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# CHEMICAL TREATMENTS OF NATURAL ARECA FIBER FOR USE IN NATURAL FIBER REINFORCED COMPOSITES

**Okoronkwo, G. O. and Madumelu, P. C.**
Department of Chemical Engineering, Chukwuemeka Odumegwu Ojukwu University, Uli, Anambra State.
ogeorgeonyeka@gmail.com

## ABSTRACT

Chemical treatments are considered in modifying the fiber surface properties. In this paper, two different chemical modifications on natural areca fibers for use in natural fiber-reinforced composites are studied. These chemical treatments include alkali and silane treatments. The chemical treatments of this fiber improved the adhesion between the fiber surfaces and the polymer matrix, modify the fiber surfaces and also increased the fiber strengths (255.63N/mm$^2$ for mercerization process at 2wt% 150mins and 255.1N/mm$^2$ for silane coupling at 10wt% 150mins, respectively). The water absorption tendencies of the areca fiber treated at these optimum treatment conditions reduced drastically.

**Keywords:** Fiber-reinforced Composites, Natural Fiber, Chemical Modifications, Surface Treatments.

## 1.0 INTRODUCTION

Processing of plastic composites using natural fibers as reinforcement has increased dramatically in recent years [6, 10, 11, 16 and 20]. Fiber-reinforced composites consist of fiber as reinforcement and a polymer as matrix. Plastic polymers including high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), polyether ether ketone (PEEK), etc. have been reported as the matrices [1]. Traditional fiber-reinforced composites use various types of glass, carbon, aluminum oxide, and many others as reinforcing component. Natural fibers, especially bast (bark) fibers, such as flax, hemp, jute, henequen and many others were applied by some researchers as fiber reinforcement for composites in recent years [13]. Advantages of natural fibers over man-made fibers include low density, low cost, recyclability and biodegradability [9]. These advantages make natural fibers potential replacement for glass fibers in composite materials. Mechanical properties of natural fibers, especially flax, hemp, jute and sisal, are very good and may compete with glass fiber in specific strength and modulus [15, 18]. Natural fiber-reinforced composites can be applied in the plastics, automobile and packaging industries to cut down on material cost [4]. A better understanding of the chemical composition and surface adhesive bonding of natural fiber is necessary for developing natural fiber-reinforced composites. The components of natural fibers include cellulose, hemicellulose, lignin, pectin, waxes and water soluble substances [8, 14]. The composition may differ with the growing condition and test methods even for the same kind of fiber. Cellulose is a semi crystalline polysaccharide made up of Dglucopyranose units linked together by *b*-(1-4)-glucosidic bonds [11]. And the large amount of hydroxyl group in cellulose gives natural fiber hydrophilic properties when used to reinforce hydrophobic matrices; the result is a very poor interface and poor resistance to moisture absorption [19]. Hemicellulose is strongly bound to cellulose fibrils presumably by hydrogen bonds. Hemi cellulosic polymers are branched, fully amorphous and have a significantly lower molecular weight than cellulose. Because of its open structure containing many hydroxyl and acetyl groups, hemicellulose is partly soluble in water and hygroscopic [2]. Lignins are amorphous, highly complex, mainly aromatic, polymers of phenyl propane units [12] but have the least water sorption of the natural fiber components [2]. Because the low interfacial properties between fiber and polymer matrix often reduce their potential as reinforcing agents due to the hydrophilic nature of natural fibers, chemical modifications are considered to optimize the interface of fibers. Chemicals may activate hydroxyl groups or introduce new moieties that can effectively interlock with the matrix. The development of a definitive theory for the mechanism of bonding by chemicals in composites is a complex problem. Generally, chemical coupling agents are molecules possessing two functions. The first function is to react with hydroxyl groups of cellulose and the second is to react with functional groups of the matrix. [3] outlined several mechanisms of coupling in materials, namely: (a) elimination of weak boundary layers; (b) production of a tough and flexible layer; (c) development of a highly cross linked interphase region with a modulus intermediate between that of substrate and of the polymer; (d) improvement of the wetting between polymer and substrate; (e) formation of covalent bonds with both materials; and (f) alteration of acidity of substrate surface. Chemical modifications of natural fibers aimed at improving the adhesion with a polymer matrix were investigated by a number of researchers [21]. However, different chemicals were used and very limited papers [7] took a partial review on the mechanism and utilization of chemical treatments in fiber-reinforced composites.

## 2.0 METHODOLOGY

### *2.1. Extraction* processes

The areca plant stem was collected from the research center and extracted by retting process. Then, tagged untreated areca stem fiber conditioned at temperature of 26$^{O}$C and relative humidity of 65mmHg in the drier prior to its chemical modifications.

### *2.2. Chemical Treatments*

The chemical treatments and its modifications conducted in this work are as depicted below in the following sub-headings:

### *2.2.1. Alkaline Treatment*

In this work, extracted raw areca stem fiber samples were soaked in NaOH solutions at different concentrations and treatments times. Their optimums were determined via response surface methodology approach before subsequent sample treatments were carried-out. The treatment conditions are 2% 10mins, 2% 20mins, 2% 30mins, 4% 10mins, 4% 20mins, 4% 30mins, 6% 10mins, 6% 20mins and 6% 30mins, at room temperature.

### *2.2.2. Silane Treatment*

The mercerized areca stem fiber samples at optimum conditions were soaked in $SiH_4$ solutions at different concentrations and treatments times. Their optimums were determined via response surface methodology approach before intermediate sample treatments were carried-out. The treatment conditions are 2% 10mins, 2% 20mins, 2% 30mins, 4% 10mins, 4% 20mins, 4% 30mins, 6% 10mins, 6% 20mins and 6% 30mins, at room temperature.

## 3.0 RESULTS AND DISCUSSION

Alkaline treatment or mercerization is one of the chemical treatments employed for natural plant stem areca fibers prior to reinforcement of thermosets. The important modification done by alkaline treatment was observed to be the disruption of hydrogen bonding in the network structure, thereby increased surface roughness. It was also observed that this treatment also removes a certain amount of lignin, wax and oils covering the external surface of the fiber cell wall, depolymerizes cellulose and exposes the short length crystallites which agree with [7]. Addition of aqueous sodium hydroxide (NaOH) to the natural fiber promoted the ionization of the hydroxyl group to the alkoxide as depicted in the equation 1:

$$Fiber - OH + NaOH \rightarrow Fiber - O - Na + \ H_2O \qquad (1)$$

Thus, it was observed that alkaline processing directly influences the cellulosic fibril, the degree of polymerization and the extraction of lignin and hemi cellulosic compounds. This is similar to the observation of [5]. In alkaline treatment, it was observed that alkali led to an increase in amorphous cellulose content at the expense of crystalline cellulose. Also, alkaline treatment had two effects on the fiber: (i) it increased surface roughness resulting in better mechanical interlocking; and (ii) it increased the amount of cellulose exposed on the fiber surface, thus increasing the number of possible reaction. This is also similar to the observations of [20]. Consequently, alkaline treatment had a lasting effect on mechanical behaviors of natural areca fibers, especially on fiber strength and stiffness in similar observations to [5].

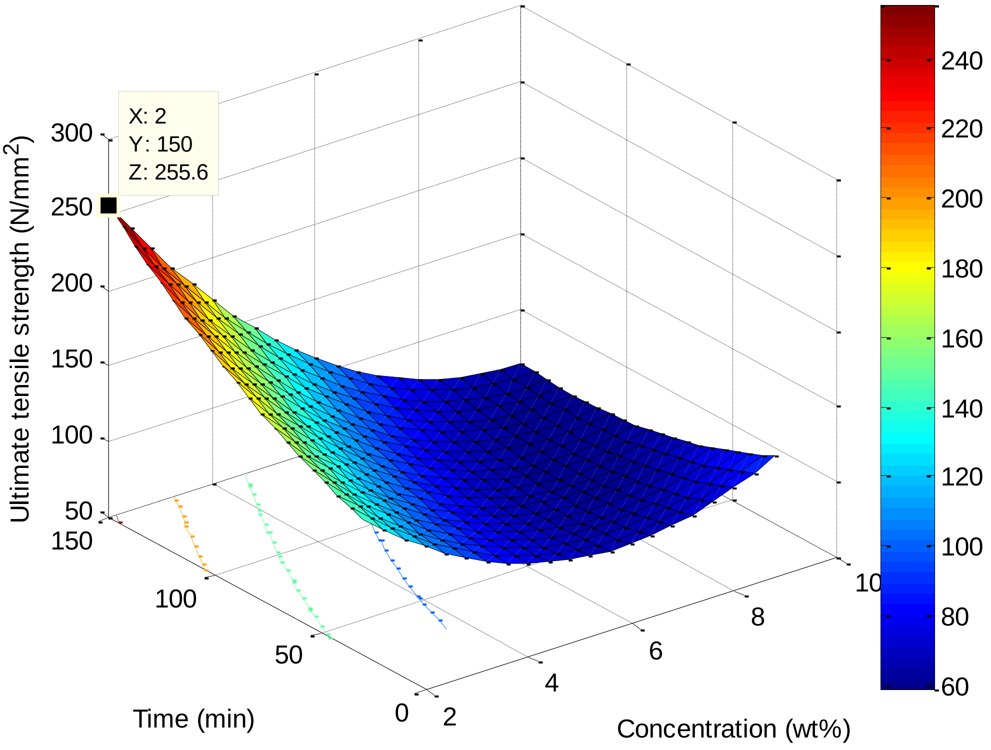

Figure 1: 3D surface plot for surface response methodology analysis of mercerized areca fiber.

### 3.1. Optimization Analysis of the Ultimate Tensile Strength of the mercerized areca plant stems Fiber

```
                    Local minimum found that satisfies the constraints
Optimization completed because the objective function is non-decreasing in feasible directions, to within the
default value of the function tolerance, and constraints were satisfied to within the default value of the
constraint tolerance.
<stopping criteria details>
Active inequalities (to within options.TolCon = 1e-006):
  lower     upper    ineqlin   ineqnonlin
          1         2
x =      2       150
fval =  -255.6250
```

The active-optimum areca fiber tensile strength were obtained to be two hundred and fifty five point six three newton per squared millimeter at one hundred and fifty minutes with two weight percent used prior to the production of reinforced areca composite materials required with its upper range variability's. This is in validation with the surface plot values in figure1.

Silane is a chemical compound with chemical formula $SiH_4$. Silane was used as coupling agent to let areca fibers adhere to a polymer matrix, thereby stabilizing the composite material. It was observed that silane coupling agent reduced the number of cellulose hydroxyl groups in the fiber–matrix interface. In the presence of moisture, hydrolysable alkoxy group leads to the formation of silanols. The silanol then reacted with the hydroxyl group of the areca fiber, forming stable covalent bonds to the cell wall that are chemisorbed onto the fiber surface. This is similar to the observations of [17] . Therefore, the hydrocarbon chains provided by the application of silane restrained the swelling of the fiber by creating a cross linked network due to covalent bonding between the matrix and the fiber. The reaction schemes are as shown in the equations (2) and (3) below:

$$CH_2CHSi(OC_2H_5)_3 \rightarrow CH_2CHSi(OH)_3 + 3C_2H_5OH \qquad (2)$$

$$CH_2CHSi(OH)_3 + Fiber - OH \rightarrow CH_2CHSi(OH)_2O - Fiber + H_2O \qquad (3)$$

Silane coupling agent was also found to be effective in modifying natural fiber–polymer matrix interface and increasing the interfacial strengths. Thermal stability of the composites was also improved after silane treatment, in similar observation to [5].

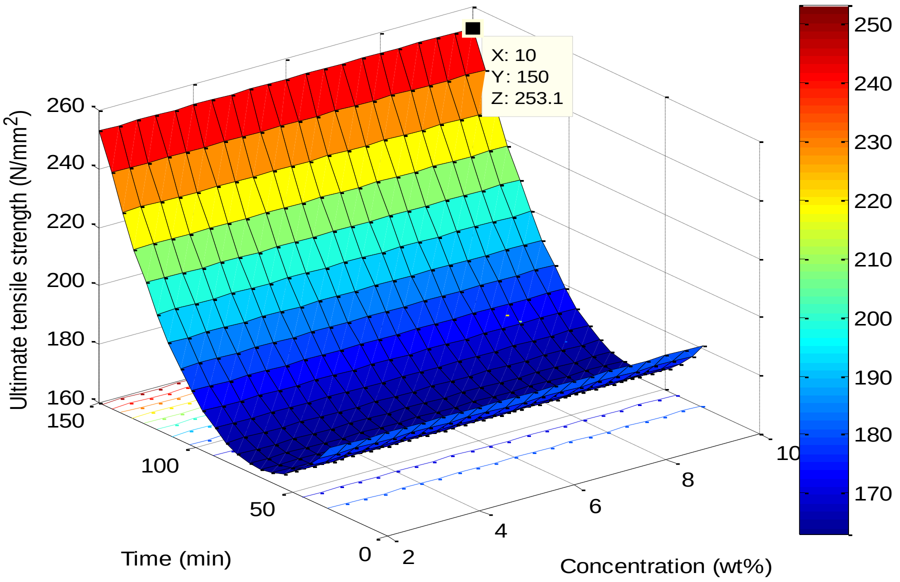

Figure 2: 3D surface plot for surface response methodology analysis of silane treated areca fiber.

## 3.2. Optimization Analysis of the Ultimate Tensile Strength of the silane Treated areca plant stems Fiber

```
                    Local minimum found that satisfies the constraints
Optimization completed because the objective function is non-decreasing in feasible directions, to within the
default value of the function tolerance, and constraints were satisfied to within the default value of the
constraint tolerance.
<stopping criteria details>
Active inequalities (to within options.TolCon = 1e-006):
  lower      upper     ineqlin   ineqnonlin
                2
x =   6   150
fval =  253.1066
```

The active-optimum areca fiber tensile strength were obtained to be two hundred and fifty three point one newton per squared millimeter at one hundred and fifty minutes with six weight percent used prior to the production of reinforced areca composite materials required with its upper range variability's. This is in validation with the surface plot values in figure 2 with small deviations at the fiber optimum concentration.

## CONCLUSION

Natural fibers are considered as potential replacement for man-made fibers in composite materials. Although natural fibers have advantages of being low cost and low density, they are not totally free of problems. A serious problem of natural fibers is their strong polar character which creates incompatibility with most polymer matrices. Mercerization and silane surface treatments, although having a negative impact on economics, were potentially able to overcome this problem of incompatibility. These chemical treatments increased the interface adhesion between the fiber and matrix, and decrease the water absorption of fibers. Therefore, chemical treatments are considered in modifying the properties of natural areca plant stem fibers. Compounds are known to promote adhesion by chemically coupling the adhesive to the material, such as sodium hydroxide and silane. Fiber modification methods discussed in this paper had different efficacies in causing adhesion between the matrix and the fiber. Sodium hydroxide and silane chemical treatments had achieved various levels of success in improving fiber strengths to $255.56 N/mm^2$ and $253.1 N/mm^2$ with the above conditions of treatments, in natural areca fiber reinforced composites.

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