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Tribological Behaviour of Jute/Vinyl Ester Composites Impregnated with Alumina Filler

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Abstract

The present experimental studies focus on analysing the effect of abrasive particle size on the 3- body abrasive of composites of Vinyl Ester reinforced with jute fibre filled with alumina nano- filler particulates as the secondary reinforcement. The laminates of composites of VinylEster with discrepant compositions are prepared by varying alumina nano-filler in the weight proportion of 1% and 2% wt and varied jute fibres in the weight proportion of 10%, 20% and 30% wt. The specimens subjected to abrasive loading of 10 N, 20 N and 30 N are tested for 3-body abrasive wear according to ASTMG-65 at different abrasive particle sizes changing from106±10 and 212 ± 10 microns. The wear characteristics of jute–vinyl composites were investigated using a rubber wheel abrasive tester apparatus. It is supposed from the experimentation that an increase in wear resistance is obtained for composites of Vinyl Ester with an increase in the addition of alumina filler. It is perceived that a composite containing 30% Jute, 68% VinylEster and 2% Alumina filler results in maximum wear resistance compared to the rest of the composites. Given the above, this investigation attempts to study the effect of alumina as a filler material in jute–vinyl ester composite.

Major Findings: *The research emphasizes the utility of natural fibre-reinforced composites with ceramic fillers as a sustainable alternative for wear-resistant materials, aligning with eco-friendly and performance-driven industrial demands. The experimental findings may suggest suitability for applications like automotive parts, bearings, clutches, brake pads, panels and sliding components where wear resistance and lightweight materials are crucial.*

Keywords: *3-Body Abrasive Wear, Alumina, Jute Fibre, Natural Fibre, Vinyl Ester*

1.0 Introduction

Resistance and wear out are major concerns in a diversified technical application. Polymer composites compassing distinctive fillers and/or reinforcements are preferred for unique applications. Additionally, it is expected that nano-fillers will substantially impact the wear characteristics of composites and polymers. It is commonly recognized that inorganic particles improve the wear characteristics of polymers. Polymer nanocomposites, or polymers filled with nanoparticles, have emerged as promising materials for disparate uses.

Natural hybrid composites represent a class of materials that integrate natural fibres with either synthetic or bio-based resins, thereby offering sustainable and environmentally friendly alternatives to conventional

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composites. Their distinctive properties-such as being lightweight, robust, biodegradable, and economically viable-have led to their rising appreciation across multiple industries. These composites effectively respond to increasing environmental concerns by minimizing reliance on synthetic materials and lowering the carbon emissions linked to both their production and disposal processes.

Wear is a deterioration of a surface caused by rubbing motion between any two elements moving relative to one another. The loss of material eventuated over a prolonged period leads to wear and it depends on how the surfaces interacted.

Abrasive wear is broadly categorized into two types:

1. Body abrasive wear
2. Body abrasive wear

On numerous occasions, however, in an extensive range of conditions, the fabrication of polymeric composites with low wear and low friction subjected to dry sliding conditions in comparison to their smooth metallic counterparts. (e.g., as gears or bearings).

A handful of filler particles enhance the invulnerability of composite material against wear. The moment the filler particles diffused it could bring out there action products that' strengthen the link between the transfer film and counter face. Many studies have sufficient evidence to suggest that, in sliding wear situations, finer particles tend to contribute more to property improvement than larger particles.

The Polylactic Acid (PLA) composites impregnated with rice husk at varying weight percentages of 90/10, 80/20, and 70/30, and compared with pure PLA in terms of their three-body abrasive wear behavior. In PLA composites, weight decreases as the applied load increases which ample the wear resistance due to increased fibre content. At 30 per cent weight of rice husk fibre in the composite, there was increased wear hindrance of composites[1,2].

The sequel of the interaction of abrasive particles on the glass-carbon thermoplastic hybrid composites' three-body abrasion wear behaviour.10 wt% SGF/10 wt% SCF (GC) were the materialsystems.The experimentation was conducted for 20 N and 30 N using varying distances at a constant velocity of 2.5 m/s under the ASTM G65 method[3].

The study aimed to find out the influence of Al_2O_3 nano-fillers addition on 3-body abrasive wear loss of jute fibre–Al_2O_3 filler-reinforced Vinylester resin composites. To obtain minimum wear loss, jute fibre was added in various wt.% reinforcement with that of Al_2O_3 fillers to obtain the best possible composition for (jute fibre – Al_2O_3 filler) Vinyl ester resin composites.

2.0 Materials and Methods

2.1 Matrix: Vinyl Ester

2.1.1 Details about the Vinyl Ester and its Curing Agents

This study provided an opportunity to understand the 3-body wear and hardness behaviour of composite laminates made of this resin system. The Vinyl Ester (VE) resin used is supplied by Naptha Resins and Chemicals(P) Limited, Bangalore – 560058under the trade name polyflexGR- 200-60. Some properties of the VE resin used in the study are provided in Table 1.

Table 1. Mechanical and physical properties of Vinyl Ester Resin

Property	Vinyl Ester Resin
Purity	99.9 %
Tensile strength(MPa)	70
Young's modulus(GPa)	3.2
Elongation	350 %
Melt Point	314deg C
Density g/cm^3	1.07



Figure 1. Vinyl ester and accelerator.

2.2 Materials Specifications

Table 2. Mechanical specifications of Vinyl EsterResin and Catalyst

Vinyl Ester Resin	
Density	1.07 g/cc
Tensile Strength and Youngs modulus	70MPa, E : 3.21 GPa
Accelerator –Cobalt napthalate	0.98 g/cm3
Catalyst/Hardener-MethylEthylKetone Peroxide (MEKP)	1.17 g/cm3

Comparing specimens with unsaturated polyester matrix to the same composites based on VE, un saturated polyester the latter exhibited a shorter life span. This is explained as an outcome of VE composites' superior flexural and tensile strength[4].

The VE resin of density 1.23 g/ml as matrix and the curing substances mixed such as MEKP, di methylacetamide and cobalt octovate[5]. VE and for polyester, 2% MEKP and 2% cobalt nephthalate (as an accelerator)[6,7].

2.3 Reinforcement: Jute

In the ongoing investigation, a laminate of natural fibre is used for fibre-reinforced composites of polymer matrix. These fibre reinforcements are jute and are selected for their potential use in structural engineering applications.

The mechanical properties of jute are given in the tables.



Figure 2. Jute fibre.

Table 3. Physical andmechanical properties of Jute Fibre

Property	Jute Fibre
Density (g/cc)	1.4
Tensilestrength(MPa)	80 -120

2.4 Filler: Al_2O_3 Nano–Particles

In the present investigation Al_2O_3 nano-fillers are used for the fabrication of fibre-reinforced polymer nanocomposites. Al_2O_3 nano-fillers were used with a diameter of 30 nm.

Al_2O_3 Nano-fillers were supplied by Ad Nano Technologies Pvt Ltd, Shimoga–577222.

Table 4. Mechanical properties of Al_2O_3 nano-fillers

Property	Al_2O_3 nano- fillers
Purity	99 %
Average Particle Size	30 nm
Melt Point	2055deg C
Density g/cm3	3.9



Figure 3. Al_2O_3 nano particles.

Nano scale filler-filled polymers have shown exceptional mechanical properties and tribological behaviour compared to those filled with micro-scale particles[8].

Hardness, compressive and flexural strength improved with increment in the filler loading of vinyl ester-based nano TiO_2 particulates[9].

The reinforcing agent Fe_3O_4 plays a crucial role in determining the material properties of engineering composites. Research indicates an improvement in mechanical characteristics, including tensile strength, compressive strength, and hardness[10].

The test result shows that Al_2O_3 nanopowder is better than TiO_2 nanopowder as filler from the hardness point of view[11].

2.5 Alkaline Treatment

The Figure 4 shows the catalysts those chemical agents that are useable to jute fibres to modify surface.

Treating jute fibre with 5%NaOH solution leads to superior mechanical properties due to improved interfacial adhesion[12].

The raw bamboo fibres were immersed in the NaOH solution for 6h.The outer layer of the fibres was sterilised of bacteria and other contaminants[13,14].

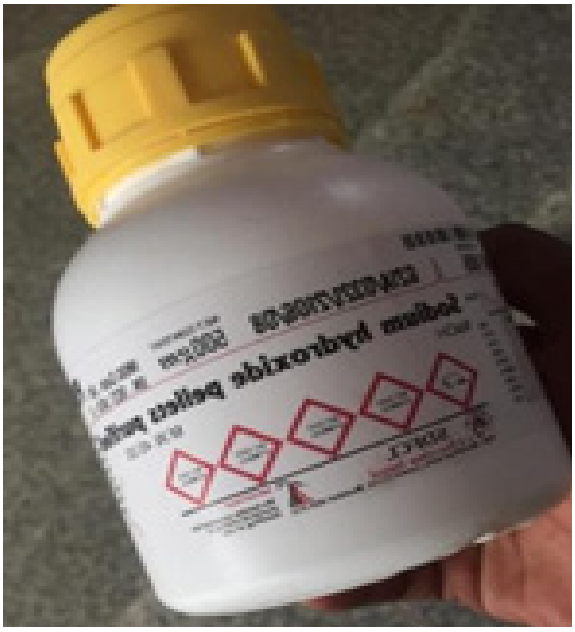


Figure 4. Sodium hydroxide pellets.

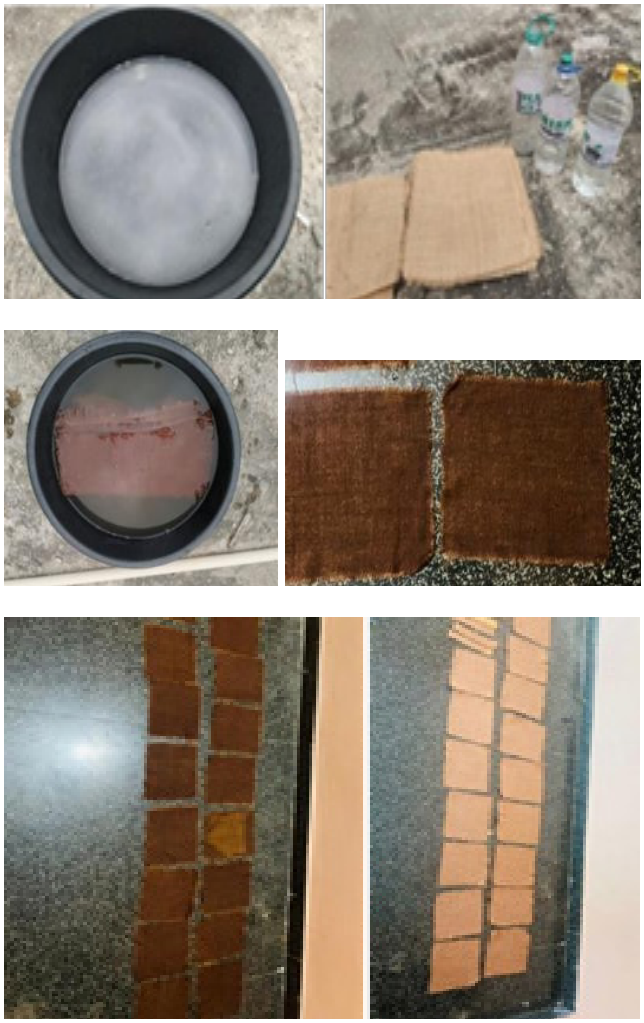


Figure 5. Chemical treatment to Jute Fibres.

2.6 Fabrication Methods of PMC's

2.6.1 Hand Layup Method

Hand lay-up is a moulding process (Figure 6) in which

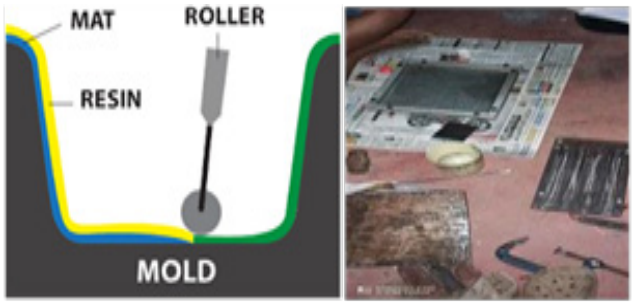


Figure 6. Hand lay–up process.

Table 5. Composite composition details

Composition	*Material ID*	*Weight Fraction Percentage(wt%)*		
		Vinyl Ester	*Jute Fibre*	*Al_2O_3Nano Particle*
VE/JF/Al_2O_3	S1	89	10	1
	S2	79	20	1
	S3	69	30	1
	S4	88	10	2
	S5	78	20	2
	S6	68	30	2

the fibre reinforcing is applied by hand and then wet with a resin matrix. The manual nature of the hand lay-up process enables almost any reinforcement material to be considered, mat. In the same way, the blend of resin and catalyst can be manipulated to enable ideal processing conditions.

2.6.2 Hand Layup Fabrication Method

Mat Jute fibres are reinforced in vinylester resin in 3 different weight proportions (10 wt %, 20 wt% and 30wt%) to prepare the composites S1 (vinyl ester + 10 wt % Jute fibre + 1wt% Al_2O_3), S2 (vinylester + 20 wt % Jute fibre + 1 wt % Al_2O_3), S3(vinylester + 30 wt % Jute fibre + 1wt % Al_2O_3), S1(vinyl ester +10wt% Jute fibre+2wt% Al_2O_3), S2 (vinyl ester+20wt% Jute fibre + 2wt% Al_2O_3) and S3(vinyl ester+30wt% Jute fibre+2wt% Al_2O_3) respectively. Al_2O_3 Nano filler is employed in these composites. The conventional hand-lay-up method is used for making the composite plates. A mould box having dimensions of 260×260×5mm^3 is used. A releasing agent is used to make it easier to remove the composite from the mould after it has cured. The vinylester resin



Figure 7. Hand layup fabrication method.



Figure 8. Fabrication details.

was cured by incorporation of an accelerator of 2% cobalt nephthalate mixed carefully in the VE resin and then hardener 2% MEKP before reinforcement.

Since fibres tend to clump and tangle together when mixed, care is taken to ensure an evenly distributed sample. Each composite cast was cured at low pressure for 24 hours before being removed from the mould.

After being taken out of the mould, this cast is then post-cured in the air for an additional 24hours. Suitable size specimens are cut using a wheel-cutting blade for physical characterization and mechanical testing. A lot of care has been taken to ensure that the composite remains homogeneous and uniformly distributed.



Figure 9. Cutting of composites.

The manual hand lay-up process was employed to create Jute/coir FRPM composites. The mechanical properties of the fabricated composites were tested by cutting the composites to the desired shape by adopting the wire hacksaw[15,16]. The laminates were created by hand layup technique[17-19].

3.0 Experimental Investigation

3-body abrasive wear studies of vinyl ester/Jute/Alumina composites were studied on a dry sand/Rubber Wheel Abrasion Test (RWAT).

3-BodyAbrasive Wear

There are many wear testing methods to identify the mechanisms and failure of wear. They are the dry sand abrader test, sand erosive test, loose slurry abrasive test and fluid jet erosion test. Among all these tests dry sand abrader test was selected for the following reasons.

- Normal load application has a better impact on a contact surface.
- Similarity between field condition and simulating condition.
- Easy to identify the mode of wear.
- Easy to identify fracture behaviour

For carrying out three body abrasion tests dry sand rubber wheel abrasion test rig was selected for conducting the experiments. The general procedure for experiments confirms G65 standards. Since the investigation is carried out in dry wear, simulation of experiments was conducted in dry sand abrader. Here, the abrader will act as the third body between the two contact surfaces. The dry sand wheel abrasion experiments were undertaken in the material science laboratory in the I&P Engineering division, NIE, Mysuru.

3.1 General Test Procedure and Parts Details

The test involves rubbing the specimen of standard dimensions. The abrader is selected as the sand of known size distribution. The test specimen was fitted into the specimen holder. The leverage load was calculated and the obtained load was applied to the loading pan. The chloro-

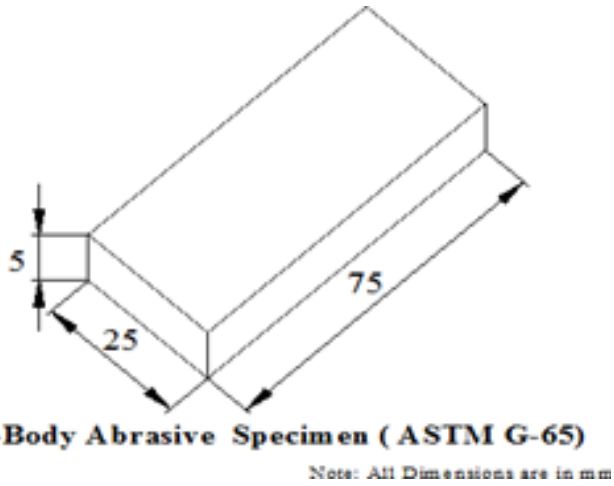




Figure 10. Three body/dry sand/rubber wheel abrasive tester [ASTMG– 65].

butylerubber was allowed to rotate at the specified speed. Sand abrader of the selected size was fed into the sand hopper. Then the abrader was allowed to flow between the rubber wheel and the target specimen. This procedure was conducted at the desired time. After that, the specimen was removed from the job holder. The abraded area of the specimen was cleaned using acetone. The specimen is weighed prior and posterior the experiments, aim in go to compute the specimen's weight loss as a result of wear.

The test set-up used in this investigation is 3-body abrasive wear test apparatus machine according to ASTMG-65 standards. The test specimens were prepared after proper cutting and polishing to 75 x 25 x 5 mm.



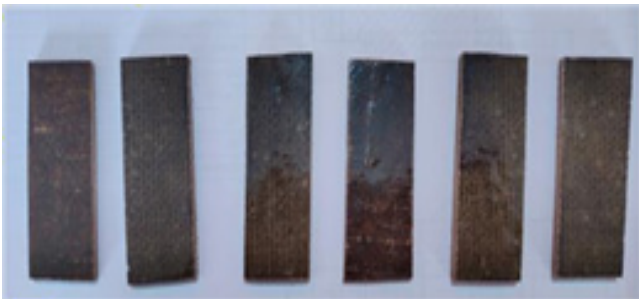


Figure 11. Specimens for 3-body abrasive test.

Figure 12. Schematic representation of different zones on the wear scar.

Table 6. Test conditions

Test Parameters	Range
Load	10, 30 and 50 N
Rotational Speed of Rubber Wheel	150 rpm
Mean Diameter of Rubber Wheel	210 mm
Abrading Distance	300 m
Abrasive Particles	Silica Sand, Angular
Abrasive Particles size	106 ± 10 and 212 ± 10 microns
Sand Flow Rate	100 ± 5 gm/min
Size of the Specimen	75 x 25 x 5 mm
Test Duration	3 min

Figure 12. Schematic representation of different zones on the wear scar.

Results and Discussion

Figure 13 shows the weight loss of composites for different load levels (10 N, 30 N, 50 N) for composites with 1% aluminium oxide at a constant speed of 150 rpm,

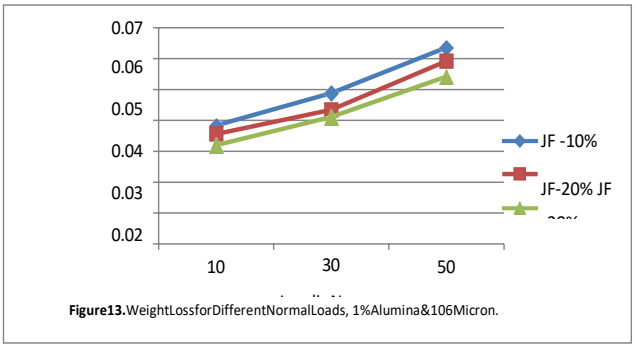


Figure 13. Weight loss for different normal loads, 1% alumina and 106 micron.

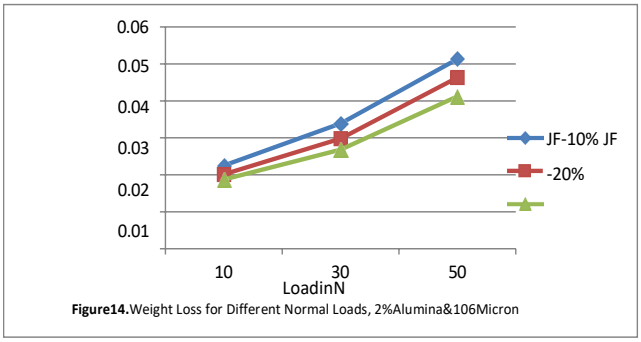


Figure 14. Weight loss for different normal loads, 2% alumina and 106 micron.

size of silica sand particles was 106 microns for3 minutes 10 seconds. The wear resistance of composite materials improves as the loading of jute fibre increases. It was found that weight loss was dependent on normal loads, highest wear resistance has been observed in 30% jute fibre-reinforced composites

Figure 14 shows the weight loss of composites for different load levels (10 N, 30 N, 50 N) for composites with 2% aluminium oxide at a constant speed of 150 rpm, size of the silica sand particle was 106 microns for a period of 3 min 10 seconds. The wear resistance of composite materials improves as the loading of jute fibre increases, the highest wear resistance has been observed in 30% jute fibre-reinforced composites.

The comparison between S1 (10% jute fibre, 89% PVE, 1% Al_2O_3) and S4 (10% jute fibre, 88% PVE,2%Al_2O_3) in terms of abrasive wear loss at 10N with a speed of 150rpm for 3minutes and 10 seconds, showing wear losses of 0.0068g and 0.0043g respectively, indicates that doubling the Al_2O_3 content from 1% to 2% significantly enhances wear resistance in jute fibre-reinforced polyvinylester composites, suggesting that increased aluminium oxide content plays a key role in reducing abrasive wear.

The comparison between S2 (20% jute fibre, 79% PVE, 1% Al_2O_3) and S5 (20% jute fibre, 78% PVE, 2% Al_2O_3) in terms of abrasive wear loss, with 0.0805 g for S2 and 0.0458g for S5 at a 30 N load with a 106-micron abrasive size at 150 rpm, indicates that increasing the Al_2O_3 content from 1% to 2% in jute fibre-reinforced Polyvinyl Ester (PVE) composites significantly improves wear resistance, suggesting that a higher aluminium oxide content can be instrumental in reducing wear loss and enhancing the durability of these composites in abrasive environments.

Comparing S3 (30% jute fibre, 69% PVE, 1% Al_2O_3) and S6 (30% jute fibre, 68% PVE, 2% Al_2O_3),with abrasive wear loss of 0.1213 mm^3 and 0.1147 mm^3, respectively, at a 50N load with a 106-micron abrasive size at 150 rpm, suggests that increasing the Al_2O_3 content from 1% to 2% slightly improves wear resistance in jute fibre-reinforced Polyvinyl Ester (PVE) composites, indicating that higher Al_2O_3 content can enhance durability against abrasive wear in these materials.

The comparison across different load levels (10 N, 30 N, 50 N) for composites with 1% and 2% aluminium oxide content reveals a consistent pattern of lower abrasive wear loss with higher Al_2O_3 content. At 10 N, the wear loss is 0.0068g for 1% Al_2O_3 and 0.0043g for 2% Al_2O_3, indicating improved wear resistance with increased Al_2O_3.

At 30N, the difference becomes more pronounced, with wear loss of 0.0805g for 1% and 0.0458g for 2%, suggesting that higher Al_2O_3 content significantly reduces wear loss at this load level.

At 50N, the difference narrows, with wear loss of 0.1213g for 1% and 0.1147 g for 2%, indicating that while increased Al_2O_3 still contributes to reduced wear loss, the impact diminishes at higher loads. Overall, the results suggest that increasing the Al_2O_3 content in jute fibre-reinforced polyvinyl ester composites enhances wear resistance across all load levels.

Figure 15 shows the weight loss of composites for different load levels (10 N, 30 N, 50 N) for composites with 1% aluminium oxide at a constant speed of 150 rpm, size of silica sand particle was 212 microns for 3min10 seconds. The wear resistance of composite materials improves as the loading of jute fibre increases

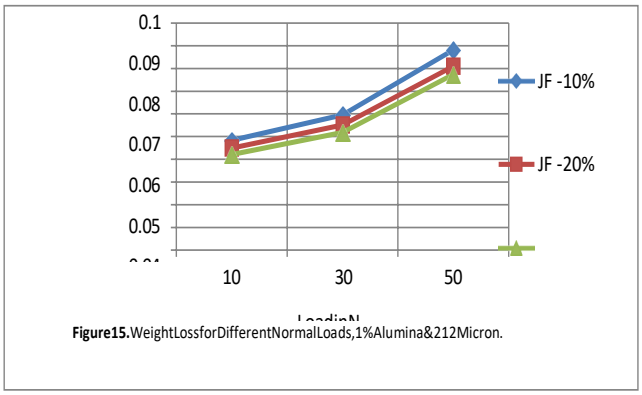


Figure 15. Weight loss for different normal loads, 1% alumia and 212 micron.

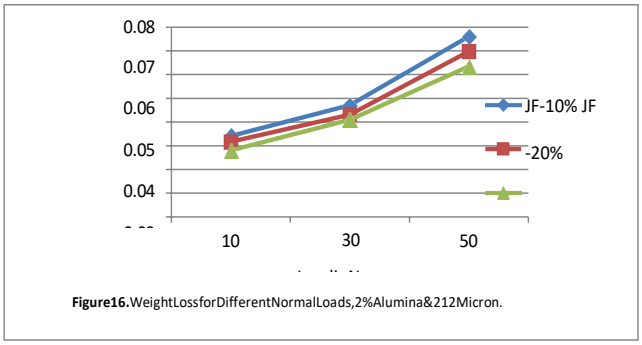


Figure 16. Weight loss for different normal laods, 2% aluminia and 212 micron.

Figure 16, shows the weight loss of composites for different load levels (10 N, 30 N, 50 N) for composites with 2% aluminium oxide at a constant speed of 150 rpm, size of silica sand particle was 212 microns for 3min 10 seconds. The wear resistance of composite materials improves as the loading of jute fibre increases

From Figures 15 and 16, a comparison of abrasive wear loss for composites S1(1%Al_2O_3,0.0181 g) and S4 (2% Al_2O_3, 0.0189 g) under a 10 N load with 212-micron abrasives suggests that doubling the aluminium oxide content from 1% to 2% does not necessarily lead to lower wear loss, indicating that higher aluminium oxide content may not always improve wear resistance when using larger abrasive particles.

Comparing the abrasive wear loss for composites S2 and S5 under a 30 N load with 212-micron abrasives, where S2 (0.0656g) shows a slightly lower wear loss than S5 (0.0684 g), suggests that doubling the aluminium oxide content from 1% to 2% in jute fibre-reinforced Polyvinyl Ester (PVE) composites might not result in improved wear resistance. This could indicate that at higher abrasive particle sizes, other factors might influence the wear behaviour, demonstrating that higher aluminium oxide content does not always guarantee lower wear loss.

The comparison between S3 (1% Al_2O_3, 0.0854 mm^3) and S6 (2% Al_2O_3, 0.0877 mm^3) in terms of abrasive wear loss at a 50 N load with 212-micron abrasives suggests that doubling the aluminium oxide content from 1%to2% in jute fibre-reinforced Polyvinyl Ester (PVE) composites does not necessarily reduce wear loss, indicating that a higher Al_2O_3content might not provide significant benefits in wear resistance when subjected to larger abrasive particle sizes and higher loads.

The comparison across all three loads (10 N, 30 N, 50 N) for composites with 1% and 2% aluminium oxide content shows that increasing the Al_2O_3content generally leads to lower wear loss.

At 10 N, 30 N, and 50 N, composites with 2% Al_2O_3 consistently have lower abrasive wear loss compared to those with1% Al_2O_3, suggesting that a higher aluminium oxide content in jute fibre- reinforced Polyvinyl Ester (PVE) composites contributes to improved wear resistance.

This pattern holds across varying loads, indicating that higher Al_2O_3content enhances wear resistance, with the greatest reduction in wear loss observed at lower loads, while at higher loads, the reduction is less pronounced but still present.

Table 7. Weight loss of composites for sand size106 Micron

Material ID	Load in N	Weight Loss in grm
S1	10	0.0384
	30	0.0488
	50	0.0636
S2	10	0.0356
	30	0.0434
	50	0.0592
S3	10	0.0320
	30	0.0411
	50	0.0542
S4	10	0.0225
	30	0.0339
	50	0.0513
S5	10	0.0201
	30	0.0298
	50	0.0463
S6	10	0.0187
	30	0.0268
	50	0.0412

Table 8. Weight loss of composites for sand size 212 Micron

MaterialID	Load inN	Weight Loss in grm
S1	10	0.0484
	30	0.0596
	50	0.0882
S2	10	0.0450
	30	0.0552
	50	0.0810
S3	10	0.0421
	30	0.0518
	50	0.0774
S4	10	0.0341
	30	0.0471
	50	0.0761
S5	10	0.0317
	30	0.0431
	50	0.0698
S6	10	0.0281
	30	0.0410
	50	0.0635

5.0 Conclusions

The following conclusions can be drawn from the experimental study on the wear behaviour of jute–vinyl ester composite filled with nano-alumina particles prepared by hand lay-up process, at various applied loads and abrasive particle sizes.

An increase in the Addition of Alumina in jute–vinyl ester composite exhibits lower weight loss, whose value drops further when the content of the nano-alumina filler in the composite is increased. This may be stated because the increased concentration of fillers and reinforcement to an extent (2wt.% of nano alumina and 30%jute) leads to good adhesion with the matrix and a voids matrix-rich region in the composite which leads to excess material loss. The inclusion of alumina nanofillers in jute-vinyl ester composites leads to better wear resistance, where as reinforcement fibre has less effect. Good wear resistance was observed at the loading of 68 wt% of vinyl ester, 30 wt% of jute fibre and 2 wt% of alumina.

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