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The effects of fiber volume fractions and composite curing times on impact and hardness properties of areca fiber reinforced epoxy composites

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Abstract: *The aim of the work was to study the effects of fiber volume fractions and composite curing times on impact and hardness properties of areca fiber reinforced epoxy composites. In present study, impact and hardness properties for areca fiber reinforced epoxy composites were evaluated. Here, areca fiber is used as new natural fiber reinforcement and epoxy resin as matrix. The extracted areca fibers from areca husk were chemically treated to get better interfacial bonding between fiber and matrix. Composite were prepared with randomly orientated fibers with different proportions of fibers and matrix ratio. Impact and hardness tests were performed and the results are reported. The results showed that, as the fiber volume fraction and composite post curing time increases the impact and hardness properties of the composite increases.*

***KEYWORDS*:** *Fiber volume fraction, composite curing time, Areca Fibers, Impact and hardness Properties, Epoxy resin.*

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1. INTRODUCTION

For the past several years, public attention has gone on natural fibers as a resource due to the fast growth (Okoronkwo et al. 2019). Nowadays, natural fibres are widely used as reinforcements both in partially and totally biodegradable Natural fiber Composites (Okoronkwo et al. 2021). Natural fibers are an alternative resource to synthetic fibres as reinforcement for polymeric materials for the manufacture of cheap, renewable and environmentally friendly composites (Okoronkwo et al. 2022). Waste plastic has caused unbearable stress to environment in recent years. Environmental awareness, new rules and legislations are forcing industries to seek new materials which are more environmentally friendly (Ezeokpube et al. 2021). Plant fibers from agricultural crops are renewable materials which have potential for creating green products and replacing synthetic materials which are currently being used such as glass fiber, carbon fiber and plastic fibers (Okoronkwo et al. 2019).

The demand for low-energy consumption processes and low environmental impact have furthered the development of natural fiber-reinforced composites (NFRCs) in various industries. Natural fibers exhibit numerous benefits compared to synthetic fibers, such as biodegradability, lightweight, cheap, low density, acoustic insulation, and improved life-cycle performance characteristics ((Sałasi ´ nska et al. 2022), (Ismail et al. 2022), (Boey et al. 2022), (Kumar et al. 2022), (Okoronkwo et al. 2021) and (Zhang et al. 2022)). The selection of materials and design plays an important role in engineering design. The materials should possess excellent physical, thermal, and mechanical properties to make better products and fulfil customer demand. The emergence of new technologies, population growth, industrialization, and housing shortages has led to the growth of construction and automotive industries worldwide (Cordon et al. 2019). There is a need for alternative building materials due to the unsustainability of modern construction materials. Using natural resources to create biodegradable composite materials is one such step toward protecting the environment. Composites manufactured from natural fibers as reinforcements are an alternative in this direction (Sałasi ´ nska et al. 2022).

Matrix material is required in fabricating NFRCs to bind natural fibers and fillers to form a structure (Vemuganti et al. 2020). Epoxy has been widely used as a matrix material in NFRCs due to its excellent abrasion properties, good electrical insulating quality, resistance to moisture and chemical attacks, high mechanical strength, and appreciable resilience((Naik et al. 2022), (Oladele et al. 2020), and (Gieparda et al. 2021)). Epoxy can be cured without using a curing agent or heating at room temperature without pressure (Prasad et al. 2022). (Naik et al. 2022) was the first to discover epoxy resins. However, the first commercial production of epoxy resin began in the late 1940s. Epoxy adhesives became commercially available in the early 1950s, and continuous innovations have been made in various applications. In 1953, the Shell Chemical Corporation initiated field tests to evaluate epoxy systems as surfacing materials on highways ((Naik et al. 2021), (Jagadeesh et al. 2021)). Additionally, in 1953, the first application of epoxy seal coating as test patches in industrial plants was made. Later, in 1957, epoxy polymer concrete was used as the first wearing course to repair popouts and spalled areas on the surfaces of bridge decks in California (Naik et al. 2022). Nowadays, epoxy resins are used as a polymer with natural fiber reinforcements in countless construction applications and automobile sectors, such as thin-layer non-skid surfacing for roads and bridges, aerospace industries, and housing ((Naik et al. 2021), (Oladele et al. 2020) and (Jagadeesh et al. 2021)).

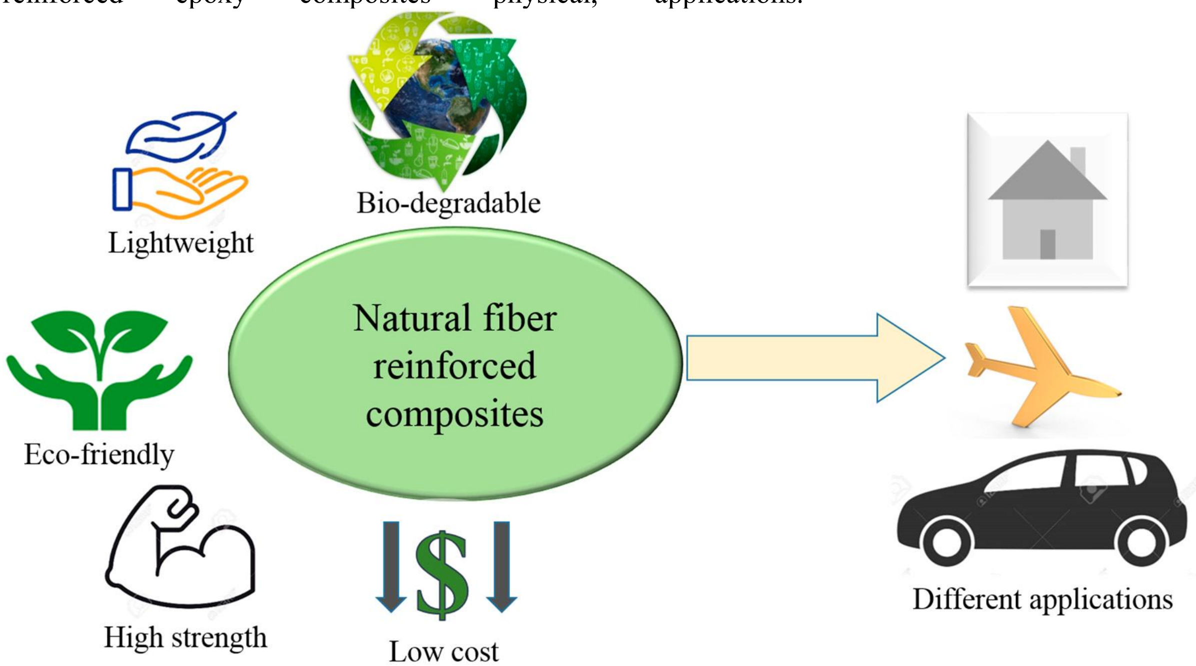
Several researchers are working on toughening/strengthening agents to enhance the properties of epoxy resin in structural and automotive applications ((Wang et al. 2020), (Farooq et al. 2020) and (Prasad et al. 2022)). Incorporating nano-silica, thermoplastic components, inorganics, carbon fibers, graphene, clay, and carbon nanotubes improves the toughness of epoxy resin (Sun et al. 2019). The common physical and mechanical properties of epoxy resin are shown in Table 1 ((Ramon et al. 2018), (Ibrahim et al. 2016), (Kumar et al. 2021), (Mittal et al. 2016) and (Zhang et al. 2022)). The epoxy matrix is composed of resin and hardener, which are usually mixed in a ratio of 10:1. The epoxy resin has a wide range of applications including uses for coatings, aerospace industries, composites, the bio-medical field, and electronics material. Figure 1a shows the properties of NFRCs and their applications. Figure 1b shows various steps involved during NFRCs fabrication.

Table 1. Physical and mechanical properties of epoxy resins **[17–20]**.

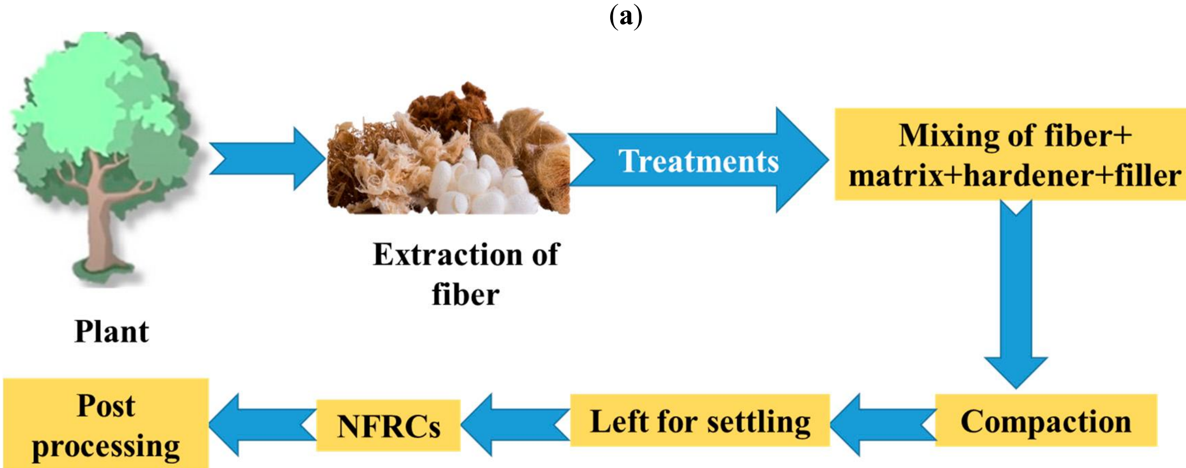
Appearance	**Colourless to Pale Yellow Liquid**
Flexural strength (MPa)	40 – 67
Specific gravity (kg/m^3)	1120 – 1210
Viscosity at 25^{o}C (kg/m s)	0.25 – 0.75
Heat distortion temperature (^{o}C)	50
Solid content (%)	84
Modulus of elasticity (MPa)	3100 to 3800

Tensile strength (MPa)	90 to 120
Max percentage elongation (%)	4
Impact strength (kg/m^2)	9
Glass transition temperatures	150 to 220°C

Few reviews are available on construction materials with synthetic and natural fiber. Still, no review covers the physical, mechanical, and thermal properties of the NFRCs used in different applications such as automotive and construction. This review paper focuses on natural fiber-reinforced epoxy composites' physical, mechanical, and thermal characteristics. Moreover, the various chemical and physical treatments and their effects on the physical, mechanical, and thermal behaviour of the NFRCs are presented. These properties are critical for the effective design and use of composite materials in construction and automotive construction applications.



(a)



(b)

Fig.1. (a) NFRCs characteristics in construction and automotive applications. (b) Steps involved in NFRCs fabrication.

Because of their environmental benefits, natural fibers are increasingly being used in various engineering applications such as automotive, infrastructure, aerospace and packaging. Compared to glass fiber and carbon fiber composites, less research has been carried out on their reuse and recycling. Alamri and Low (Kumar et al. 2022) used different fiber loadings of 19, 28, 40, and 46 wt.% to make recycled cellulose fiber (RCF)-reinforced epoxy composites. The results revealed that flexural strength, flexural modulus, fracture toughness, and impact strength increased when the fiber content rose. With 46 wt.% fiber, the maximum mechanical characteristics were obtained. Water absorption influence on the mechanical and physical characteristics of RCF/epoxy composites has also been studied. The maximum water absorption and diffusion coefficient increased as the fiber content increased. As moisture absorption increased, the flexural strength, flexural modulus, and fracture toughness decreased. However, with water absorption, the impact strength was observed to rise somewhat ((Kumar et al. 2022) and (Prasad et al. 2019)). Using paper sheets made from recycled cardboard boxes, Soya oil-based resin and cellulose fibers were successfully used to manufacture the composite structures. Epoxy composites made from recycled aggregate generally have two-fold benefits: first, wastage is reduced; second, a high-strength composite can be obtained from these wastes.

Bio-composites made from epoxy polymer and natural fibers have a great scope of research for engineering applications such as structural applications. Researchers have continued working with natural fiber and epoxy polymer-based bio-composites over the last decade. The problem with natural fibers is that they cannot be used as reinforcement material due to lignin hydrophobicity (Beluns et al. 2022) and some impurities. However, the alkali treated fibers can be used as the alkali treatment of fiber removes such impurities (Sinha et al. 2017). Therefore, the researchers focused on alkali-treated natural fibers to control synthetic fibers, and non-biodegradable waste, to produce epoxy-based bio-composites. Natural fiber composites possess environmental benefits as they are biodegradable. Natural fibers have many advantages: high strength, light weight, water resistance, corrosion resistance, high durability, electrical resistance, fire resistance, good thermal and acoustic insulating properties, and chemical resistance. As natural fiber composites are environmentally friendly, they regain attention over the synthetic fiber. The first used natural fiber composite was straw-reinforced clay for bricks and pottery ((Ibrahim et al. 2016), (Maharana et al. 2020) and (Prasad et al. 2020)). NFRCs are either a combination of natural fiber and synthetic resin or natural fibers and bio-resin. Bio-resins refer to resin biodegradability; bio-resins and synthetic resins are in the form of thermoplastic or thermoset resin. Thermoset resin is the most used resin for the structural applications of natural fiber composites. NFRCs are used in aerospace industries ((Asim et al. 2018), (Mansor et al. 2019)) and automobile industries (Chaudhary et al. 2018). These composites have also been used in biomedical applications such as tissue and bone repair (Reddy et al. 2022).

Common natural fibers are hemp, jute, nettle, coir, agave, sugar palm (Gomuti), sisal, flax, ramie, and cotton. These fiber composites are gaining importance due to their strength, corrosion resistance, biodegradability, and many more advantages in engineering applications such as automobile, aerospace, structural components, and construction. However, some disadvantages are associated with NFRCs, such as moisture absorption and processing temperature. Due to their unique features, such as low density and a cellular structure, natural fibers provide great acoustic and thermal insulation (Chaudhary et al. 2018). However, some of these disadvantages can be improved with fiber treatments before composite fabrication. The fiber orientation and length improve the natural fiber composites' mechanical and physical properties ((Vemuganti et al. 2020), (Vemuganti et al. 2020)). NFRCs are composites whose mechanical efficiency is determined by the fiber–matrix interface and the stress transfer function, which transfers stress from the matrix to the fiber. Many investigators in several research papers have reported this ((Prasad et al. 2020), (Nath et al. 2019) (Xu et al. 2016), (Silva et al. 2017), (Krishnudu et al. 2018), (Balakrishnan et al. 2019), (Cisneros-López et al. 2016), (Khan et al. 2018), (Zhang et al. 2018), and (Ighalo et al. 2020)) [26,33–42]. In order to develop composite made from natural fibers with enhanced strength, stiffness, durability and reliability, it is necessary to study the mechanical behaviour of natural fiber composites. The mechanical properties of a natural fiberreinforced composite depend on many parameters, such as fiber strength, modulus, fiber length, orientation, and fiber-matrix interfacial bond strength. A strong fiber-matrix interface bond is critical for high mechanical properties of composites. A good interfacial bond is required for effective stress transfer from the matrix to the fiber whereby maximum utilization of the fiber strength in the composite can be achieved. Most research reviewed indicated the effect of alkali treatment in improving fiber strength, fibermatrix adhesion and the performance of the natural fiber composites. The present work emphasis on the effect of alkali treatment on mechanical behaviour of areca fibers reinforced epoxy composites. Finally, the effects of fiber volume fraction and composite curing time on mechanical properties of areca fibers reinforced epoxy composites are studied.

III. MATERIALS AND METHODS

A. Materials

The Epoxy-556 resin and the hardener (HY951) are supplied by Nucil CCRD Nigeria Ltd. Areca empty fruit bunch Fibers (husk) were obtained from local farm in Owerri, Imo State, Nigeria.

B. Methods

a. Fiber extraction

Selected areca fruit husks were used to prepare the composites. Dried areca husk was soaked in deionised water for about five days. The soaking process loosens the fibers and can be extracted out easily. Finally, the fibers were washed again with deionised water and dried at room temperature for about 15 days. The dried fibres are designated as untreated fibres.

b. Alkali treatment

First, the areca fibers were treated in a solution of 10% KOH (Potassium Hydroxide) where the total volume of solution. The fibers were kept in this alkaline solution for 36 hours at a temperature of 30° C; it was then thoroughly washed in running water then neutralized with a 2% acetic acid solution. Lastly, it was again washed in running water to remove the last traces of acid sticking to it, so that the pH of the fibers is approximately 7 (neutral). Then, they were dried at room temperature for 48 hrs to get alkali treated fibers.

c. Preparation of composites

Fiber configuration and volume fraction are two important factors that affect the properties of the composite. In this work, the randomly distributed fibers are reinforced with epoxy resin in two different weight proportions (50 wt. %, and 60 wt. %) to prepare the composites. First, the mould is polished and then a mould-releasing agent (Polyvinyl alcohol) applied on the surface is used to facilitate easy removal of the composite from the mold after curing. The low temperature curing epoxy resin LY556 and corresponding hardener (HY951) are mixed in a ratio of 10:1 by weight as recommended. The mixing is done thoroughly before the mixture filled into the mould of 300 x 300 x 50 mm size and pressed in a hydraulic press at the room temperature and a pressure of 0.5MPa for 30 minutes is applied before it is removed from the mould. Then, this cast is post-cured in the laboratory at standard atmosphere for different hours to study the effect of post curing time on mechanical properties.

d. Characterization

The prepared composite boards were post cured for 15(360 hours), 30(720 hours) and 45(1080 hours) days at standard laboratory atmosphere prior to preparing specimens and performing mechanical tests. The appropriate ASTM standards were followed while preparing the specimens for test. At least five replicate specimens were tested and the results were presented as an average of tested specimens. The tests were conducted at a laboratory atmosphere of 27oC and 46% relative humidity. Impact tests on specimens were performed by using both Charpy and Izod methods as per ASTM D 256. According to ASTM D 785 standard for composites, the specimens were prepared for Rockwell-B hardness test. The specimen size is of 25mm diameter and a length of 20mm. The hardness properties of the composites along and across the fibers are carried out.

III. RESULTS AND DISCUSSION

The investigation of mechanical properties of composites is one of the most important techniques in studying the behaviour of composite materials. Mechanical properties of fiber-reinforced composites depend on the nature of matrix material and the distribution and orientation of the reinforcing fibers, the nature of the fiber-matrix interfaces and of the interphase region. Even a small change in the physical nature of the fiber for a given matrix may result in prominent changes in the overall mechanical properties of composites. It is well known fact that, different degrees of reinforcement effects are achieved by the addition of hydrophilic fibers to different polymers. This may be due to the different adhesion strength between matrix and fibers.

a. Mechanical properties

i. Impact properties

Impact resistance is the ability of a material to resist breaking under a shock loading or the ability to resist the fracture under stress applied at high speed. Impact behaviour is one of the most widely specified mechanical properties of the engineering materials. Both Izod and Charpy methods perform impact tests on areca fibers reinforced with epoxy composite specimens as per ASTM-D256-90. The variations of impact strength with respect to fiber volume fraction and composite curing time as shown in Figs.1 and 2 for Charpy and Izod method of impact test respectively. These figures indicate that, the impact strength of composites increases with curing time at a greater degree when compared to fiber volume in the composite. The important aspect regarding impact strength of the areca composite is that, as the composite curing time increases the alkali treated composites becomes more brittle than the untreated fibers.

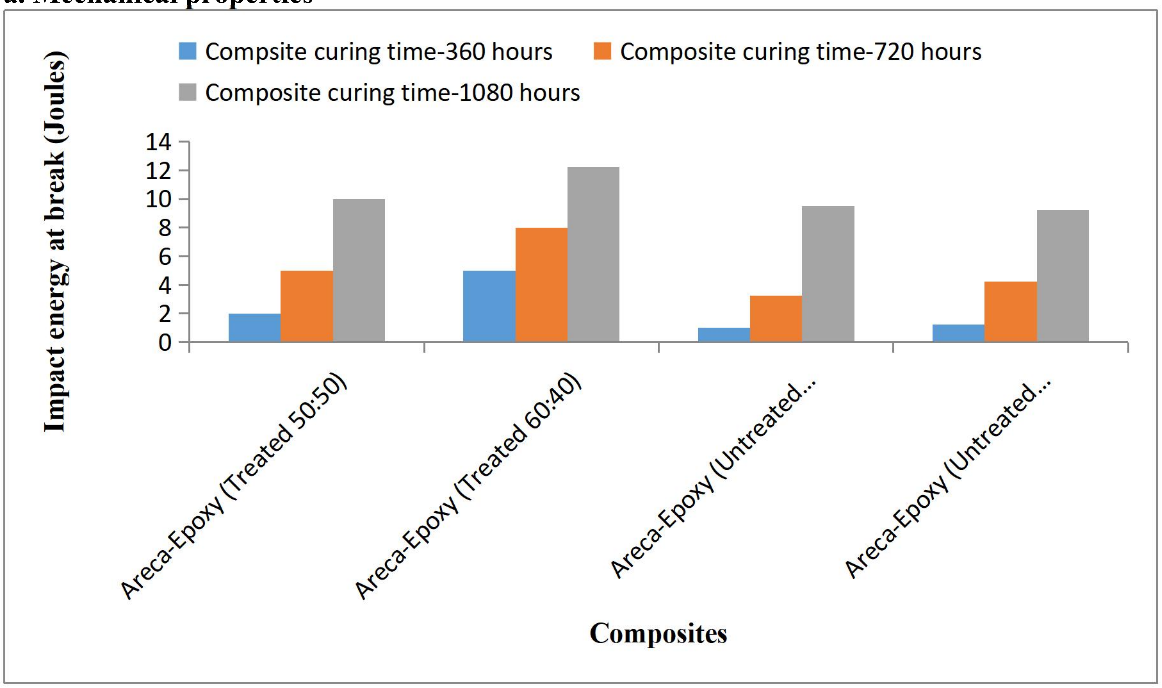


Fig.1. Shows impact energy of composites in Charpy impact test

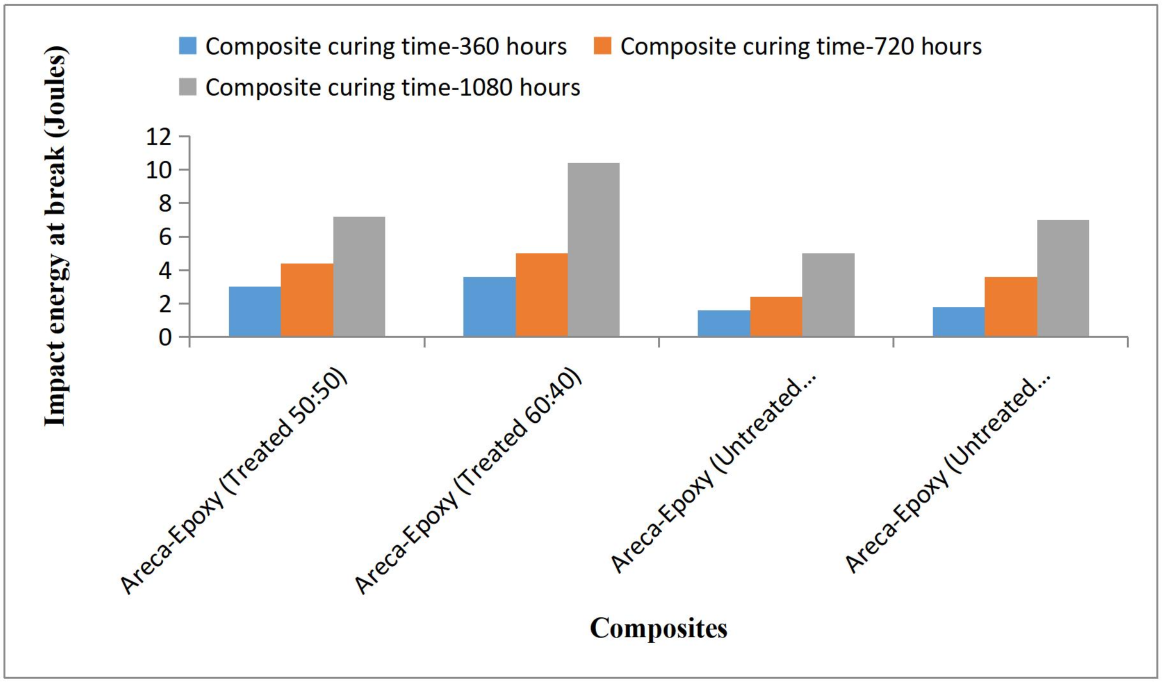


Fig.2. Shows impact energy of composites in Izod impact test

V. CONCLUSION

The results in the present work indicate that, it is possible to enhance the properties of fiber-reinforced composites through fiber surface modification. The mechanical properties of composites of chemically treated areca fibers show better results when compared to natural untreated fibers. It is also worth noticing that the strength of areca fiber composites increases with increase in volume fraction of fiber in the composite and post composite curing time. This is a very rare phenomenon which is not observed inmany of the natural fiber composites. Hence, based on the availability, cheaper and good strength of areca fiber composites investigated in the present research work. The composite can certainly be considered as a very promising material to fabrication of lightweight materials used in automobile body building, office furniture, packaging industry, partition panels, etc. compared to conventional wood-based plywood or particle boards.

Conflict of interest

The authors declare that there is no conflicting interest in the publication of this paper.

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