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Areca Short Fiber Reinforced Polylactic Acid (PLA) Composites: Influence of Physical Treatment on Properties

Raghuveer H. Desai, L. Krishnamurthy, T.N. Shridhar

Abstract: ***There is growing need to develop new biodegradable composite material which are eco-friendly and at the same time cater to the product application requirements. The research emphasis on study the properties of composites prepared by arbitrarily distributed UV treated areca fibers with Polylactic acid. Ultraviolet – a physical surface treatment has been carried out to treat areca short fibers which have been extracted from areca husk. Surface treatment significantly improves the bond between the fiber- matrix interface. The preparation of test samples has been performed using plain Polylactic acid, Polylactic acid - untreated areca short fiber (PLA-UnASF) and Polylactic acid - UV treated areca short fiber (PLA-TrASF) as per ASTM standards by means of injection moulding method. Varying fiber loading viz., 10%, 20%, 30% and 40% by weight have been utilized to develop test specimens. Developed composites have been portrayed for properties like density, moisture absorption, mechanical - tensile strength and modulus, flexural strength and modulus, izod impact strength, hardness, electrical - dielectric strength, thermal – TGA and DSC and soil degradation. The results indicate an improvement in strengths of composite with increase in fiber loading and physically treatment. This new material can be utilized for house hold appliances, automobiles and industrial applications.***

Index Terms: Areca Short Fiber, UV Treatment, Interface Ponding, Properties, Soil Degradation and Polylactic Acid

I. INTRODUCTION:

Nowadays, products or materials with tag “biodegradable”, “recyclable”, “renewable” and “sustainable” are capturing significant market at a faster rate, due to their eco-friendly nature. The interest in developing these kinds of material has increased manifold. In recent decades, development of these new eco-friendly materials using natural fibers with petroleum based plastics (thermoplastic and thermoset) has been practiced.

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* Correspondence Author
Raghuveer H. Desai*, Student of Department of Mechanical Engineering, The National Institute of Engineering, Mysuru, Karnataka, India
Dr. L. Krishnamurthy, Faculty of Department of Mechanical Engineering, The National Institute of Engineering, Mysuru, Karnataka, India
Dr. T.N. Shridhar, Faculty of Department of Mechanical Engineering, The National Institute of Engineering, Mysuru, Karnataka, India

However, most of the petroleum based polymers are non-degradable in nature, thus composites made from these are neither fully degradable nor eco-friendly.

Therefore, these are still a problem for the environment [1]. Thus, the whole research society is working towards new biodegradable composite materials which could cater to the extensive product application requirement.

These new composite materials will be a combination of natural fibers and biodegradable polymers [2]-[7]. Utilization of natural fibers is increasing due to their diversified and value-added motives, which favor the utilization of natural fibers as a substitute for any other manmade fibers. Biodegradable composites with natural fiber as reinforcement have the following advantages viz., eco-friendly, lightweight, competitive mechanical properties, high specific modulus, less expensive, allow clean energy recovery and reduced energy consumption [7]. To produce these composites, it is basic to comprehend the chemical configuration and surface properties of natural fiber. The fundamental components of natural fibers comprise lignin, cellulose, hemicellulose pectin and waxes. The natural fibers composition largely depends on the place its grown and rising environments. Semi-crystalline polysaccharide is the primary content of the cellulose with vast number of hydroxyls, giving hydrophilic properties to natural fibers. This influences the fiber-matrix interfacial bonding, prompting moisture absorption [8].

Polylactic acid (PLA) is the most encouraging and very frequently used biodegradable polymers these days, as a matrix for many of the biodegradable composites where natural fiber has been used as reinforcement. Mainly renewable resources like surgecane, potato starch, corn starch and sugar beet etc. are being used to produce aliphatic thermoplastic polyester from lactic acid monomer through fermentation. It can also be produced in different grades for diverse applications. This has shown increasing commercial interest because it is comparatively inexpensive and has outstanding properties like high strength, low elongation at break and good stiffness. This promises range of different applications such as food packaging, degradable bottles, medical application, etc. The major disadvantage with PLA is its high brittleness, which limits its wider applications [1], [9].

However, much work using different areca fiber and natural fibers as reinforcement with different thermoplastic and thermoset matrix have been carried out [10]-[18].

Literature study indicates that among all natural fiber materials, areca looks to be most assuring material as reinforcement. But very less work has been carried out on the usage of areca fibers with biodegradable thermoplastic [2], [19]. Many researchers have used different surface modification processes on the natural fibers as an enhancer to have better compatibility between the fiber and matrix. Literature study also reveals that most commonly used surface treatment is the chemical (alkali) treatment.
This not only improves the natural fiber adhesion properties, also reduces the sensitivity towards moisture absorption [5], [7], [13], [20]-[22]. Along with these advantages there are numerous limitations noticed in the present chemical surface treatment processes of natural fibers. The fiber considerably shrinks causing 8-13% weight reduction when soaked in the chemical treatment bath. Additionally, there is decrease in strength of the fiber due to degradation when fibers are soaked for extra time and the fibers become more fragile with this effect. The other key shortcoming of chemicals used for the treatment is not eco-friendly and their disposal causes environmental issues. Accordingly, to subdue these problems one can think of adopting different surface treatment processes [23], [24].

In this research work, areca fiber surface has been Ultraviolet (UV) light treated, a form physical surface treatment. This method oxidizes and etches the areca short fibers (ASF) surface forming rougher outer fiber surface. This treatment has aided to enhance strong areca short fiber - PLA interfacial bonding, improving properties of composites. Composites have been prepared using biodegradable PLA as matrix and reinforcement as untreated and UV treated chopped short areca fibers by extrusion process. Injection moulding method has been exercised to develop test samples. Short fibers are oriented to attain isotropic properties which improve performances of composites significantly. Interfacial bonding between the untreated and UV treated areca fibers with PLA has been reported. Density, moister absorption, tensile strength and modulus, flexural strength and modulus, izod impact strength, hardness, dielectric strength, thermogravimetry analysis (TGA), differential scanning calorimetry (DSC) test and soil degradation test for the PLA - untreated areca short fibers (PLA-UnASF) composite and PLA - UV treated areca short fibers (PLA-TrASF) composite have been determined. The significance of the fiber loading on the properties of the PLA - areca short fibers also has been discussed.

II. EXPERIMENTS:

A. Materials:

Areca raw fruits used in this research work have been taken from a farm near Sagar District, Karnataka. Low density and high heat resistance biodegradable thermoplastic polymer PLA pellets have been procured from ZHEJIANG HISUN BIOMATERIALS CO., LTD, China. These pellets have a melting temperature of about 175°C, and the density is around 1.25 g/cm3.

B. Extraction of Areca fiber:

Raw areca fruits seeds were removed from selected raw areca fruits by crushing the shell. Running water was used for rinsing and areca shell soaked for 3 to 4 days. Soaking procedure loosens the areca husk and thus fibers are extracted easily. These fibers were rinsed again in running water and fibers were dried for 10 -15 days at room temperature. Then fibers were chopped to a length of around 2 to 4 mm. These dried areca fibers are termed as untreated fibers.

C. Treatment of Areca fibers Surface by Ultraviolet Light:

During the study, physical surface treatment has been carried out on the extracted and chopped areca fibers. The areca short fibers were treated with UV light rays emitted from LEDs at 365 nm wavelength for one hour at room temperature [25].

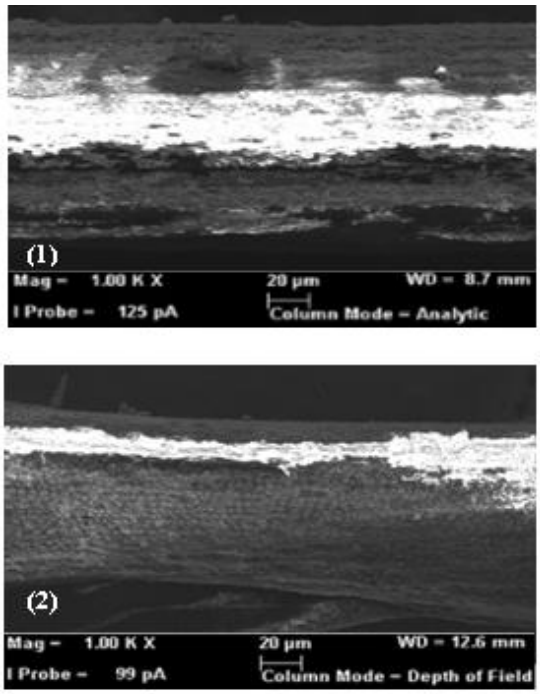


Figure-1 : SEM images of (1) Untreated, (2) UV Radiation Treated Areca Fiber

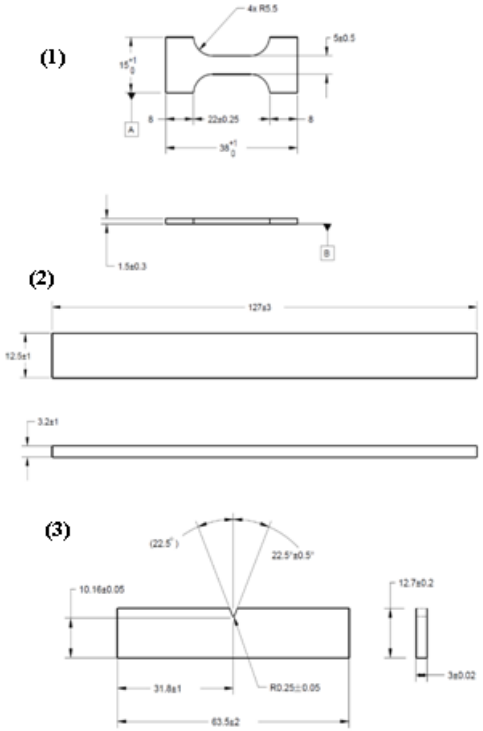
Figure-1 shows the SEM images of areca fibers surface morphology with UV treated and untreated. Usually the untreated fibers will have smooth surfaces due to dense scales on them which creates barrier for the surfaces to become wet. It can be observed from Figure-1 (1) that the untreated areca fibers have smooth and even surfaces. However, after UV treatment, the surface scales of the fibers are removed due to the etching effect. During this process, active rays bombard the surfaces of areca fibers which clean and etch the surfaces and increases the surface area by breaking the fiber bundle. Thus, surfaces of the areca fibers become rough because of the UV treatment as shown in Figure-1 (2), which helps in building strong fiber-matrix covalent bonds. Thus, fiber surface treatment influence the composite properties.

D. Preparation of PLA - Areca short fiber composites:

All blends were prepared with PLA as matrix and randomly distributed UV treated (PLA-TrASF) and untreated (PLA - UnASF) areca short fibers reinforced at different weight proportions such as 10%, 20%, 30% and 40%. Compounding of the composites has been done with help of twin screw Omega 20P Do/Di 1.80 extruder machine. The extruded composite has been collected, dried and converted into pellets.

Fiber loading fraction significantly impact the properties of composite.

Preparation of Test Sample:



The composite test specimens have been developed as per ASTM standards dimensions as shown in Figure-2 to determine tensile strength, flexural strength,

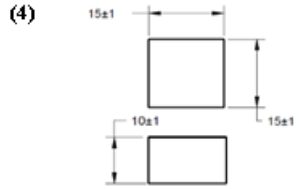


Figure-2: Test Samples for (1) Tensile, (2) Flexural (3) Impact and (4) Hardness

izod impact strength, hardness & dielectric strength. A hand operated Injection moulding machine has been used for preparing composite test specimens. The pelletized composites which are dried, have been utilized in injection molding. At the beginning, inner surface of the mould has been sprayed by a mold-releasing agent to allow easy ejection of test specimens from the mold after curing.

E. Morphology Analysis of Areca Fiber Composites:

The test Samples have been gold coated with the help of vacuum sputter coater to take SEM images of PLA-TrASF and PLA -UnASF composites. Zeiss Merlin FE-SEM has been used to analyze changes in morphology using a voltage range – 5kV to 20 kV, and probe current - 125 pA.

F. Characterization:

Estimation of densities are done by the method of displacement per Archimedes rule and test samples were tested as per ASTM D792 by WENSAR-MAB-220. In this test, analytical balance has been utilized to weigh each of the samples. At first weigh the test specimen in air, closest 0.1 mg for specimens. A measuring jar with distilled water with millimeter levels marked on it has been considered. A sample holder (water immerse) has been attached. The samples weight was recorded and then dropped into the sinker. The discrepancy between the initial and final readings gives volume of the test sample dropped in it. The density of the composites has been obtained by weight of sample to its volume ratio. For water absorption test, ASTM D570-98 standard has been used to develop and test the specimens. The initial test samples weight has been recorded after drying them and then immersed in water. Periodically these test samples taken out from water and weighed for the water absorption. While measuring, test samples were washed and absorbent paper has been used for wiping water droplets from the surface of test samples. The percentage of moisture content absorbed in test samples was calculated as upsurge in weight when related to the weight of dry specimen.

Tensile and flexural test specimens have been developed per ASTM- D1708-13 & ASTM-D790-02 standards individually. These properties of the composites have been found out using a Mecmesin universal testing machine by means of a load cell and cross-head speed maintained at 1 mm/min. For the Izod impact strength, energy absorbed by the notched specimens with impact load has been found per ASTM D256- 02 by Instron Pendulum - 9050 Manual Tester. To estimate strength, the average dimensions of test specimens have been used. The ASTM- D695-02 has been utilized to prepare hardness test samples and durometer testing machine - TH210 (Shore-D) has been used to determine the properties of the composites. The estimation of the hardness has been done perpendicular to PLA – areca short fiber composite.

For determining the dielectric strength, the test specimens have been prepared per ASTM-D149. The dielectric break down voltage has been measured at three points at a frequency of 50 Hz for each specimen and the average value has been noted. To avoid flash during the testing, sufficient distance has been maintained between the points during measurements. Micrometer has been engaged to find the specimen thickness at break down point [26].

The thermogravimetric analysis (TGA) of composites has been executed per ASTM D-1131 utilizing HITACHI STA 7300 analyzer instrument at 10°C /min heating rate. Differential Scanning Calorimetry (DSC) has been done as per ASTM- D3418 on a HITACHI DSC 7020 calorimeter at 10°C / min heating rate between 25°C and 260°C under nitrogen atmosphere. All tests have been conducted at a standard laboratory atmosphere.

Microorganisms plays a vital part in soil degradation of the natural fiber based composites. These microorganisms use natural fibers / biodegradable polymer as food source. Degradation happens by reaction among polymer chain and enzymes released by the organism. During the degradation, polymer chain will be disturbed, altering its original form. For the degradation, suitable conditions like pressure, moisture and temperature must be maintained. These biodegradable material / products are nontoxic and ecofriendly. Natural fiber contains mainly lignin and cellulose, with minimum moisture level in the soil these are easily degradable. Before burring into the soil, individual samples were weighed, weight was recorded and then buried. Every fortnight test samples were removed from the soil cautiously, washed and wiped with absorbent paper.

The dried samples have been weighed and weight of each individual test samples has been recorded. These tests have been carried out for 4 to 5 months. For each composition 3 samples have been tested and averages of test results have been taken.

III. RESULTS AND DISCUSSIONS:

A. Surface Interface Bonding Analysis:

All natural fibers are made up of hydroxyl group. Untreated areca fibers also contain abundant hydroxyl groups on the surface, which leads to higher water absorption influencing weak interfacial bond with matrix. Chopped short areca fibers were UV treated, this strengthen the surface interfacial bonding, resulting enhanced properties of the composites. A strong UV light radiation remove majorly lignin, cellulose, hemi cellulose from the surface of the fiber. The UV surface treatment contributes to the growth of aldehyde groups from the hydroxyl group, producing surfaces with O-C=O and –O=C functionalities for improved bonding properties. Areca short fiber UV surface treatment resulting in to oxidation effect by induced active species. Increase in oxygen percentage is the consequence of UV treatment, leading to substantial enhancement in bonding between the PLA - areca short fiber. This phenomenon has been confirmed by the EDS analysis showing the surface properties of the UV treated and untreated areca short fiber and its composites [23] [27].

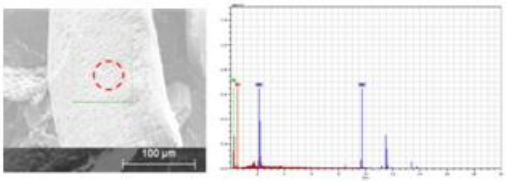


Figure-3: Areca Short Fiber – Untreated: 51% of Carbon and 49% of Oxygen.

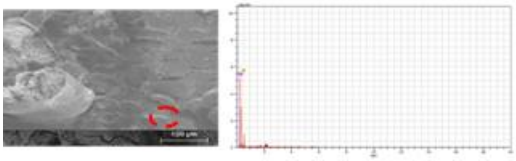


Figure-4: Polylactic Acid: Carbon - 53% and Oxygen - 47%

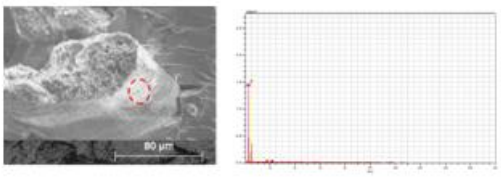


Figure-5: Areca Fiber - UV Treated: Carbon - 39% and Oxygen - 61%

From Figure-3 it tends to be noticed that untreated areca short fiber has around 51% of Carbon and 49% of Oxygen. While PLA has 53% carbon and Oxygen around 47%, additionally affirms that the presence of oxygen in PLA shows that it has a biodegradable polymer which is evident that from Figure-4.

From Figure- 5 it has been noticed that composite with PLA – TrASF, carbon has reduced to 39% and Oxygen has increased to 61%. An increase of 14% oxygen content in UV treated areca short fibers is due to the oxidation effect. The growth in oxygen comprising surface groups provides a polar surface and enhances wettability to get stronger bonding. This treatment leads to the breaking of areca fiber bundle into fine strands, thus increasing the availability of more surfaces for wettability.

B. Physical:

Density:

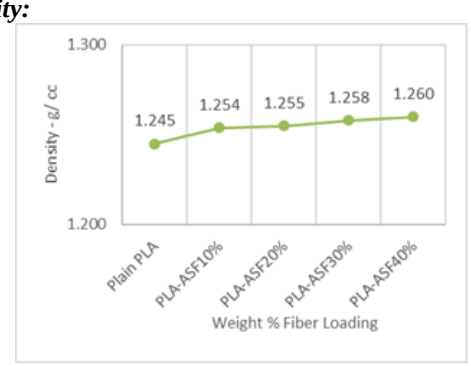


Figure-6: Density for PLA-ASF Composite with Different Fiber Loading 10%, 20%, 30% and 40%

From above Figure-6, it has been observed that with adding ASF to composite there has been increase in density. plain PLA specimen has a density of 1.245g/cm³. Maximum density can be observed at PLA-ASF40% which is 1.260g/cm³. Surface treatment does not make much difference to the density.

Water Absorption Test:

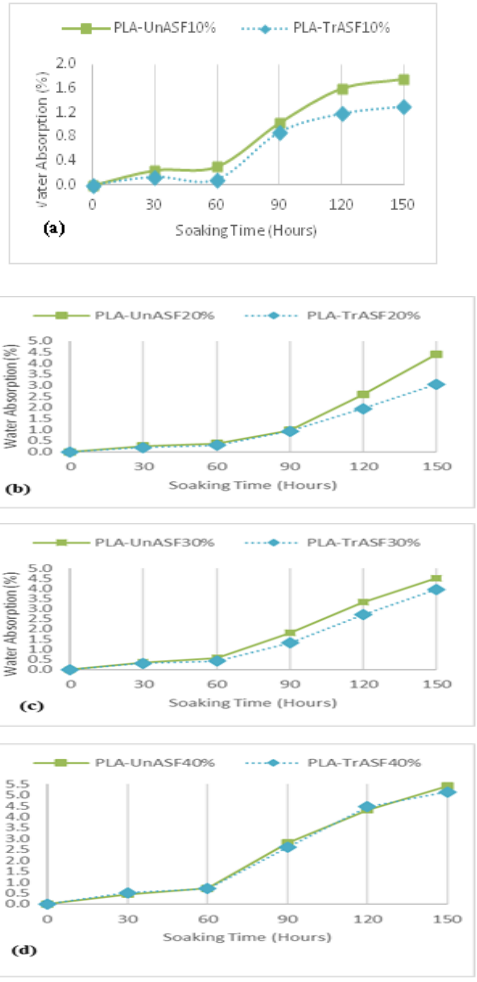


Figure-7: Water absorption for PLA-UnASF and PLA-TrASF Composite with Different Fiber Loading (a) 10% (b) 20% (c) 30% and (d) 40%

It is a well-known fact that many of the natural fibers absorb moisture. The plain PLA, PLA-UnASF and PLA-TrASF composites have been tested and compared. These test samples immersed in normal water for the total period of 150 days at ambient temperature and pressure. The quantity of water absorbed in the composites is an indication of the increase in weight of the material. The measurement of weights has been carried out at regular intervals using electronic balance. The percent of the moisture content in the test specimen has expressed as ratio of weight gain by dry specimen, W_z is

$$W_z = 100 \times (W_x - W_y)/W_y \quad (1)$$

Where Wx and Wy is specimen weight after and before absorption, the test specimens were intermittently taken out of the water, wiped with absorbent paper, reweighed and immediately place back into the water. Figure-7 (a) – (d) shows water absorption with respect time along with result of areca short fiber loading on the water absorption performance.

Upsurge in water absorption was noticed with fiber loading with all PLA-UnAF and PLA-TrAF, it has been observed highest at 40% fiber loading. As evident from the Figure-7, the UV treated areca short fibers showed lowest absorption percentage of water. This is due to of strong bonding among the UV treated areca short fiber and the PLA matrix. The fiber cellulose, which has OH group are choked by their interface with the matrix and restricting the water to have the accessibility of bonded interface in these composites. The moisture absorption lead to the composite property degradation.

C. Mechanical

Tensile Strength

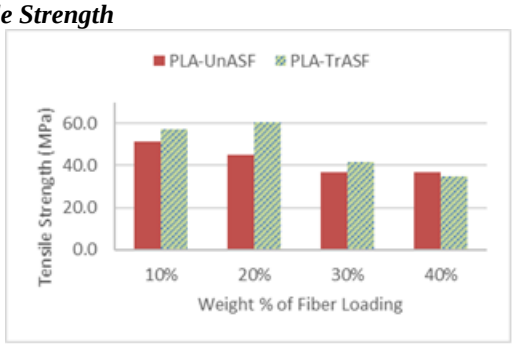


Figure-8: Tensile Strength of PLA– UnASF and PLA-TrASF Composite at Different Fiber Loading

Tensile strength of the PLA-UnASF and PLA-TrASF composites at varying fiber loading percentage has indicated in Figure – 8. From the outcomes, it can be noted that there has been upsurge in the tensile strength of PLA-UnASF composite up to 20% of fiber loading and with further increase in the fiber loading reducing trend in strength has been noticed. For PLA-TrASF composites the tensile strength has been found to be 60.41 MPa at 20 %, whereas for plain PLA is about 50.18 MPa. This specifies that maximum stress from the PLA matrix has transferred to the UV treated areca short fiber at 20% of fiber loading, presenting an improved interfacial bonding between the areca short fiber and the PLA. Further, beyond 20% fiber loading the strength decreases for PLA-TrASF composites.

Flexural Strength

From the results, it has been observed that the PLA-UnASF and PLA-TrASF composites, with increase in fiber loading there has been a substantial decrease in the flexural strength. The flexural strength of 71.04 MPa has been observed at 20% for PLA-TrASF composites and 59.85 MPa for plain PLA matrix. This demonstrated that there has been considerable interfacial bonding enhancement between the PLA and UV treated areca short fiber at 20% of fiber loading. The flexural strengths of the PLA-UnASF and PLA-TrASF with different fiber loading percentage are shown in Figure-9.

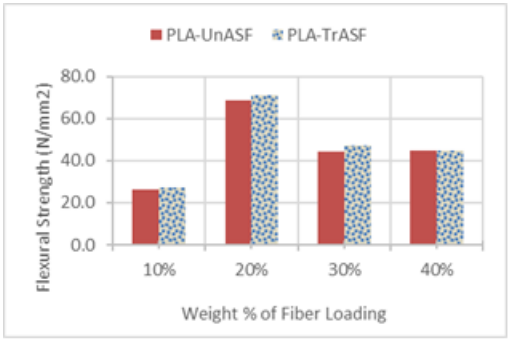


Figure-9: Flexural Strength of PLA - UnASF and PLA – TrASF Composite at Different Fiber Loading

Tensile and Flexural Modulus:

The tensile modulus and flexural modulus of the PLA-UnASF and PLA-TrASF composites are compared individually as shown in Figure-10 & Figure-11 respectively. Results have shown, that there has been increase in the modulus with increasing fiber loading in comparison with plain PLA which has around 35.05 ± 1.00 MPa. However, this increasing trend have seen till the 30% of fiber loading and beyond 30% its shows a decreasing trend, this may be because of high stiffness of the areca short fiber composites.

From the above tensile and flexural test results, it has been noticed that PLA-UnASF composites, initially increase with fiber loadings and then decrease after anteing optimum fiber loading percentage i.e. 20%. Reduction in properties after optimum fiber loading may be attributed to the feeble interfacial bonding between the areca fiber and PLA. And, few more reasons like, existence of wax and dust at the surface of the fiber and non-uniform dispersion of the fibers in the PLA. The PLA cannot penetrate fully in between two adjacent areca fibers and wet these fibers. This reduces the PLA - areca fiber interaction and increasing the fiber – fiber interface. It has been experimented that there has been enhancement in the strengths of the composite because of UV treatment. A strong UV radiation will remove lignin from the surface and expose cellulose and hemi cellulose. It has observed that the UV treatment increases the Hydroxyl group on the areca short fiber surface which has very much available for bonding. Hence, strength of UV treated areca fiber composites higher in comparison with untreated areca short fiber ones at the optimum fiber loading [27].

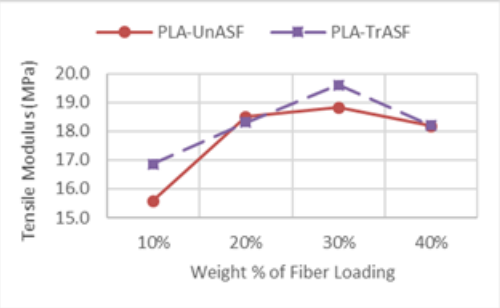


Figure-10: Tensile Modulus of PLA-UnASF and PLA-TrASF Composite at Different Fiber Loading

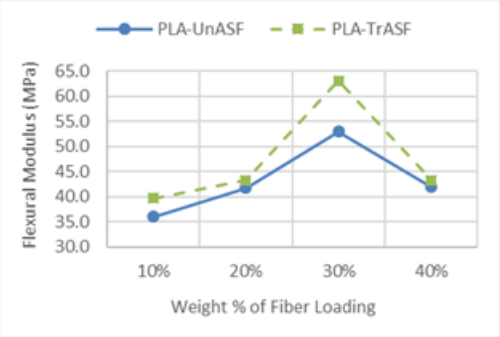


Figure-11: Flexural Modulus of PLA-UnASF and PLA-TrASF Composite at Different Fiber Loading

Izod Impact Strength:

Results have shown that increase in the impact strength with the fiber loading in both PLA-UnASF and PLA-TrASF composites. Also, Figure – 12 shows the Izod Impact strength of PLA-UnASF and PLA-TrASF composites for different fiber loading. It can be noticed from the graph that the PLA-UnASF composite has better impact strength than the PLA-TrASF composite. This is because PLA-TrASF composite turn out to be more brittle than the PLA-UnASF composite.

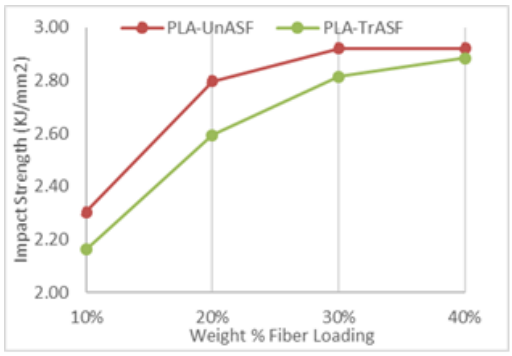


Figure-12: Impact Strength of PLA-UnASF and PLA-TrASF Composite at Different Fiber Loading

Hardness:

The Shore -D hardness tests have been conducted on test specimens of both PLA-UnASF and PLA-TrASF composite at varying fiber loading percentage. From Figure – 13 it can be noticed that hardness has increased with increase in fiber loading. Experiments were repeated for three times; the measurements have been reported has been averaged.

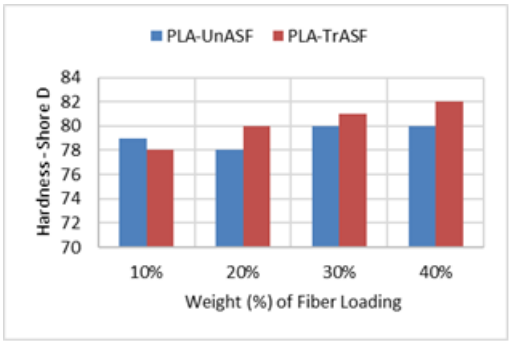


Figure-13: Hardness of PLA-UnASF and PLA-TrASF Composite at Different Fiber Loading

There has been a substantial enhancement in the hardness with increase in fiber loading percentage in both the PLA-UnASF and PLA-TrASF composites, when compared to plain PLA. At 40% of fiber loading both PLA-UnASF and PLA-TrASF composites exhibited increase in hardness when compared to plain PLA which has been 77 Shore-D.

D. Electrical:

Dielectric Strength:

Figure – 14 express the dielectric strength of PLA-UnASF and PLA-TrASF composites at different fiber loading. From the experiments, it can be observed that dielectric strength of both PLA-UnASF and PLA-TrASF composite have much higher than the of plain PLA. Additionally, it can be noticed that there has been increase in the dielectric strength of composites with increase in fiber loading. The maximum dielectric strength of PLA-UnASF composite noticed 3.99 KV/mm at 30% of fiber loading and PLA-TrASF composite has 3.92 KV/mm at 40% of fiber loading when compared with plain PLA which has 1.88 KV/mm.

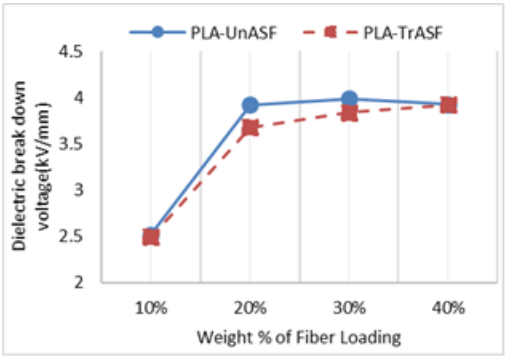


Figure-14: Dielectric Strength of PLA-UnASF and PLA-TrASF at Different Fiber Loading

E. Thermal:

Thermogravimetric Analysis (TGA):

TGA curves of PLA-ASF composites with different fiber loading are shown in Figure-15. In all cases the obtained TGA curves represents a decomposition in one-stage and thus represents the thermal stability limit of the composite. From Figure-15 for all the PLA-ASF composites thermal degradation starts between 350 to 380 ºC range. From this it can be determined that the PLA-ASF composites have lower thermal stability than plain PLA which starts to degrade in around 380 ºC. TGA curves of PLA-ASF composites with different fiber loading are shown in Figure-15.

Table-1: T_g, T_c and T_m for PLA-ASF at Different Fiber Loading

Composites	Glass Transition Temp. (T_g)	Crystallinity Temp. (T_c)	Melting Temp. (T_m)
Plain PLA	63	93	176
PLA-ASF10%	57	86	173
PLA-ASF20%	63	90	175
PLA-ASF30%	64	88	173
PLA-ASF40%	63	90	174

In all cases the obtained TGA curves represents a decomposition in one-stage and thus represents the thermal stability limit of the composite. From Figure-15 for all the PLA-ASF composites thermal degradation starts between 350 to 380 ºC range. From this it can be determined that the PLA-ASF composites have lower thermal stability than plain PLA which starts to degrade in around 380 ºC.

For the analysis, degradation has been considered at 10% mass loss of the areca fiber. At 10% mass loss, the temperature for the PLA-ASF10%, PLA-ASF20%, PLA-ASF30% and PLA-ASF40% are 347°C, 345°C, 335°C and 310°C respectively, whereas 354°C for plain PLA noticed. Thus, it can be observed that the fiber reinforced composites have insignificantly lesser thermal stability than the plain PLA. Start of earlier degradation indicate the bonding between the fiber-matrix in the composite.

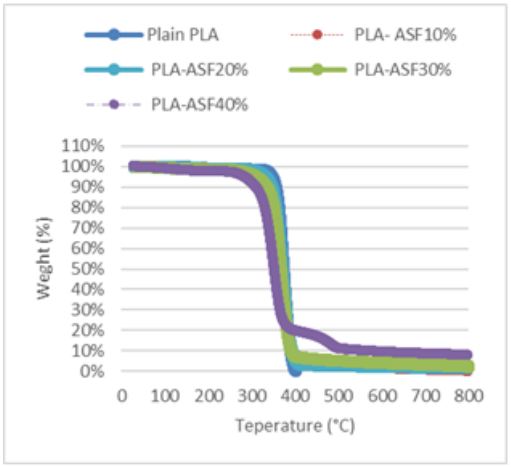


Figure-15 TGA curve of PLA-ASF at Different Fiber Loading

Differential Scanning Calorimetry (DSC):

DSC has been utilized to categorize glass transition temperature and melting temperature, also to compute the measure of energy discharged or absorbed by the plain PLA granules and PLA-ASF composites when these are heated. Figure-16 presents DSC plot for plain PLA and PLA-ASF composites taken up to 260°C for endothermic (heating) and exothermic (cooling) cycles. The glass transition temperature (Tg) of plain PLA and PLA-ASF composites noticed at the initial endothermic peak (heat absorbed) at a temperature of 62°C and 56-64°C respectively. The second peak displays the melting temperature (Tm) of plain PLA and PLA-ASF composites at a temperature of 176°C and 172-175°C respectively. Likewise, crystallization temperature (Tc) were observed in plain PLA and PLA-ASF composites at a temperature of 93°C and 86-90°C respectively during exothermic (cooling) peak. It has been seen that glass transition temperature, melting temperatures and crystallization temperature have been decreased negligibly in PLA-ASF composites as listed in Table-1 when compared to plain PLA, which shows reinforcing of ASF in PLA does not impact thermal properties much in PLA-ASF composites.

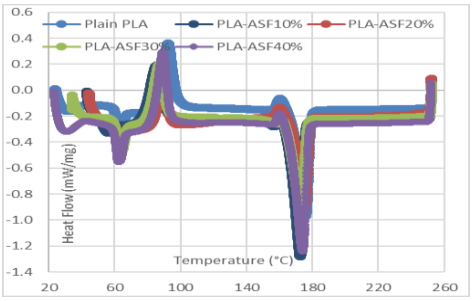
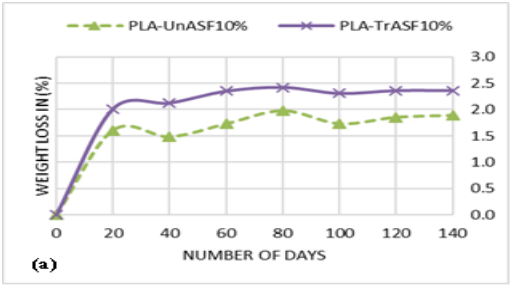


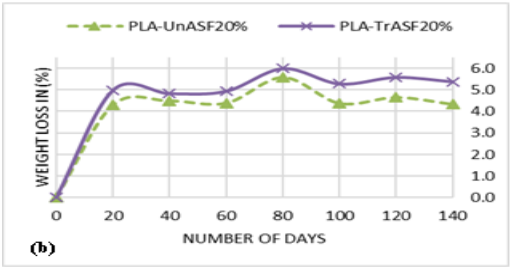
Figure-16: DSC curve of PLA-ASF at Different Fiber Loading

F. Soil Degradation:

Figure-17: Sample Specimens of Composites Immersed in Soil

The test specimens have been prepared with the dimension 15-mm wide and 65-mm long and 3 mm thick. Experimentation has been conducted to observe weight changes in the specimens. Specimens were kept for a period of 4–5 month in soil as shown in the Figure-17. Moisture in soil has been maintained around 25 % throughout the experimentation.





From the Figure-18 (a)-(d) it has been noticed that initially the test specimens show a weight gain with-in 20 days to one month and then start losing weight. Similar cycle pattern of weight gain and loss has been observed for 80 days and beyond, exhibiting biodegradability. During this process, unseen enzymes present in the soil react at the interface between the areca short fiber and PLA, gradually losing weight with the time resulting in biodegradability. Studies have been conducted on the following composites viz., PLA-UnASF and PLA-TrASF with different fiber loading.

In case of PLA composites, PLA-UnASF shown resistance to the degradation than the PLA-TrASF till 20% of fiber loading and thereafter PLA-UnASF has shown more degradation in comparison with the PLA-TrASF. This has been due to both PLA and areca fibers are degradable in nature, thus leading to the higher degradation. Figure-18 (a)-(d) also indicates that the composites absorb moisture existing within the soil in the beginning and therefore there has been increase in their weight for some period.

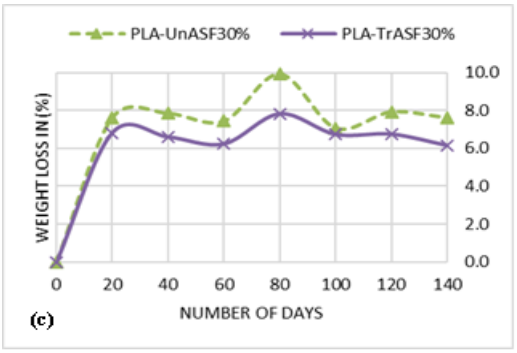


Figure-18: Soil Degradation Test for PLA-UnASF and PLA-TrASF Composite with Different Fiber Loading (a) 10% (b) 20% (c) 30% and (d) 40%

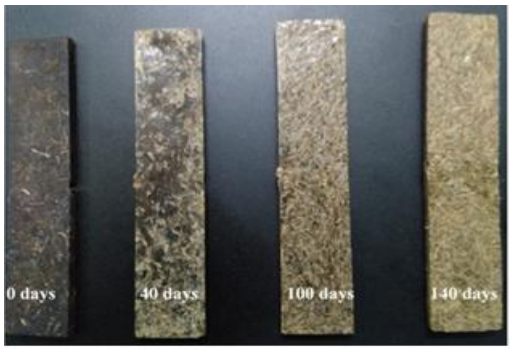


Figure-19: Soil Degradation of PLA-TrASF with 30% areca fiber loading

As shown in the Figure-19, the soil degradation has been from 0 to 140 days of PLA-TrASF at 30% fiber loading, which indicates that it can totally degrade and mix into the soil after 4 to 5 months. Thus, it can be interpreted that soil degradation cannot be discussed in isolation and hence there is a need to take cognizant of the matrix used, percentage of fiber loading, fiber surface treatment and number of days it has been kept under experimentation.

G. Surface Morphology:

The fracture surface morphological study reveals that there has been a sign of fiber pullout producing lots of holes in the PLA in case of PLA-UnASF as shown in Figure – 20 (1). This demonstrates that untreated areca short fiber had inadequate surface wettability and compatibility with the PLA, contributing to deprived interfacial bonding. However, from Figure-20 (2) it appears that in case of PLA-TrASF, the fiber rupture has occurred at the uppermost surface cross section of the PLA. This is a direct result of the significant modification of the areca fiber surface with UV treatment. UV treated areca short fiber appears to have encountered improved bonding between areca fiber and PLA.

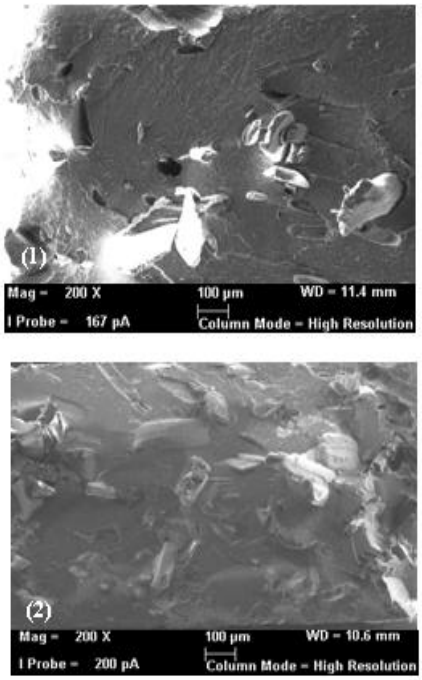


Figure-20: SEM image of PLA- ASF Composite after Tensile Test with (1) Untreated (2) UV treated

Figure-21 shows the tested samples with interface bonding between the PLA-UnASF and PLA-TrASF composites.
From the Figures -21 (1) and 21 (2), it has been detected that the untreated areca short fibers have loosely bonded with PLA and while the UV treated areca short fibers have attached very strongly with PLA. This improvement in the interface bonding may be attributed to the rough surface and etching effect due to UV treatment.

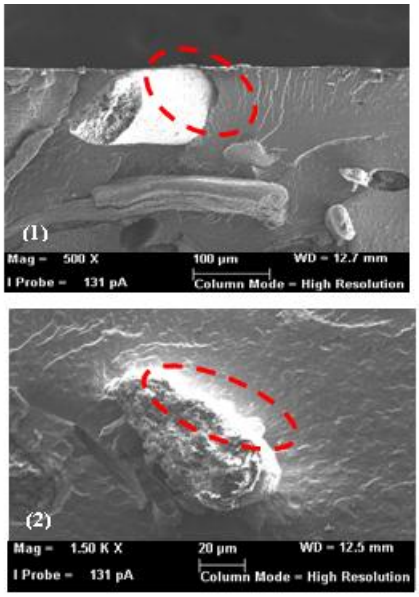


Figure-21: Areca Fiber Bonding with PLA (1) Untreated-Weak (2) UV Treated – Strong Interface Bonding

IV. CONCLUSIONS:

PLA-UnASF and PLA-TrASF composites with different fiber loading (weight percentage) have been adequately created utilizing injection molding technique. Interfacial, physical – density, moisture absorption, mechanical properties i.e., tensile strength and modulus, flexural strength and modulus, izod impact strength, hardness, electrical - dielectric strength, thermal – TGA and DSC and soil degradation were determined experimentally. The following conclusions can be depicted from this examination.

- UV treatment of areca short fibers improved the interfacial bonding strength and the wettability of PLA-ASF composites, which can be evidently observed from SEM images.
- Density and moisture absorption percentage has increased with increase the fiber loading, moisture absorption has been lesser in PLA-TrASF compared to PLA-UnASF.
- Tensile strength and modulus, Flexural strength and modulus and hardness of PLA-TrASFs are superior when compared to PLA-UnASF.
- In case of Izod impact strength, experimental outcomes show that strength has been much higher at all fiber loading percentage in PLA-UnASF composite when compared to PLA-TrASF composites.
- Dielectric strength of both PLA-UnASF and PLA-TrASFs have enhanced with increase in fiber loading. PLA-UnASF and PLA-TrASF composites has been noticed to be near to two times the value of plain PLA.
- With fiber loading thermal stability, glass transition temperature, melting temperature and crystallization temperature resulted insignificantly lesser when compared to plain PLA.
- PLA-UnASF has shown lose bonding between areca short fiber and PLA, while the PLA-TrASF very strong bonding between areca short fiber and PLA.
- PLA-TrASF composites shown better strengths compared to plain PLA. Thus, these composites have significant applications in the areas of fast moving consumer goods and house hold equipment due to their inexpensive and biodegradable nature.

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AUTHORS PROFILE

Raghuveer H. Desai was born on May 15, 1980. He received Masters of Technology from VTU, Belagavi, India in 2005, in the stream of Product Design and Manufacturing (PDM) and holding 2nd Rank to the University. Presently Pursuing his Doctor of Philosophy (PhD). He is having 14+ years of experience from different multinational industries having exposer to aerospace, automobile and hydraulic systems. He has 5 patents and several international papers which includes IEEE publication.

Dr.L.Krishnamurthy is Professor in the Department of Mechanical Engineering. He has received his Ph.D. from Kuvempu University, M.Tech from IIT-Kharagpur and B.E. from University of Mysore. His teaching and research interests are in the field of Manufacturing Engg, Composite Materials, Nano–Technology & Automation. He has 30+ years of Teaching and Training experience. He has 60+ National and International paper publications in his name and attended several conformances across the globe. Co-authored a book titled "Engineering Metrology and Measurements" with Dr, N.V. Raghavendra, published by Oxford University Press.

Dr.T N Shridhar is Professor in the Department of Mechanical Engineering and Controller of Examinations. He has received his Ph.D. & M.Tech from IIT, Madras and B.E. from University of Mysore. His teaching and research interests are in the field of Thermal Engg, Energy,Turbo machines, CFD. He has 30 years of Teaching and Training experience. He has 20+ National and International paper publications in his name and attended several conformances across the globe. He is life member of ISHRAE and ISTE. At present 6+ candidates are pursuing MSc / PhD under his guidance