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Effectiveness of Areca (Betel) Fiber as a Reinforcing Material in Eco-friendly Composites: A Review

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ABSTRACT

This review paper is collective information about the research done until date on areca fiber chemical composition, characterization, and physical properties. Further, it states the significance of the areca fibers as a reinforcing material in biodegradable composites. Several studies have shown underutilization of these areca fibers as a reinforcing material in composite research and its relevant application in product development. In the recent past, it has been noticed that not much appreciable research been carried out on the optimized surface treatment, manufacturing techniques, and product application using the areca fibers. Hence, there are more opportunities to develop economical and ecologically superior engineered material by utilizing these areca fibers and its composites.

Key words: *Areca fiber, Surface treatment, Mechanical properties, Composite processing.*

1. INTRODUCTION

With growing environmental awareness, new rules and legislations scientists and engineers are forced to seek new materials which are more eco-friendly in nature. Hence, the attention of the research community is focused toward finding an eco-friendly material which can give high performance at affordable costs. The keywords with which the eco-friendly materials focused are "biodegradable," "recyclable," "renewable" and "sustainable" [1-4]. Natural fiber composites are one such kind of materials. The usage of natural fibers in the composites is well-known, because of its inherited qualities such as lignocelluloses, renewable, and biodegradability [5]. There are other several reasons that favor the use of natural fibers instead of any other artificial or synthetic fibers. They are lightweight materials having superior strength, competitive specific mechanical properties, high specific modulus, and reduced energy consumption. Further, they are non-toxic and nonhazardous in nature, naturally recyclable, available in abundance, flexible in usage, less expensive and that allow clean energy recovery, etc. [6-8].

These natural fibers are essentially composed of cellulose, hemicellulose, lignin, pectin, wax, and ash. The compositions basically depend on the geographic origin, agricultural condition, fiber extraction, and processing technique [3].

Studies on the most of the natural fibers such as cotton, coir, sisal, jute, banana, flex, maize, and areca, to list few, have been carried out. The main limitations of these natural fibers are hydrophilicity - Most of these are hydrophilic (exhibit high moisture absorption) in nature because of hydroxyl and other polar groups in their constituents. Because of this, these natural fibers have limited applications. Thermal stability - It is limited in natural fiber usually processing temperature restricted from 180°C to 230°C and under extreme environment will bother these fibers very easily [9].

To develop a composite material made from natural fibers with significantly improved strength, stiffness, durability, and reliability, it is important to have better fiber-matrix interfacial bonding. This can be achieved by the surface treatment of the fiber and also the manufacturing process technology used to produce the composite. Broad studies on natural fibers such as sisal, jute, pineapple, banana, and oil palm empty fruit bunch fibers with thermoplastic and thermosetting material have been carried out recently [3,4]. Compared to studies on the other natural fiber reinforced composites, though, very less efforts and attention have been made toward the areca fiber and its reinforced composites and literature available is also scarce.

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This paper gives an overview of recent past literatures, covering all aspects of areca (betel fiber husk) fiber; like characteristics, chemical composition, and mechanical properties and also comparing areca fiber with the other known natural fiber. Further, this also includes some of the recent developments made in the area of areca fiber biological, physical, and chemical pretreatments for improving the fiber strength, fiber-matrix adhesion, their morphology and properties.

The fact that these areca fibers, which have very less slenderness ratio (SR), have an opportunity to be used as short fiber/powder form in the preparation of composite. The surface treatment of areca fiber has a lot of research potential, which can be fulfilled by considering the different surface treatments such as physical and mechanical. In addition, an opportunity is there for better processing methods like injection molding and extrusion, for areca fibers composite having suitable thermoplastic to make them more open to industrial applications such as textile, housing construction material, automotive, aerospace, and home appliances.

2. CONTEMPLATION ABOUT ARECA FIBER

2.1. Overview on Areca (Betel Nut) Fiber

The usage of natural fibers as reinforcement in composites is not new; numerous surveys and studies on properties and behavior of natural fiber-reinforced composites have been carried out to a great extent. However not much study on using the areca fiber as a reinforcing material has been done, very few references are available. Areca fiber is being a very high potential perennial crop, abundantly available and also inexpensive among all the natural fiber reinforcing materials. Details about the species, origination, cultivation, and constitution are noted [2]. The husk produces approximately 2.50-2.75 g of areca fiber can be produced from each husk [10]. A some of the authors noted that, areca fiber possesses a very good fiber surface roughness, this will intern help in achieving better interfacial bonding between fiber and matrix, which will lead to high mechanical properties for the composites [11]. In present days, these areca husks being widely used as fuel in the processing of areca nut. The unmanaged green areca husk left in the plantation causes terrible odor and other decay-related problems [12]. Therefore, an extensive planning for the disposal of husk is necessary. Thus, the use of this unmanaged and underutilized husk as reinforcement to structural material has been thought and some amount work has been done.

From areca husk, areca fibers will be extracted, they are generally lignocelluloses, consisting of helically wound cellulose microfibrils in an amorphous matrix of lignin and hemicellulose. A chemical composition plays a significant role is defining the properties fiber and its composites. The primary composition of areca husk is the varying proportions of α-cellulose, hemicellulose, lignin, pectin, wax, and moisture. It is noted here that, areca fibers consists of alpha cellulose 53.20%, hemicellulose 30-64.8%, lignin 7-24.8%, 4.4-4.8% of ash, 11.7% of moisture, and very negligible percentage of the pectin and wax [2,3,7,10,13].

Areca fiber being short in nature and its SR (aspect ratio [AR]) is very less. SR is the ratio of the length of fiber to the diameter of the fiber. This is derived value from the dimensions of the fiber. Fiber length and fiber diameter are among the important parameters to determine the strength of natural fiber. The variation of the length and diameter and the standard for densities are discussed elsewhere [7]. Figure 1 shows SR of all natural fibers. Areca fiber being very short measuring around 30-60 mm in length and 28-90 mm in diameter. Natural fiber with high SR is more favorable as it possesses high tensile strength. In addition, it has a significant effect on the flexibility and rupture behavior of natural fiber [14]. Strength of areca fiber has noted that E = 2.54 ± 0.5GPa, and the elongation at breaking 15±3% [6].

2.2. Compatibility Study of Areca Fiber with Matrix

A compatibility of the areca fiber is a study understanding interfacial bonding between fibers with the matrix. Adhesion/anchoring or bonding between the areca fiber and the matrix is an extremely important factor, which will affect the mechanical properties of its composite. Bonding guarantees the good stress transfer from matrix to fiber. This type of bonding can result from a chemical crosslinking or from physical origin [1]. Like any other natural fiber, areca fiber also has disadvantages in the preparation of the composites like; the compounding difficulty; because of inherently polar and the hydrophilic nature of the fiber and the non-polar characteristics of the matrix will lead non-uniform distribution. This will significantly weaken the properties of the composites. Similarly, restriction in the processing temperature will be another constraint of fiber because the natural fibers will degrade at higher processing temperature; this internally restricts the selection of the matrix material, i.e., restricted to 180-230°C.

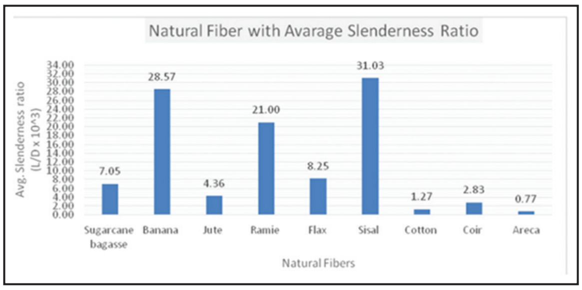

Figure 1: Slenderness ratio of natural and areca fiber [2,3].

Wettability of the fiber plays an important role in deciding the compatibility of the fiber with matrix. The wettability of the fiber mainly depends on the viscosity of the matrix and surface tension of the both the materials. It should be noticed that surface tension of the fiber should always more than the matrix. Low microbial resistance and susceptibility to rotting will be other constraints to the successful utilization of natural fibers for long lasting composites application. These properties create severe difficulty during storage, shipping, and composite processing. Apart from, the above mentioned serious problem, the nonuniformity, variation of dimensions and of their mechanical properties will also lead to other problems in developing the composites. The presence of a natural waxy substance on the fiber surface and hydroxyl groups lead to ineffective fiber-matrix bonding and poor surface wetting [15].

Literature study reveals that the advantages of the areca fiber and natural fiber are more when compared with disadvantages. The deficiency has a corrective measure in terms of surface treatment. To get the desired the properties, surface modification of the areca fiber surface plays a key role.

2.3. Fiber Surface Treatment - An Interface Energizer

It is been very well-understood and established by many researchers that the mechanical, thermal and acoustical performances of the composites depend not only on the properties of the principle components but also on the nature and strength of the interface. The interface plays a significant role necessitating a study on modification of the fiber surface.

Surface treatment/modification will help to get optimized properties of the natural fiber; hence, the surface treatment of the fibers is essential. In general, the surface treatment/modification of natural fibers will not only enhance the bonding between the fiber and matrix but also improve many specific aspects such as reducing the moisture absorption sensitivity and providing better and greater adhesion. The similar polarity between the two materials will add/improve adhesion strength between the matrix and natural fiber. Hence, the surface modification/treatment will be major criteria to enhance the properties of the fiber [2,16,17]. Different surface modification processes are involved, majorly four are extensively and exhaustively used to improve the properties; chemical, physical, physical - chemical, and mechanical. The above-mentioned treatments are helpful in improving the adhesion property between the fiber and the matrix, by improving the surface roughness on the fiber, which will lead to the significant increase in the strength or other properties of composites. An additional information on different surface treatment/modification of natural fibers may be referred in many references [3,9,16,18].

Many researchers have analyzed that the chemical modification of the natural fibers optimizes the interface locking between the fiber and the matrix and improving the other properties. During this process, hydroxyl groups which are on the natural fibers were activated or some new functional groups will be introduced, which will create effective interlock bonding with the matrix. It is very difficult to have a particular mechanism theory of bonding by chemical treatment in composites and to achieve it is very much complex in nature. In general, chemical modification/treatment or coupling agent will process two functions. The first most function is to react with the hydroxyl group of the fiber cellulose and the second to react with functional groups of the matrix. Several mechanisms of coupling in material were outlined by Bledzki and Gassan. Chemical treatments used as surface treatments are such as alkaline, acetylation, permanganate, acetic anhydride, stearic acid, silane, maleic anhydride, and benzoylation have been studied by many researchers [19].

2.4. Present Methodology Used on Areca Fiber: Preparation of Fiber

From the recent past, it has been noted that alkaline treatment is considered to be most widely used the treatment on the areca fibers to improve its adhesion and other properties. A non-chemical treatment like biosoftening is also used for the treatment both been discussed in this paper.

2.4.1. Alkali treatment

Areca fibers are amenable to chemical modifications due to the presence of hydroxyl groups. One of the methods used commonly to treat the areca fiber is alkaline treatment method. Alkaline treatment or mercerization is used to modify the hydrogen bonding in the network structure, by increasing the surface roughness of the fiber exposing the microfibrils resulting in better mechanical interlocking. This is because increasing the number of possible reaction area by increasing more exposed cellulose fiber surface. Alkali treatment leads to the increase in the amount of amorphous cellulose at the expense of crystalline cellulose. With these cellulose microfibrils are modified, this results in morphology changes and increase in the number of reactive hydroxyl groups. This treatment removes (like bleaching) some of the components, like lignin, wax, oils and artificial impurities, which are covering the external surface of the cell walls [15,20]. The changes with this treatment improve the fiber surface tension, adhesion, wetting ability, swelling, and compatibility with materials. This process is mainly used for the treatment of the natural fibers when these fibers are used as reinforcement for thermoplastic and thermoset composite. The following reaction may take place as a result of alkali treatment.

$$\text{Fiber-OH+ROH} \rightarrow \text{Fiber–O}^{-}\text{R}^{+}\text{+H}_2\text{O} \quad \text{(i)}$$

The type of the alkali, i.e., R in the above equation can be Na, K, and Li. Its concentration will also influence the degree of swelling [18,21].

The strength of the areca fiber after the treatment favorably increases because of the crystalline cellulose dissolves and lignin increase in the areca fiber. Once the areca fiber is soaked into the chemical treatment bath the material considerably shrinks during the drying. Figure 2 shows the scanning electron microscope images of the surface of untreated and treated areca fiber [12-18,22-24].

Some researchers have even considered the hybrid fiber composition, i.e., areca fiber with varying percentage of maize, jute, *Sansevieria cylindrical*, kenaf, etc., with varying in chemical percentage and soaking time. Few of them have mentioned about the soaking of fibers in detergent before the surface treatment and then washed with acids and running/deionized water after the treatment. These are room temperature dried or oven dried for 2 h ~ for a day. It has been observed from the studies that the lesser the percentage of the chemical concentration, requires more soaking time to improve the strength.

Biosoftening; a study on the biosoftening areca fiber treatment has been carried out; it is physiochemical treatment, used to modify the surface of the natural fiber to get the better interfacial bonding between the natural fiber and the matrix. Biosoftening is process in which the bio-polishing effect of the natural fiber is achieved with the use of specific micro-organisms, with chosen enzyme particularly toward surface cell wall components. With the biosoftening, the following characteristics like softening, thinning, and bleaching of the fiber can be achieved. This process carried out without using the caustic chemicals, thus it will minimize pollution. Biosoftening process has been explained in detail by researchers. In this lignin which imparts, the brittleness to the areca fiber has been removed from the surface partially. With this removal, the components of the fibers like cellulose and hemicellulose to become more compact, thus resulting increase in strength and flexibility of the areca fiber. Thus, quality after biosoftening did not get worse [16].

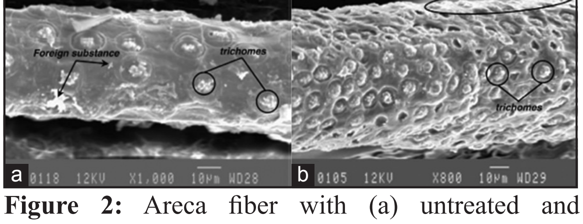

Figure 2: Areca fiber with (a) untreated and (b) treated [24].

2.5. Processing Facet of Areca Fiber Composite

The most important factors that need to be considered during the development of the areca fiber composite includes; proper fiber selection and extraction method, suitable surface treatment for the fiber, selection of the appropriate matrix, proper mixing process and low cost but high-speed technique. While processing natural fiber composite some of the major advantages are noted, those are availability of the reinforcement in a suitable form, less abrasiveness on the tools unlike other synthetic fibers, less the respiratory problems to the workers, because of its nonexistence of airborne particles. In earlier studies, it has been noticed that there are three processing methods, which includes first one in which composite sheets were made using compression molding, i.e., dry processing; second process in composite sheets were made using sheet molding, i.e., wet processing. The third one is composite sheet is made out of powder infusion, i.e., powder impregnation. The volume fraction and the configuration are the two significant factors that affect the properties of composites. The areca fiber composites were prepared with randomly distributed orientation; hand layup layer by layer, unidirectional, etc., orientation of fibers, studies and characterization has been carried out by many researchers [11,20,23-26]. In general, press molding technique has been preferred by most of the areca fiber composite material. Few are listed below.

2.5.1. Hydraulic pressing

This process is used for shaping fiber reinforced polymer matrix. The material is usually a woven mat or hand lay, mixed with polymer matrix. Hot/cold mold is used, polymer matrix melt and spread through the reinforcement.

2.5.2. Hot press

Considering the fiber (treated/untreated), thoroughly mixed with particular polymer matrix, i.e. phenol formaldehyde, urea formaldehydes, polypropylene and shellac waste (small % hardener) and natural rubber for the particular time and temperature, followed by hydraulic pressing at specific higher temperature, some researchers have even considered room temperature and 2-20 MPa pressure for specific duration. After that, it was post cured at room temperature or elevated temperature for few hours [5,8,13,22,27-29].

2.5.3. Cold press

Few researchers have used cold press; in this the low-temperature curing resin and hardener are mixed thoroughly in a recommended ratio. The known weight of the areca fiber is mixed and then the mixture is poured into the definite mold. To take away the air bubbles from the composite mixture layer flat a steel roller was used. This process was repeated until a desired maximum thickness was achieved. This is pressed hydraulically at room temperature, required pressure maintained for minimum time before it is removed from the mold [2,30].

Using these process samples were prepared using ASTM D 638, ASTM DIN 53455, ASTM DIN 53452, ASTM DIN 53453, ASTMD256-90, ASTM D790, ASTM D3039, ASTM D2344, ASTM-D3410, IS: 2380, testing and characterization has been carried out. The properties are listed in the following paragraphs.

2.6. Hand Lay Up Process

Hand lay-up technique is the simplest method of composite processing. Considering the fiber (treated/untreated), the resin like unsaturated polyester/other epoxies and hardener were evenly mixed using an electrical stirrer and poured into a closed defined mold. For easy ejection of the component, thin layer of release agent is sprayed to the inner wall of the mold. Then, the first layer was obtained by pouring the matrix mixed with predefined wt. % hardener into the mold. Over this, a waved sheet of areca fiber mat was placed on the first layer of matrix. To take away the air bubbles from the composite mixture, layer flat a steel roller was used. This process was repeated until a desired maximum thickness was achieved (which may resulting with "x" layers of fiber mats and "x+1" layers of matrix). Then, a thin steel plate of the same size as the mold was placed and required pressure was applied, this will remove all the trapped air bubbles from composite. Composite is cured under the pressure. Some researchers have even post cured the composite at elevated temperature for few hours [6,11,20,23-26]. Using this process, samples were prepared using ASTM D 638, ASTM D790, ASTM D695, and ASTM D3039, and characterization has been carried out.

2.6.1. Vacuum bagging

Plain woven mat is prepared to the required size by weaving equipment. This will be used in the preparation of the composite. This process is also called as vacuum bag laminating; in this process, atmospheric pressure will be used as clamping force to hold the resin coated laminates until it cures [6]. Samples were prepared using ASTM D3822-01, ASTM D790 testing has been carried out.

In this process, areca fiber (treated/untreated) was slowly added into the resin and stirred with hardener. Then, this mixture is poured into the mold and curried in oven for few hours [30]. Using this process, the samples were prepared using ASTM D3039, testing and characterization has been carried out. The properties are listed in the following paragraphs.

2.7. Properties of Areca Fiber Composite

Areca fiber composite properties are mainly depending on the extraction of fiber, surface treatment, and manufacturing processing. Thus, it is so significant to select proper optimized processes for the suitable end application. Stating the importance of these process few of the researchers have studied the properties which are critical for the functionality of the composites like tensile strength, compression strength, static bending/flexural strength, impact strength, hardness, elongation at break, tensile and bending modulus, wear and frictional coefficients, moisture content and absorption and biodegradation [2,5-8,12-15,17,18,20,23,26-30].

3. FUTURE SCOPE

Continuous research is being carried out to have optimized process solution for the areca fiber reinforced composites. There are a number of limitations and disadvantages are noticed in the present followed surface treatment process. Since the areca fiber is soaked into the chemical treatment bath, the material considerably shrinks during the drying. Weight of areca fiber is decreased by 8-13% after the alkali treatment. Further, with the more soaking time, the ratio of the strength decreases due to the degradation of the areca husk. The disadvantage of the areca fiber soaked in chemical is that it becomes highly flexible. Thus, to overcome these issues one can think of using different treatment process like Physical, mechanical, etc. This will help in getting strengthened/improved areca fiber which can be used in composite for different application with significant improvement in properties.

Presently whole areca fiber is used as a reinforcing agent in the preparation of the composite. This will be a limiting factor for the usage of areca fiber in advanced complex molding process like injection molding, extrusion, shot molding, etc. Thus, there is an opportunity to use this areca fiber in powder form which has numerous advantages over the present manufacturing process. Those are low energy consumption, the nonexistence of voids, ease of mixing, non-usage of organic solvents, dispersion of multiphase components, and the possibility of recycling of powders. This method also has some disadvantages, which can be overcome with proper selection of the parameters.

4. CONCLUSION

Many researches are happening to come up with a simple solution for areca fiber composite to produce and commercialize into product. At present, the most of the researchers have used areca fiber as a whole in preparation of composite. Moreover, these areca fibers with other natural fibers are used in the preparation of the hybrid fiber composites. These fibers are treated chemically and used in the different manufacturing process to get the required composite specimen.

Take away from this review paper is that these areca fibers which have very less SR can be extended to use as a short fiber or powder in the preparation of composite. There is a dearth in the surface treatment of areca fiber, which can be full filled by considering the different surface treatments such as physical and mechanical. Moreover, there is an opportunity in using better and stronger processing methods like injection molding, extrusion, etc., for areca fibers composite using suitable thermoplastic as a matrix to make them more open to industrial applications.

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