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Investigation Of Long-Term Acid Aging, Electrical, Thermal And Mechanical Behaviour Of Coir Whistling Pine Seed Reinforced Low-Density Polyethylene

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ABSTRACT
Material reinforcement has paved way for alternative materials with definite thermophysical properties to meet up specific need of our immediate environments. This experimental study was carried out to introduce a new reinforced biofiber material based on the chemical composition and physical positioning of the bonny environment. The whistling pine seed powder (WpSP) was used as biofiber, while the low-density polyethylene (LDPE) was used as polymer matrix for our reinforcement experiment. Our composite samples S1, S2 and S3 respective has 80% in wt WpSP and 20% in wt LDPE, 70% in wt WpSP and 30% in wt LDPE and 60% in wt WpSP and 40% in wt LDPE were all characterize for long-term acid aging (27days), water absorption rate, coefficient of friction, thermal conductivity, and electrical resistivity. Result obtained reveals how the biofiber loading affects the thermal conductivity, electrical resistivity, coefficient of friction and density through the rate of water absorption.
Keywords*:* Whistling pine seed, Material reinforcement, Composite, Biofiber, low-density polyethylene

1.0 INTRODUCTION

The use of reinforced low-density polyethylene matrix to obtain materials with enhanced and special mechanical, physico-chemical behaviour, and also to obtain materials with greater strength and stiffness, density, electrical and thermal conductivity, electrical resistivity, friction, flame retardant and wear resistance. Material reinforcement which could be either in the form of flakes, filler, particulates or fiber have so far been considered in research. Fiber matter has been categories to be either synthetic or natural fiber, also referred to as biofiber. Materials made from composite have been greatly used in fabrication works as superior materials for centuries now. Many high technology materials are made out of composites, as they can be readily formed and manufactured to demonstrate very good strength, weight properties. There is growing interest particularly in the engineering industry such as automotive, civil engineering and aerospace industries. Bio-composites which is lower in cost and less dens than conventional composites made out of synthetics, and have also shown added benefit of being constructed from renewable and environmentally friendly and biodegradable components, which has consequently made them become environmentally superior choice. Bonny island, an island that houses most of the multinational oil companies in Nigeria that are associated with a lot of electrical, mechanical and oil & gas facilities whose components can be greatly improved in terms of electrical and thermal insulation, corrosion and flame retardants, and physical and mechanical behaviour with a better and environmentally friendly sensitive and light-weight biofiber reinforced composite.

In an experimental study of the use of bamboo culm as a natural fiber for reinforcement on polypropylene-matrix base composite, that is further characterize for chemical analysis, Fourier transform electron microscopy and scanning electron microscope. They also carried out electrical characterization of their strain of composite. A frequency dependent dielectric constant, capacitance and resistivity was observed from the polypropylene and bamboo culm reinforced composite at a constant temperature of 303.5K (30^{o}C). In an attempt to also evaluate the insulating property of their sample of composite material, they observed that at a range of frequency, a significant drop in the dielectric constant, capacitance and resistance of the material occur [1](Latif, et *al*, 2015). a similar study where the dissipation factor, loss factor and dielectric constant as a function of fiber loading, temperature and frequency were carried out [2] (Sreekumar *et al*, 2012) as they investigate the electrical characterization of sisal fiber and polyester reinforced composite using the resin transfer mold. At the end of their study, they were be to establish a relationship between the fiber loading at various frequency range, the volume resistivity at different fiber loading across a range of frequency. They also drew up conclusion on a relationship between dielectric constant at different temperature. Fiber-based composite materials can enhance or overcome the shortcomings of any single material in addition to retaining their original qualities through functional modification of the fiber materials. Their study's main goal is to introduce a number of widely used fiber-based reinforcing materials, including basalt fibers, carbon fibers, aramid fibers, glass fibers, ultra-high molecular weight polyethylene fibers, poly (p-phenylene benzobisoxazole) fibers, and their composite materials. It also introduces a number of frequently used modification techniques and the mechanisms that underlie them. Better mechanical qualities, impact resistance, wear resistance, and fire resistance are displayed by modified fiber-based composites, which makes them appropriate for usage in a variety of industries including aerospace, high-rise construction, bridge and highway construction, and maritime facilities [3] (Yang *et al*, 2019). In an experiment wherein a continuous fiber-reinforced polymer composite's out-of-plane fiber waviness was experimentally measured. The transverse-strip method, the ply-drop method, and the constant-thickness ply-drop method are the three fabrication techniques that were created. The outcomes of the experimental characterization showed that it is simple to produce specimens with a variety of waviness characteristics. Their methods identified a few key characteristics that are straightforward to produce and just need a basic experimental setup. To verify the methods, an optical characterization of an industrial part was performed, revealing a maximum misalignment angle of 5.3° [4] (Wang *et al*, 2012). An investigation of the flexural characteristics of composites created by adding varying ratios of bagasse, coir, and banana fiber as additional natural fibers to an epoxy resin matrix was conducted. When compared to particle board, which is employed in some industries, the hybridization of the reinforcement in the composite exhibits about the same strength, but it costs far less than our natural fiber reinforced composites. The composite is basically made up of 70% bagasse and 30% coir has about the same strength, density, and water absorption rate as other composites, making it more cost-effective and environmentally benign [5](Mursalin *et al*, 2018). Polypropylene (PP)-based composites reinforced with pineapple leaf fiber (PALF) were effectively created using a traditional compression molding method. Composites were made with varying percentages of fiber. Evaluations were conducted on the following metrics: impact strength (IS), bending strength (BS), bending modulus (BM), elongation at break (Eb%), and tensile strength (TS). Comparing the 45 weight percent PALF/PP composite to the matrix material (PP), an increase was seen. The functional group analysis of composites was conducted using Fourier Transform Infrared (FTIR) Spectroscopy. The composites showed reduced water uptake for all fiber percentages. After 60 minutes in an alkali solution, the manufactured composites had lower TS, TM, and Eb% than the control composites [6] (Hoque *et al*, 2018). Using pyrolysis to remove the resin from the carbon fiber in carbon fiber reinforced composites (CFRPs), recycled carbon fiber (RCF) was created. The degree of degradation of epoxy resin was verified through the use of a scanning electron microscope (SEM) and thermal gravimetric analysis (TGA). To create a carbon fiber composite sheet, the RCF was chopped and ground (CFCS). Recycled carbon fibers and other thermoplastic fibers were used in the production of CFCS. Numerous characterizations were carried out, including as mechanical characteristics, crystallization enthalpy, and morphological evaluations of the CFCS at various cooling temperatures [7] (Lee *et al*, 2015). Poly (lactic acid) (PLA) and cellulosic natural fibers were used to create polymer composites by fusing the film stacking composite-making technique with the wet-laid fiber sheet forming method. High yield pulp from hardwood, high yield pulp from softwood, and fibers from bleached kraft softwood pulp were among the natural fibers examined. The mechanical and thermal characteristics of the composite were described. Pulp fibers were added, which greatly enhanced the composite tensile moduli and strengths, encouraged PLA's cold crystallization and recrystallization, and greatly raised the composite storage moduli and elasticity. The maximum composite tensile strength recorded was 121 MPa, which is almost a factor of 10 larger than the clean PLA value. Compared to traditional random short fiber-reinforced composites, the overall fiber efficiency factors for composite tensile strengths determined from the micromechanics models were found to be much greater, indicating that the fiber-fiber bond also positively contributed to the composites' strengths [8] (Du *et al*, 2014). In the reinforcement of an hybrid natural fiber (NF) and polylactic acid (PLA) biocomposites made via melt extrusion. NFs from plants cultivated nearby were used as fillers. To increase PLA's processability, plasticizer polyethene glycol (PEG) was employed. Thermal and mechanical properties were used to evaluate the impact of processing PLA/NF biocomposite. The samples were also subjected to thermo-mechanical and dynamic mechanical analyses. When compared to PLA, the mechanical characteristics of PLA/NF biocomposites improved. Overall, the results of this work showed that because PLA/NF biocomposites have good stiffness, tensile strength, and dimensional stability, they have the potential to be innovative biocomposites and ideal for further application, particularly in biomedical applications [9] (Alothman *et al*, 2023).

The concentration of acid in the immediate human environment in bonny island is relatively higher because of the salt water dominated terrain and the contribution of chemicals from industrial activities such as gas flaring and the density of depositions of both human and industrial waste. Hence conventional materials tend to corrode and decay much faster than they are meant to be, as they struggle against the acidic constituent of the environment, and also against excess water absorption because of the constant damping of the environment. Natural reinforcements such as biofibers will enable the fabrication of more durable, sensitive and controlled-weight materials that can replace the conventional and synthetic fiber materials used in the oil & gas industry, civil engineering constructions, and for domestically related works. To therefore, we examine the electrical and thermal insulation properties, physical and mechanical behaviour of whistling pine reinforced matrix, to test and evaluate the impact of long-term acid aging of the whistling pine seed reinforced composite, as well as water absorption evaluation, friction and wear testing of the whistling pine seed reinforced composite.

2.0 MATERIALS AND METHOD

2.1 Materials

The matrix used in this study is the low-density polyethylene which was collected from household within and around the Federal Polytechnic of Oil and Gas Bonny Island, Abalambie road, Bonny, Rivers State, Nigeria. The low-density polyethylene is the plastic sachets used in packing water used for daily consumption. The whistling pine seeds is collected from the vicinity of the Federal Polytechnic of Oil and Gas Bonny Island, Abalambie road, Bonny, Rivers State, Nigeria. The powder of the whistling pine seed is obtained by crushing the seeds using the 800A high-speed multi-function mill to obtain a finely crushed whistling pine powder. The Hydrochloric (HCl) and sodium hydroxyl (NaOH) acid used in the treatment of our samples was obtained from Chike chemicals Ltd, building materials line mile 3 diobu, Port Harcourt, Rivers State Nigeria.

2.2 Biofiber Composite Fabrication

The whistling pine seed was gathered and soaked in a warm water at about 35 - 40^{o}C for 48hours before washing. The dried samples of the whistling pine seed were then treated with 7.5% wt of sodium hydroxyl (NaOH) solution (i.e 15M in aqueous solution) to ensure the removal of alkali and all other residual compound and particles. It was then dried in an oven at a temperature of 120^{o}C for 6hours, then it was crushed and converted into powder using the 800A capacity high speed multi-function mill machine. The low-density polyethylene was shredded using a crusher for low-density plastics materials. The following sample S_1, S_2 and S_3 with the respective percentage composition

20% whistling pine seed powder and 80% shredded low-density polyethylene, 30% whistling pine seed powder and 70% shredded low-density polyethylene and 40% whistling pine seed powder and 60% were mixed vigorously to get a homogenous sample. It was then subjected to heat treatment for 45min at a temperature of 150°C using a two-mill roller. The composite samples were further thermoformed by subjecting them to hot pressing machine.

2.3 Biofiber Composite Exposure condition

The selected samples were subjected to acid aging by immersing them completely into salt water, whose pH ranged from 7.56 to 7.88 mg/L according to [10], and [11] presented a pH of 8.87. the soaking of composite samples was done for a period of 54 day to represent the duration for acid aging. The choice of salt water as our acid medium is basically due to the abundance of the acid medium in the Bonny Local Government Area.

2.4 Material Characterization

2.4.1 Hardness Testing

The Vickers (FIE MV1-PC) indentation hardness tester was used to examine the hardness of all strains of our biofiber composite materials by subjecting them to a load of 4.90N (0.5kgf) over the surface of the material at a time interval of 10s. the hardness value of each strain of our composite material was obtained. The hardness value of all selected samples was then subjected to acid aging for a long-term period of 54days.

2.4.2 Friction Wear Testing

The pin-on-disc tribometer (DRTB, 70090) was use to carry out the testing for friction wearing. To ensure that the disc surfaces and pin are in complete contact with our novel biofiber composites, a pre-rubbing process was first carried out on each sample. The testing was carried out at an ambient atmosphere with relative humidity of about 47$\pm$10% and a temperature of about 23$\pm$5°C after thorough cleaning of the samples. A load of 5N was applied in a direction normal to the sample that is subjected to a rotating disc whose speed is 10cm/s at a sliding distance of 15.71m. Other values of the parameters under considerations are; the radius that is set at 5mm, the test time was carried out for 300s. The frictional behaviour of our composites all through the period of the sliding was considered in this study, as test speed and time was kept constant. The same parameter of testing was considered for all strains of our biofiber composites, both before and after acid aging. The track image was collected under optical microscope in order to ascertain the friction value using the ICC50, DM 750 LEICA device.

2.4.3 Water Absorption on Density Testing

The effect of material re-enforcements and acid aging on the capacity of biofiber on water retention was evaluated through the water absorption testing. The selected strains of our biofiber composites were weighed (in mg) after being dried up in an oven at 60°C and is allowed to cool down to room temperature. The samples were then immersed in a water bath filled with pure samples of water at 26°C for 5days (120hrs), after each day (24hrs), each strain of our biofiber composite were removed from the water, the surfaced dried up using a clean towel and weighed (in mg) within 60s of the removal from water, and is then immersed back into the water.

The density of all strains of our biofiber composites before acid aging, and after acid aging were computed using the expression

$$\rho_{S1} = \left(\frac{M}{V}\right)_{S1}$$

Where ρ_{S1} is the density of the i^{th} sample before acid aging, *M* and *V* is the mass and volume respectively of the sample before acid aging. The mass of each sample of our composite was obtain from the weight measurement before the water absorption testing, and the volumes of our samples were obtained by measuring the dimensions of the rectangular block of our composite sample before the water absorption testing. The computation of the density of all the selected samples were repeated after the water absorption testing of 5days. Where the mass after water absorption testing is obtained from the measurement of the weight after the testing, and the volume is obtained from the product of the dimensions of the rectangular block of our biofiber composite after water absorption testing.

2.4.4 Electrical conductivity testing

The four-point method recommended by [12] of evaluating the resistivity of our whistling pine composite involves the following steps:

2. An ammeter is connected in between a current source that is connected to both ends of our composite, to measure the current magnitude that will flow through our composite, and also to enable our voltmeter to produce the corresponding voltage of across the composite for every current that flows through it.

Then the electrical resistivity is the computed from the equation

$$\rho = \frac{Vwh}{I \times l'}$$

where V is the voltage across the voltmeter, w is the width of our rectangular composite material, h is the height of our composite material, l' is the length of the two selected point with our rectangular composite block in which the voltage is measured and I is the current recorded by the ammeter.

2.4.5 Thermal conductivity testing

the thermal conductivity testing was carried out using the guarded heat flow meter, on a composite sample whose dimension are 40mm by 15mm. The temperature difference T_1 and T_2 between two points separated by length l, and the thermal conductivity k is given by

$$k = \frac{ql}{\Delta T}$$

where ΔT is the temperature difference between T_2 and T_1

3.0 RESULTS AND DISCUSSION

Electrical Resistivity of composite

Result presented in Table 3.1 shows the electrical resistivity obtained from measurement of our novel composite samples with percentages on their fiber content. Relationship between the fiber content and the LDPE content, and their respective electrical property has revealed that increase in fiber content causes an increase in the resistivity of our fiber composite.

Table 3.1: Different values of electrical resistivity obtained from our composite samples.

	Electrical Resistivity		
Composite samples	S_1(60% in wt of WpSP; 40% in wt of LDPE)	S_2(70% in wt of WpSP; 30% in wt of LDPE)	S_3(80% in wt of WpSP; 20% in wt of LDPE)
	15.20mΩ	15.91 mΩ	16.01 mΩ

Thermal conductivity of composites

Results obtained shows a decrease in thermal conductivity of the reinforced sample of our composite, as the percentage in weight (% in wt) of the powder content of whistling pine seed increases. S_1 with relatively lower percentage in weight (60% in wt) of whistling pine seed powder (WpSP), and higher percentage in weight (40% in wt) of low-density polyethylene (LDPE) is observed to be at a much higher value of thermal conductivity than S_2 and S_3 which is respectively reinforced with a relatively higher content whistling pine seed powder (70% in wt and 80% in wt)

Table 3.2: Different values of thermal conductivity obtained from our composite samples.

	Thermal Conductivity		
Composite samples	S_1(60% in wt of WpSP; 40% in wt of LDPE)	S_2(70% in wt of WpSP; 30% in wt of LDPE)	S_3(80% in wt of WpSP; 20% in wt of LDPE)
	0.430W/mK	0.375W/mK	0.320W/mK

Hardness of composite before and after water acid aging

Results of the hardness testing presented in figure 3.1 of the profile for hardness value for and after the 27days acid aging shows an increase in this hardness values as the content of the whistling pine seed powder (WpSP % in wt) increases. The hardness value of 15.33, 36.70 and 41.09Hv were observed for S1, S2 and S3 respectively with their percentage in weight for WpSP and LDPE corresponding to 60% in wt and 40% in wt, 70% in wt and 30% in wt, and 80% in wt and 20% in wt. after the 27days acid aging, an increase in the hardness value of 18.72% was observed for S1, for S2 an increase in hardness value of 4.96% was observed, and for S3 an increase of 6.96% is observed. The higher acid exposure period altered the hardness of the samples, and the findings are in agreement with Banna et al. [20] which show the similar trend.

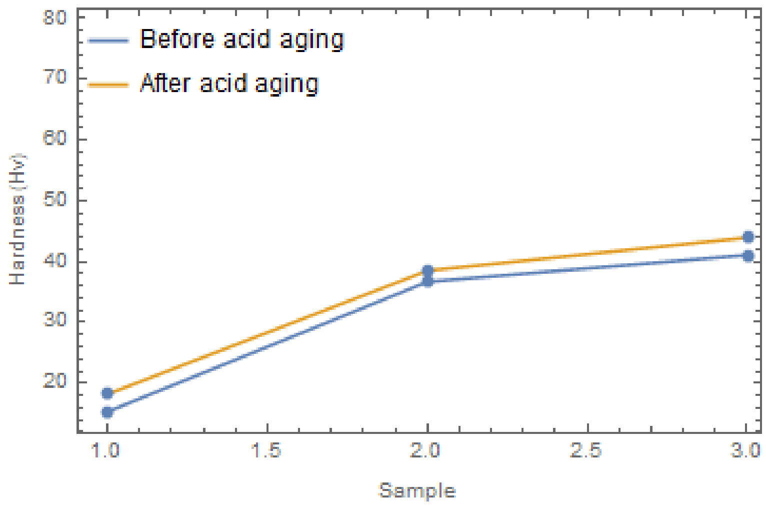

Figure 1: Hardness profile for all samples

The increase in hardness for the polymers can be ascribed to the fact that the polymer chains become larger in sizes and twisted together, giving strength to the polymer.

Coefficient of friction before and after acid aging

The profile of coefficient of friction of our reinforced composite before and after acid aging is presented in figure 3.2. The coefficient of friction of S1 before and after acid aging show's a value of 0.32μ, and after the acid aging the value decreases by 65.63% to a value of 0.11µ. The sample S2 which has a coefficient of friction value of 0.41µ before acid aging, show's a 60.98% drop in this value after the 27days acid aging to a new value of 0.16µ. While the third sample tagged S3 whose value of coefficient of friction is 0.47µ before acid aging, becomes 0.21µ after acid aging corresponding to 57.45% drop in value. Hence, the results shows that as the percentage in weight of WpSP contents of our samples increases as LDPE matrix decreases, the coefficient of friction increases correspondingly before and after acid aging. Also, acid reduces the coefficient of friction of our novel composites by more than 50%.

The possible reason why these gradients were noticed is that at the initial stage of rubbing, friction is low and this low friction can be ascribed to the presence of a layer of foreign material, for instance, moisture, oxides, etc. on the surface of the polymers under experimentation.

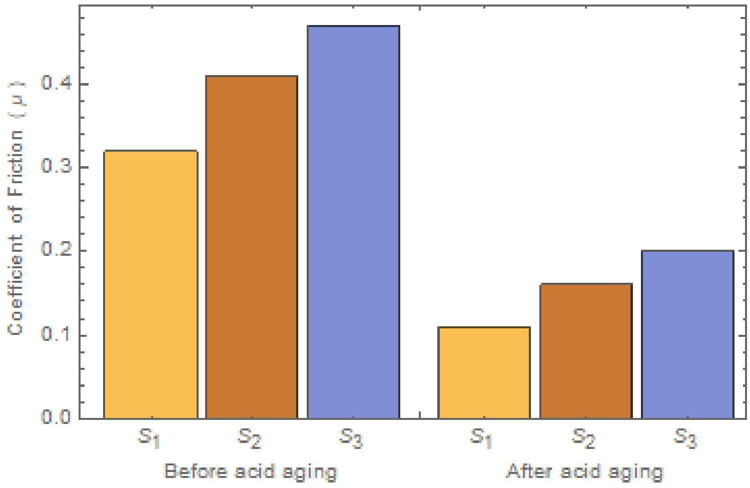

Figure 2: Coefficient of friction for all samples before and after acid aging

It can be observed that the friction force in most cases increases with duration of rubbing and reached a certain steady state value which allows the values of friction coefficient to remain relatively constant for the rest of the testing time [12, 13].

Density of composite before and after water absorption

Results profile of density for all novel samples of our composites presented in figure 3.3 shows the rate of water absorption for all the samples every 24hrs for a period of 120hrs which corresponds to 5days. Results obtained for the first day show's 1.50%, 2.33% and 2.31% increase in density for S1, S2 and S3 respectively. The change in density observed in the second day for S1, S2 and S3 are 2.22%, 2.29% and 2.31% respectively. An increase corresponding to 2.90%, 2.34% and 1.11% was observed for S1, S2 and S3 on the third day. And on the fourth day, S1 increased by 2.98%, S2 increased by 1.65% and S3 increased by 1.71%. On the last and fifth day of our testing, results observed show's a 3.02% increase for S1, 2.10% increase for S2 and 1.31% increase for S3. Hence, for our composite samples an increase in water absorption rate for S1 is observed as the testing days goes by, because the highest absorption rate was observed on the fifth day of the test, while the least absorption rate was observed on the first day of the testing. For the second sample S2, the daily rate of water absorption is almost constant. And the third sample S3 which shows the least water absorption rate, has its daily water absorption rate to be almost a constant throughout the period of the testing. Possible reason of the pattern of results obtained [24] is that the coir whistling pine seed powder (WpSP) which is a natural fiber has numerous hydroxyl group in its structure which enable the fiber to become reactive with water molecule to produce hydrogen.

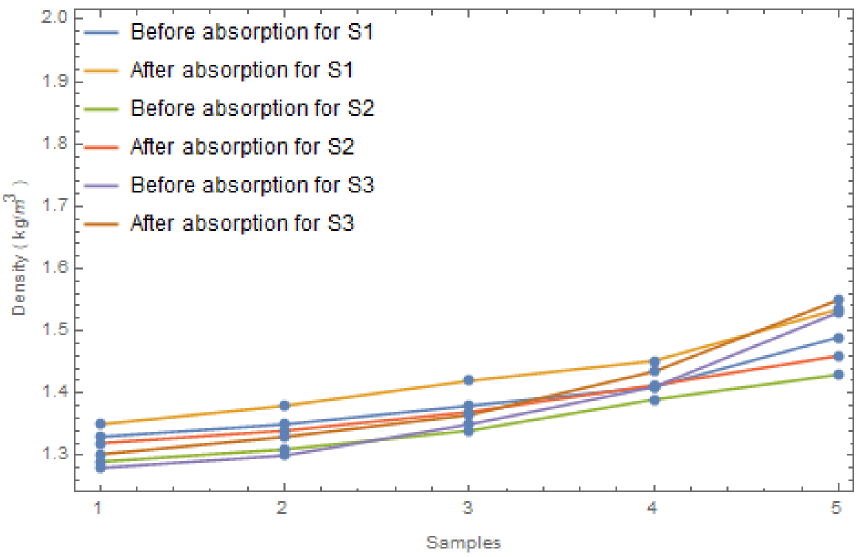

Figure 3: Density profile for all samples before and after water absorption

The decrease in water absorption rate as whistling pine seed powder content increases, can be attributed to the fact that the saturation point for 5days were already exceeded, hence the observed drop in weight gained due to water absorbed for some period is consistent with the Fickian diffusion process [14].

CONCLUSION

The following conclusion can be drawn in the research investigation of the acid aging, electrical, thermal and mechanical behaviour of whistling pine seed reinforced composite.

1. The electrical resistivity obtained from measurement of our novel composite samples with percentages on their fiber content. Relationship between the fiber content and the LDPE content, and their respective electrical property has revealed that increase in fiber content causes an increase in the resistivity of our fiber composite.
2. There is a decrease in thermal conductivity of the reinforced sample of our composite, as the percentage in weight of the powder content of whistling pine seed increases.
3. The hardness value before and after the acid aging shows an increase in this hardness values as the content of the whistling pine seed powder increases.
4. As the percentage in weight of WpSP contents of our samples increases as LDPE matrix decreases, the coefficient of friction increases correspondingly before and after acid aging. Also, acid reduces significantly the coefficient of friction of our novel composites.
5. A steady and increasing water absorption rate resulting into increasing density is observed for sample S1 with relatively low WpSP loading, while a constant change in absorption rate is seen in samples S2 and S3 with relatively much WpSP loading.

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Data availability statement

The unprocessed data required to re-produce any part of these research findings cannot be released at this time as the raw data is also part of an ongoing research investigation.

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