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Experimental investigation on wear properties with micro-structure behavior of arecanut reinforced polymer composite material

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This study is mainly focused on wear behavior analysis of the different compositions of arecanut reinforced with polymer composite materials. The recent research is focused on the Fiber Reinforced Polymer composites (FRPC) because of the natural fiber composites are not able to meet the required mechanical properties with durability. The primary challenge of Fiber Reinforced Polymer composites is to attain high strength and less wear resistance with less weight. In this study concentrated to study the wear characteristics of reinforced polymer composite with arecanut fiber and the samples were prepared by the weight percentage with the different ratios from 0 to 30 wt%. The composite material was prepared with the help of the injection moudling technique. As per ASTM-G99 the test specimens were prepared to wear behavior analysis on the pin-on-disk wear analysis. The results were validated based on load, wear rate, sliding velocity, sliding distance, % of weight reinforcement. The wear behavior of the composite materials morphological characteristics was studied by SEM analysis and the results of SEM analysis revealed that less wear behavior is attained by applying maximum load.

1. Introduction

Over the last few decades, polymer matrix composites have been manufactured and most commonly utilized for structural applications in the aviation industry, automobile industry, and chemical industries, and in offering options to traditional metal materials [1]. The characteristics that make composite materials so encouraging as the design and manufacturing substances are their high-level particular strength, high specific rigidity, and the possibilities to customize the material characteristics via the fiber control and matrix structures. Composites have been developed for improved mechanical strength and this target frequently in conflict with the concurrent accomplishment of improved wear resistance [2]. Recently, there was a huge development in research and development in the field of organic fiber-reinforced complex materials. Because natural fibers are easily recyclable, and non-abrasive. It has good quality calorie content and displays superior mechanical characteristics [3–5]. Such fibers were relatively cheap and are a renewable source of substances around the world, particularly in the tropical zone. Due to such qualities, natural fiber replaced synthetic fibers in many ways. These were very popular in the field like construction and automobile industries [6–8]. Recently, considering the ecological situation of the developed world, many scholars concentrated to utilize natural fiber as reinforcement in a polymer matrix instead of synthetic fiber. The integration of both glass and natural fibers enhance the flexural and the tensile strength and those composite materials can be utilized for moderate strength products [9]. A variety of research was performed on the possibilities of natural fibers such as jute, pineapple leaf fibers, citrus fruit fiber, sisal, industrial hemp, coir, and so on.

2. Literature review

The present study focused on the Arecanut fiber which is a waste commodity of Arecanut farming, consequently, at no additional expense, such fibers could be achieved for manufacturing reasons [10,11]. The wear behavior of HMWHDPE (High Molecular Weight High-Density Polyethylene) / MoS_2 composite materials in

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accordance with abrasive wear and dry sliding circumstances was studied [12]. The author concluded that the integration of HMWHDPE to MoS2 enhances its abrasive and sliding wear performance with a substance of MoS2 for minimal wear rate over 10 wt % [13]. They discovered that the frictional coefficient of UHMWPE was improved with adding wollastonite fibers, whereas the resistance to wear of the composite materials was the maximum once the fiber content remained around 10 wt% [14]. It was examined that the abrasive and sliding wear behavior of carbon fiber and short glass-reinforced PEEK composite materials at ambient temperature. The author concluded that adding PEEK to SGF has demonstrated an insignificant increase in the resistance to abrasion [15]. They examined the mechanical characteristics of reinforcement of short Arecanut/sisal fiber with randomly orientated blended crossbreed polyester composite materials. Research findings demonstrate that there is a strong adhesion among matrix and fiber and stress transmission was discovered to be excellent in composite with a comparative volume fraction of sisal and Arecanut 1:3, resulting in maximum bending modulus and tensile strength. The frictional coefficient and rate of wear were reduced throughout the dry sliding wear of reinforcement of epoxide and nano-ZrO2 [16].

In the epoxide matrix incorporated into the lower percentage of Al2O3 nanoparticles, there was a considerable reduction not just in the rate of wear as well as in the frictional coefficient [17]. The manufactured and assessed the characteristics of BSGRP i.e. Arecanut and glass fiber reinforced polyethylene composite materials. From the findings, it is recognized that the crystallization, space modules, and heat decomposition temperature were improved due to improvement in melting temperature, and optimal viscosity [18]. Tribological characteristics of the epoxide hybrid particles in the composite materials. 5% SiC þ35% graphite filler composite displayed approximately 85% improved wear behavior, 40% SiC composite displayed approximately and 40% graphite composite displayed approximately 40% improved wear behavior, 36% improved wear behavior in comparison to the (pure) epoxide [19]. Fabricated composite materials with Arecanut fiber as reinforcement and polyvinyl alcohol as a matrix and analyzed their physical properties. It was discovered that an improvement in the fiber content increases the physical features and reduces the extent to which it is swelling in comparison to pure composites [20]. The abrasive wear performance of reinforcement of epoxide composite materials and potassium titanate whisker. In wear tests, the whiskers were discovered to have made contributions to the wear behavior of fine-sized abrasive materials, even though it had the reverse impact on the particle abrasive materials of large and medium-sized scale [21].

3. Material preparation

The substances utilized in this research for hand layup fabricated are epoxy resin as matrix and Arecanut fibers as reinforcement, and hardener. The Arecanut fibers will be gathered from agricultural land and the epoxy resin and hardener are bought from a local distributor in Chennai. Fig. 1 demonstrates the Arecanut fiber. The gathered Arecanut fibers were divided into separate and washed with purified water. Then slashed into the desired length using a cutter. The slashed pieces were washed with water and dry in sun and the desired amount is evaluated. Composites have been equipped with 10 mm to 40 mm of fiber length and 0 to 30% of fiber content [22]. The injection modeling technique was utilized for the composite manufacturing process. The specimens were prepared with dimensions 130x100x6mm [23].

The washed fibers have been placed in the mold and then a determined quantity of epoxide resin and hardener in the ratio of 9:1 by weight had been taken and blended with Arecanut fiber with a soft stirring to reduce the air entrapment. A vacuum was applied at the same time. Then the pressure was applied on the upper side and the mold was permitted to be cured at ambient temperature for 72 hrs. Throughout the application of pressure, a certain quantity of epoxy resin and curing agent squeezes out. During fabrication, the treatment has been carried to consider this loss in such a way as a continual thickness of the specimen might be fabricated. Such a method has been implemented for the preparation of 0 to 30 wt% of Arecanut fiber. After 72 h the specimens were removed from the mold, slashed into various sizes, and stored in a closed container for additional research. So that the wear behavior analysis has been determined. The Spectrography was utilized to validate the chemical analysis of each and every single specimen followed method as per ASTM E 1251 &OES. The mixed chemical composition as illustrated in Table 1.

3.1. Fabrication of casting by the injection molding process

The injection molding process is one of the most significant processes in the preparation of FRPC due to economic support, less expensive, and time-consuming. So many researchers preferred this technique for the preparation of the specimen. Initially, the different specimens were prepared with different weight ratios like 0 to 30%wt and reinforced with a different weight ratio of Polymer composite. In this study, arecanut is selected with different weight percentages, and polymer composite materials are selected with some other different weight percentages. The preparation of these FRPC is demonstrated in Fig. 2.

A Three-phase electric furnace is chosen to heat the specimen. Initially, the heating temperature is increased step by step. Finally, the material is heated at 960 °C. Initially, the recant is poured into the preheated furnace and heat the poured material at the same temperature. As a result, there is a formation of a glue Condition. Then the attached mechanical stirrer with a blade was feed into the furnace with a 10-minute range and with a sliding speed of

Fig. 1. Arecanut fiber.

Table 1
Chemical compositions of % of /ASTM E1251 & OES.

Type of specimens	Percentage of polymer composition	Percentage of Fibre composition
Specimen A	0%wt	99.11
Specimen B	5%wt	91.11
Specimen C	10%wt	79.11
Specimen D	15%wt	83.1
Specimen E	20%wt	79.12
Specimen F	25%wt	80.72
Specimen G	30%wt	76.11

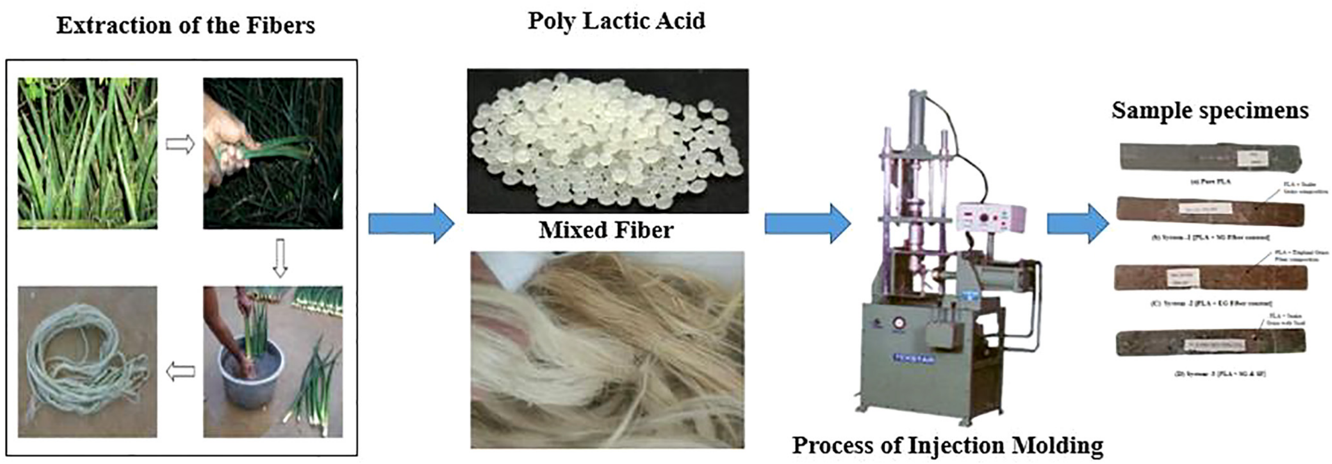


Fig. 2. Process of injection molding.

100–1000 rpm. At this stage, the reinforced oxide particles are feed into a furnace at the temperature is in the range of 700–750 °C and solidification takes place with respect to the time and speed (rpm). Finally, the molding stage was attained. In this stage, the die is added. As per the ASTM standard, the die is prepared in the range of 200 mm × 100mm × 10mm.

3.2. Preparation of flat composite

The specimen is in the size of 200mm × 100mm × 10mm. Entire specimens are validated in the 10 × 10 region with more than 100 nodes as shown in Fig. 3. The highly attained wear region is observed and selected for the wear behavior analysis and pin on disc wear analysis and abrasive wear analysis is performed. In the selected region is slashed into the square rod with a 30 mm length, 10 mm width, and 10 mm thickness with the help of the water jet cutting method. According to the ASTM G99 standard, then lathe technique was utilized to modify the shape of the square rod into the round rod with 30 mm × 8 mm. These modified specimens are treated as blocking pin composite.

3.3. Methods of testing process

3.3.1. Wear behavior analysis

Commonly, there are various categories of wear. Intentionally, few frictional engineers scan prompt wear for different reasons. The three general categories of wear are corrosion, adhesion, and abrasion. Each category has fundamental difficulties and advantages that can impact surface finishing, lubrication, and material. The present research mainly focused on pin-on -Disc wears and Abrasive Wear to examine the reaction of wear and friction. Pin on Disc Wear: In this research, the pin-on-disc device was utilized to examine the reaction of wear and friction in the sliding contact surface of the samples as shown in Fig. 4. According to ASTM G99 standards, the tests had been performed by applying various loads like 10, 20 and30 under dry conditions at a constant sliding time of 5S with various sliding velocities from 0.99 to 2 m/s. Initially, the pin was washed with acetone and weighed with accuracy by utilizing a digital electronic balance. EN-32 steel was utilized to prepare the disc material with the hardness of 42 HRC. At the conclusion of every single test, the weight loss of the sample is observed and expressed in terms of the coefficient of friction, specific wear rate, and sliding wear. The coefficient of friction is the proportion of the

Fig. 3. Preparation of Flat composite.

Fig. 4. Experimental arrangements of Pin On Disc [POD].

frictional force among two bodies and the force pressing them all together. The specific wear rate represents the volume loss per sliding distance and load. Sliding wear is associated with the interaction among the surfaces and exactly the deletion and distortion of material on a surface due to the mechanical effect of the contrary surface.

3.3.2. Abrasive wear

When the relative movement of both hard and soft surface areas in contact with each other, abrasive wear was observed. This is one of the main sources of material waste and wastage of mechanical efficiency. Abrasive Belt Wear tester is utilized to perform abrasive wear and the apparatus were demonstrated in Fig. 5. From the figure, it is observed that the weight ratio of the five specimens was measured before and after testing. The samples were machined into pins with a 30 mm diameter in length and an 8 mm diameter in width respectively. Initially, according to the ASTM G99 standard, the sample is weighed by utilizing an electronic weigh-in machine then attached to the holder to the testing machine and exposed to wear for 60 s and weight has been measured and the weight loss was registered in analog mode. The procedure has been repeated for 5 to 10 times and the total loss is determined before and after weight fractions and the experimental setup is shown in the Fig. 6.

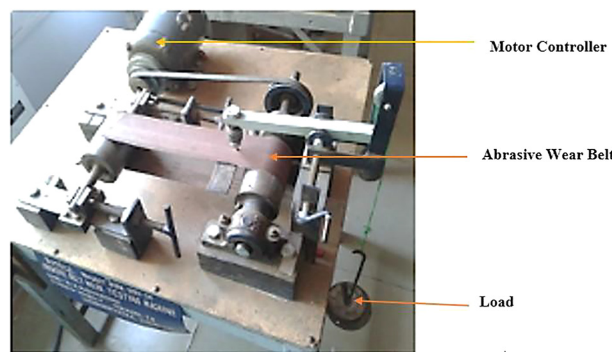


Fig. 6. Experimental arrangement – Abrasive wear.

3.3.3. SEM analysis

The information from a specimen at the nanoscale has been attained through an electron beam which is utilized by SEM. The primary category of signals is Secondary Electrons (SE) and Back Scattered (BSE) which produce a grayscale image of the specimen at elevated magnification levels. Therefore, there are several different signals which could be a particular effect of the electron-matter interface and these can offer extra information on the specimen. The different kinds of signals were produced by electron beam-matter interaction that transmits various information about the

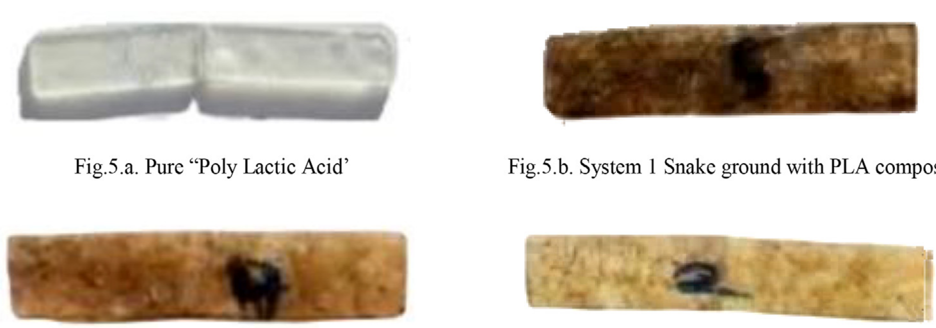


Fig.5.a. Pure "Poly Lactic Acid'

Fig.5.b. System 1 Snake ground with PLA composite

Fig.5.c. System 2 Snake ground with Elephant Grass Fiber reinforced PLA composite

Fig.5.d. System 3 Snake ground with Sisal Fiber reinforced PLA composite

Fig. 5. (a, b, c, d) Abrasive wear samples.

specimen gets iteration in 3times each. For instance, the contrast image is generated by backscattered electrons that bear data on variations in the atomic number, the topographical information was provided by secondary electrons, the chemical structure of materials and the electronic structure information was provided by cathodoluminescence and crystallography and inner structure of the specimen was explained by diffused electrons. A different category of signal that is commonly utilized in SEMs is X- rays. Thus, SEM can be utilized to optimize the research procedures and execute better performance and save precious time.

4. Results and discussion

4.1. Coupled wear analysis or pin-on-disc analysis

The removal of the material process among the two materials is treated as wear analysis. In the various application of the engineering field, these wear analyses are one of the big challenges to solve the tribological and strategical approach. This tribological study was analyzed with a variety of devices. But the most familiar one is pin-on-disc or POD. Through this device, the five different parameters like sliding speed, the velocity of disc rotation, load, feed rate, depth of wear can be adjusted as per the ASTMG99 standard. Based on these five different parameters, the friction factor of the wear was examined. When the wear is performed with maximum velocity and maximum load range defined in 1, 1.5, 2, 2.5, 3, the maximum hardness of the composition of the pin was examined with constant time 5 mm/Min.

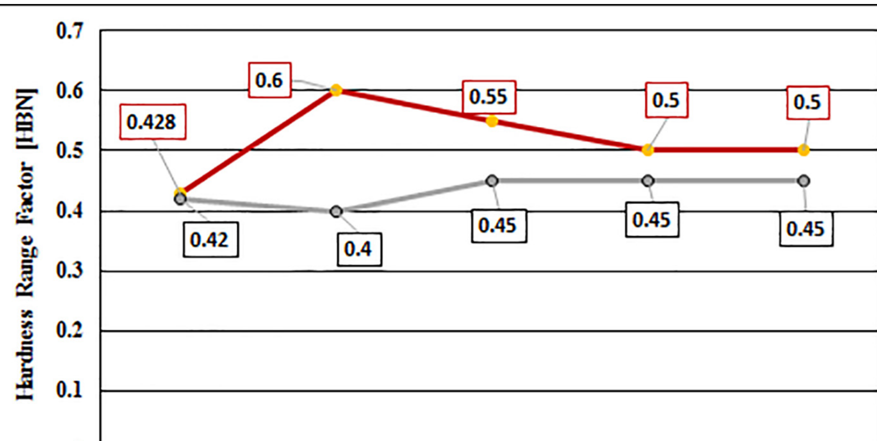
In this research, the three specimens like sample A, sample B, and samples C, D, E, F, G were utilized with a different percentage. These were demonstrated in a table in the figure These specimens were applied to the pin-on-disc device to examine the wear rate with respect to constant time, different velocity, and with different loads. The corresponding experimentation values were described in Fig. 7. The specifications of the machine were illustrated in a table as well as in Graphical Figure represented. In pin-on-disc, the wear rate is represented on the graphical representation. The graphical representation illustrates the specimen of the co-efficient of the friction regarding wear rate, co-efficient of the friction regarding Wear load. In the above graph Fig. 8, the different specimens are demonstrated in different color bars. There is a formation of FRPC with 20% of the co-efficient of the friction regarding wear rate in a specific load with time and Feed-5 mm/min. Table 2 consist of coupled wear analysis data and the Fig. 9 shows the percentage of before and after weight ratio.

4.2. Abrasive wear analysis

The abrasive wear analysis is the plastic deformation among hardened surfaces and soft surfaces or hardens materials or soft materials. As per the ASTM DG288 standard, three parameters like the rotational speed of abrasive material, bluck in of pin load, and feed rate were utilized in this research. With respect to more velocity, the rotational speed was varied in the range among 100 rpm into 1000 rpm with constant time, the Five different specimens were plugin with a 30 $\times$ 8 mm pin and increase the feed rate with vary in the range among 10 and 100 mm. At every time there is an improvement in 20 mm. The various load 10 N, 20 N, and 30 N were applied on every single specimen and the wear behavior is examined. These were represented in graphs like the co-efficient of friction regarding the velocity of abrasive belt rotation speed, coefficient of friction regarding wear rate with respect to time. The comparison between three different specimens illustrated in the bar chart. In this, time is kept constant for 5 min and the rotational speed is increased from 100 rpm to1000 rpm, the applied load is varied from10N, 20 N, and 30 N. These are illustrated in Table 3.

4.3. Coupled-wear analysis or pin-on-disc wear analysis

In reinforced arecanut polymer composite, the examination of SEM analysis is performed based on macro-size analysis to micro-size analysis with the help of high-intensity deformation analysis. The highly reinforced polymer composite was passed to every single specimen with the help of ultrasonic waves. As a result, the acquisition streaming effect was attained with high-resolution. These effects were named as transition cavitation effects. These processes were taking place only in FRPC. Based on past literature, these transition cavitation distribution analyses were validated based on the SEM technique. As a result, the resolution like 5X, 10X, 50X, 100X, and 200X is attained and represented in Fig. 10. Before the resolution analysis, the hardness range physical characteristics were performed in an entire die specimen and better results were attained. The highly attained



	4%	8%	12%	16%	20%
Top Surface	0.428	0.6	0.55	0.5	0.5
Bottom Surface	0.42	0.4	0.45	0.45	0.45

Fig. 7. Hardness measurement analysis.

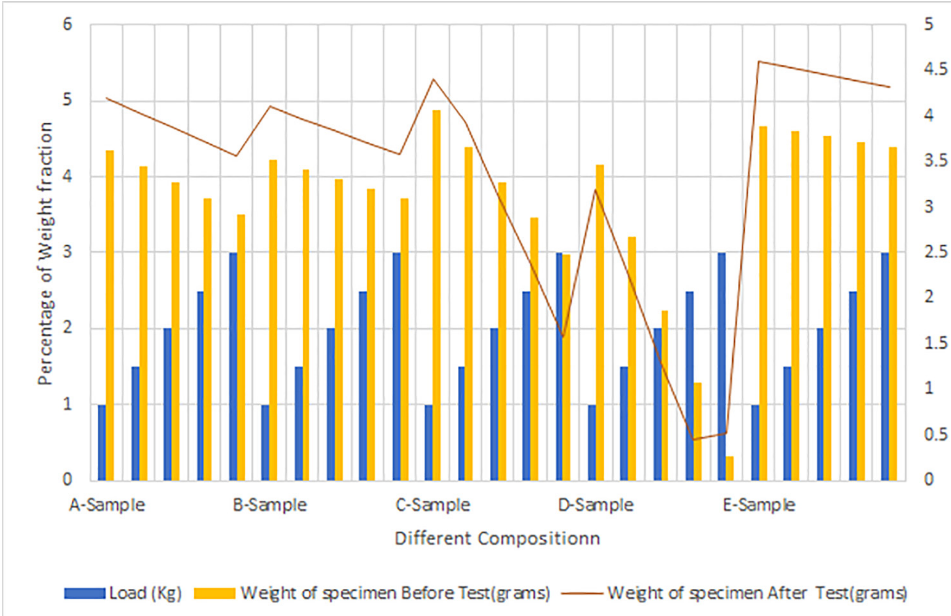


Fig. 8. Percentage of before and after weight ratio.

Table 2
Coupled wear analysis.

Specimens of composites	Load (Kg)	Wear (Micron)	Frictional Force (Newton)	Weight of specimen before test (Grams)	Weight of specimen after Test (Grams)	Weight loss (Grams)	% of weight loss
	1	513	37.7	4.359	4.2	0.159	1.59
	1.5	2169	15.4	4.147	4.041	0.106	1.06
A-Sample	2	920	18.2	3.935	3.882	0.053	0.53
	2.5	2170	15.8	3.723	3.723	0.053	0.053
	3	2890	18.8	3.511	3.564	0.053	0.053
	1	296	1.1	4.231	4.1	0.131	1.31
	1.5	82	12.7	4.1	3.969	0.131	1.31
B-Sample	2	1562	19.7	3.969	3.838	0.131	1.31
	2.5	1519	15.5	3.838	3.707	0.131	1.31
	3	2269	23.2	3.707	3.576	0.131	1.31
	1	112	8.2	4.871	4.4	0.471	4.71
	1.5	675	9.1	4.4	3.929	0.471	4.71
C-Sample	2	1167	15.5	3.929	3.148	0.781	7.81
	2.5	2564	27.2	3.458	2.367	1.091	1.091
	3	2761	24.3	2.987	1.586	1.401	1.401
	1	1243	9.7	4.156	3.2	0.956	9.56
	1.5	5123	10.2	3.2	2.244	0.956	9.56
D-Sample	2	892	17.2	2.244	1.288	0.956	9.56
	2.5	3241	28.3	1.288	0.456	0.832	8.32
	3	6543	25.3	0.332	0.532	1.256	12.56
	1	1327	10.4	4.672	4.6	0.072	0.72
	1.5	865	15.3	4.6	4.528	3.6	1
E-Sample	2	6751	20.6	4.528	4.456	3.328	1.2
	2.5	6151	30.5	4.456	4.384	2.956	1.5
	3	2186	32.2	4.384	4.312	2.684	1.7

hardness region and nodes were identified and slashed into1cmX1cm. The better wear performance in the sample is identified and selected as a refined grain structure. These are performed with the help of the pin-on-disc apparatus and the high-intensity of localized transient cavitation value is validated and presented.

4.4. Abrasive wear analysis

The coefficient of friction value is based on the wear performance among abrasive steel belts and composite pin. This is an essential characteristic of abrasive wear analysis. In general, the frictional coefficient values are validated based on adjacent method, asperity deformation method, and blucking method.

4.5. Morphology studies of Arecanut reinforced polymer composite

Day-by-day, various experimentation is performed in a different composition. The main purpose of establishing such composition is to find the high-resolution performance, structure quality, internal characteristics of particles, internal boundary structure of a single composite. In this study, JOEL SEM machinery was utilized to analyze the wear behavior of composite materials. The reaction of wear and friction wear behavior is examined by the fol-

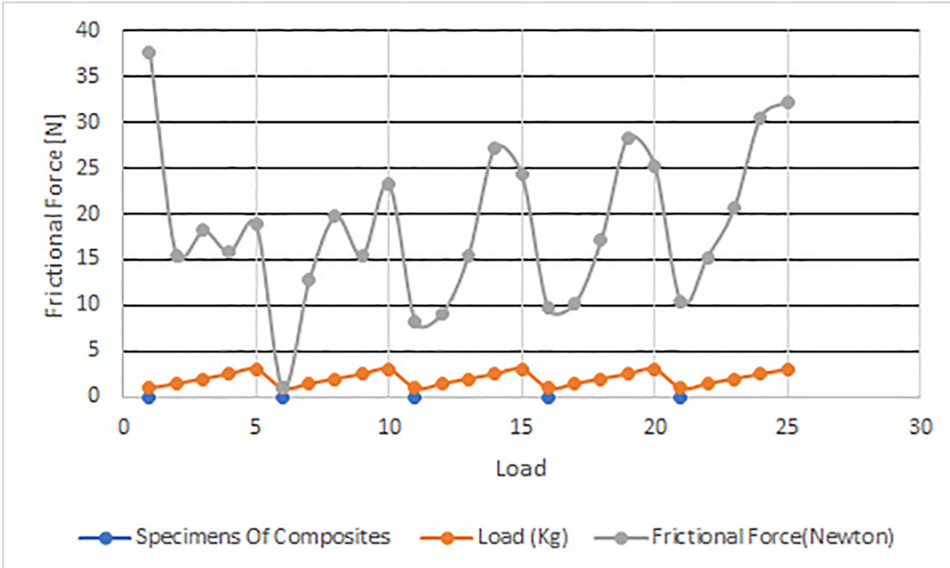


Fig. 9. Graphical presentation of load Vs frictional force.

Table 3
Abrasive wear analysis.

Composites	Test (grams)	Test (grams)	Loss (Grams)	Loss
A	3.159	3.2	0.169	1.69
B	3.531	3.1	0.121	1.21
C	3.371	3.4	0.481	4.81
D	3.356	3.2	0.966	9.96
E	3.472	3.6	0.092	0.92

lowing procedure. Coupled-wear analysis or pin-on-disc wear analysis.

In this research work, the blucking technique is utilized to find the coefficient of friction value. The coefficient of friction value is calculated by analyzing frictional force in the rotational process of the belt with respect to the pin load. In this research, two important parameters like force and weight of blucking of the composite pin were utilized. The running of abrasive pin ranging from minimum rpm to maximum rpm in different loads is represented in Fig. 11. The wear analysis of the specimen is validated and the better wear performance of a particular specimen is observed. The better wear performance is attained with maximum rpm and minimum wear. These are analyzed with the help of SEM analysis. Based on the best specimen, the worn surface is observed. These analyses are utilized to observe the presence of a crack, probably pull-out of reinforced particles, minimal reinforcement of particles. The abrasive velocity of the specimen is calculated based on sliding distance. In the modern engineering field, the wear rate is examined by applying a high load with maximum velocity. From SEM images, the brittle surface of the specimen

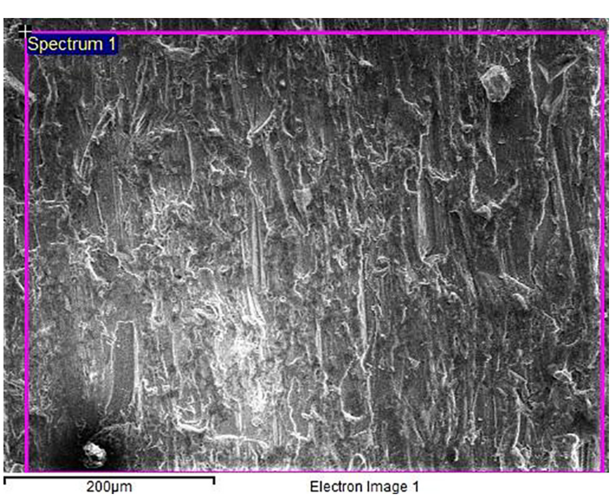


Fig. 10. Wear behavior analysis in 20% specimen composite.

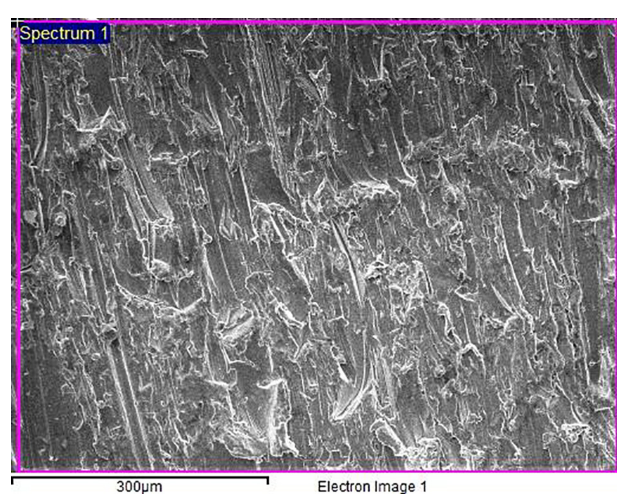


Fig. 11. Abrasive wear analysis in 20% specimen composite.

and also stronger or weaker performance of wear specimen is identified. Sample pictures are demonstrated with the range of 50 μm with a high magnification of 300 μm is investigated.

5. Conclusion

In this article, arecanut is reinforced with polymer composite and the wear behavior analysis of Coupled-wear analysis or pin-on-disc wear analysis was made and the morphological characteristic is examined by SEM analysis. From the study, it has been noticed that the wear rate depending on the value of the normal load application and the weight-loss increases normally with the rising of the applied normal load they directly proportional to each other. The reason behind the rise in the wear rate is an increase of the applied load; because of an increase in the plastic deformity at the tip of the sample surface asperity.

- In Coupled-wear analysis or pin-on-disc wear analysis, with the maximum load 2.5 N at constant time 5 mm/m, the 20 wt% of wear was attained in the specimen 'E'.
- Similarly, in abrasive analysis, with a maximum load of 2.5 N, at 5 mm/min, and at 1000 rpm, the specimen E attained 20 wt% of wear.
- SEM analysis is performed to examine the wear behavior, and these were represented through the SEM image.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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