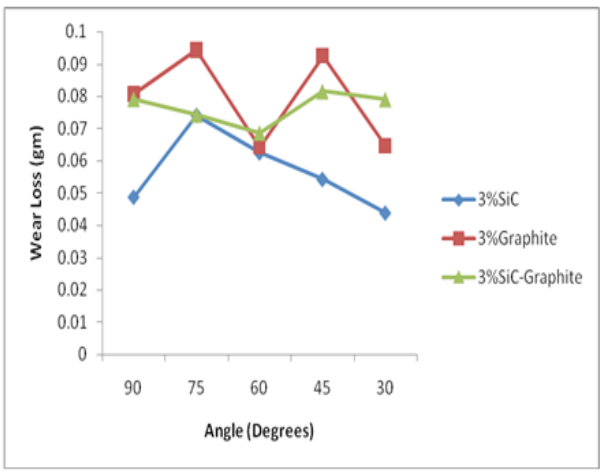


Figure 11. Comparison of erosion wear loss with varying angles for 3%SiC, 3% Graphite and 3%SiC-Graphite filled composites with silica sand.

3.3 Surface Morphology Study

3.3.1 Silicon Carbide Filled Composites

The worn surfaces of 3% Sic and 9% Sic-filled composites abraded with silica sand at a load of 22N were displayed using a vision measuring machine.

Figure 12 shows the worn surface of the 3% Sic and 9% SiC-filled composites abraded at a load of 22N.

The worn surface shows the formation of tracks by ploughing and also the surface exhibits scratches owing to ploughing. Photomicrographs with 9% Sic-

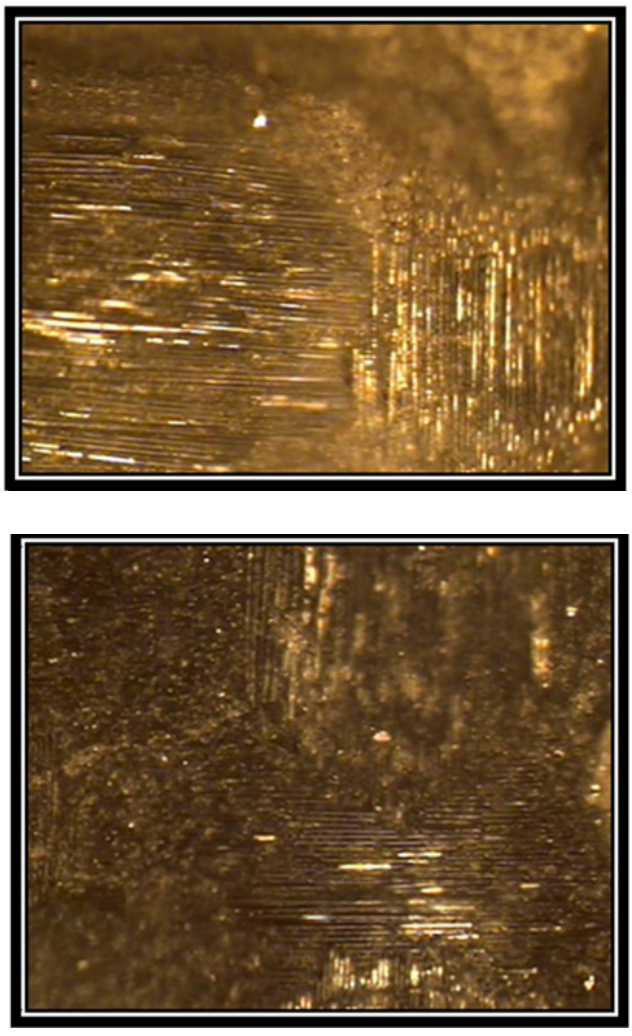


Figure 12. Vision measuring machine picture showing the worn surface of 3% silicon carbide-filled composites at 22N with silica sand and 9% silicon carbide-filled composites at 22N with Silica sand.

filled composites show lesser surface damage and the tracks are found to be less when compared to 3% SiC-filled composites. It can be also seen that matrix wear and distortion of 9% Sic-filled composites were found to be less when compared to composites with 3% SiC. This reveals that an increase in silicon carbide filler content increases the wear resistance properties of the composites.

3.3.2 Graphite Filled Composites

Figure 13 depicts the worn surface of the 3% graphite and 9% graphite-filled composites abraded with silica sand at a load of 22N displayed under vision measuring machine. It can be seen from the photomicrographs that 3% graphite-filled composites show lesser formation of tracks and ploughing when compared to 9% graphite-filled composites. This reveals that an increase in graphite filler content decreases the wear resistance properties of the composites.

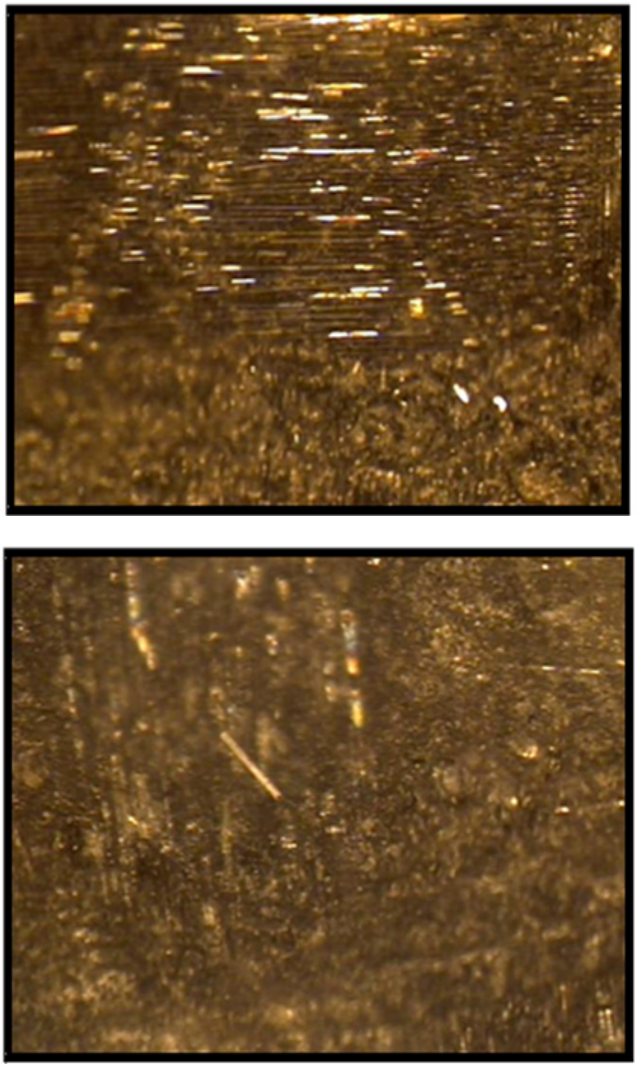


Figure 13. Vision measuring machine picture showing the worn surface of 3% graphite-filled composites at 22N with Silica sand and of 9% graphite-filled composites at 22N with Silica sand.

4.0 Conclusions

The literature review gave an insight that the tribological properties of fibre-reinforced composites improved by an addition of particulate fillers This observation is proved right by the results obtained from the tests obtained on graphite, silicon carbide as well a mixture of SiC-Graphite filled composites.

Results confirm that addition of Silicon carbide to vinyl ester glass fabric composites enhances tribological properties as compared to Graphite filler. When compared with all other combinations of filler materials, 3% SiC-filled composites showed good wear resistance properties. Graphite-filled composites showed poor wear resistance properties when compared to Silicon Carbide-filled composites. The composites which contained a mixture of Silicon Carbide and Graphite in equal proportion of weight showed wear and erosion resistance properties which were intermediate between Silicon Carbide and Graphite Filled composites. All these composites wear at a higher rate when in contact with quartz sand than with silica sand. Pictures taken from the vision measuring machine were analyzed and the images validated the results.

From the experimental observation, it can be concluded that Silicon Carbide filler material as compared to graphite and a mixture of graphite-SiC, significantly enhances the wear resistance of E-glass fibre-reinforced vinyl ester composites.

5.0 References

1. Benzing R, Goldblatt I, Hopkins V, *et al*. Friction and wear devices. 2nd ed. Park Ridge, IL: ASLE;1976.
2. Chand N, Fahim M. An introduction to tribology of FRP material, 1st ed. Allied Publishers; 2000.
3. Friedrich K. Wear of reinforced polymer by different abrasive counterparts. Friction and Wear of Polymer

Composite Materials. 1986; 1. https://doi.org/10.1016/B978-0-444-42524-9.50012-0
4. Gay D, Hoa SV, Tsai SW. Composite materials: Design and applications. CRC Press; 2002. https://doi.org/10.1201/9781420031683
5. Vinson JR, Chou TW. Composite materials and their use in structures. Appl Sci Publishing:1975
6. Czichos H. Tribology - A system approach to the science and technology of friction, Lubrication and Wear. 1st ed. Elsevier. 1978. https://doi.org/10.1115/1.3453269
7. Goodman SH. Handbook of Thermoset Plastics. Noyes Publications; 1998.
8. Murthy VSR, Jena AK. Gupta KP, Murthy GS. Structure and properties of engineering materials. Tata McGraw-Hill; 2003.
9. Verma IK, Gupta VB. Thermosetting resin properties. IIT Delhi, India. 2000; 2. https://doi.org/10.1016/B0-08-042993-9/00177-7
10. Subramanian C, Asaithambi P, Kishore. Friction and wear of epoxy resin containing graphite. J Reinf Plast Compos. 1986; 5:200-208. https://doi.org/10.1177/073168448600500304
11. Cirino M, Freidrich K, Pipes RB. Evaluation of polymer composites for sliding and wear application. Compos. 1988; 19(5):383-395. https://doi.org/10.1016/0010-4361(88)90126-7
12. Sinha SK, Biswas SK. Effect of sliding speed on friction and wear of un-directional aramid fibre phenolic resin composite. J Mater Sci. 1995; 30:2430-2437. https://doi.org/10.1007/BF01184597
13. Siddaramaiah SV. Suresh VB, Atul, *et al*. Effect of aggressive environments on composite properties. J Appl Polym Sci. 1999; 73:795-799. 4628(19990801)73:5<795::AID-APP19>3.0.CO;2-5
14. Visconti C, Langella A, Durante M. The wear behavior of composite materials with epoxy matrix filled with hard powder. Appl Compos Mater. 2001; 8:179-189. https://doi.org/10.1023/A:1011234301664
15. Fahim M, Indumati J, Bijwe J. Statistical data analysis of abrasive wear performance of polythermide composites. J Reinf Plast Compos. 2001; 20(12):1013-1023. https://doi.org/10.1177/073168401772679219
16. Perepelkin KE. Polymer fibre composites, basic types, principles of manufacture and properties. Part 2. Fabrication and properties of polymer composite materials. Fibre Chem. 2005; 37(5):381-400. https://doi.org/10.1007/s10692-006-0012-5
17. Karbhari VM. Dynamic mechanical analysis of the effect of water on E-glass vinyl ester composites. J Reinf Plast Compos. 2006; 25(6):631-644. https://doi.org/10.1177/0731684406058274
18. Suresha B, Chandramohan G, Renukappa NM. Mechanical and tribological properties of glass epoxy composites with and without graphite particulate filler. J Appl Polym Sci. 2007; 103:2472-2480. https://doi.org/10.1002/app.25413
19. Suresha B. Chandarmohan G. Siddramaiah. The influence of cenosphere filler additions on the three body abrasive wear behavior of glass fibre reinforced epoxy composites. Polym Compos. 2008; 111:307-312. https://doi.org/10.1002/pc.20380
20. Suresha B, Chandramohan G, Renukappa NM. Influence of silicon carbide filler on mechanical and dielectric properties of glass fabric reinforced epoxy composites. J Appl Polym Sci. 2009; 111:685-691. https://doi.org/10.1002/app.29116
21. Friedrich K, Almajid A. Manufacturing aspects of advanced polymer composites for automotive applications. Appl Compo Mater. 2013; 20:107-128. https://doi.org/10.1007/s10443-012-9258-7
22. Chauhan SR, Kumar A, Singh I. Study on friction and sliding wear behavior of woven S-glass fibre reinforced vinylester composites manufactured with different comonomers. J Mater Sci. 2014; 44:6338-6347. https://doi.org/10.1007/s10853-009-3873-1
23. Annual book of ASTM Standards, ASTM G65, Standard Test Method for Measuring Abrasion Using the Dry Sand/Rubber Wheel Apparatus. Philadelphia, PA: ASTM; 1994.