Original Article

Extraction and characterization of vetiver grass (Chrysopogon zizanioides) and kenaf fiber (Hibiscus cannabinus) as reinforcement materials for epoxy based composite structures

Anish Khan\textsuperscript{a,b,*}, R. Vijay\textsuperscript{c}, D. Lenin Singaravelu\textsuperscript{e}, G.R. Arpitha\textsuperscript{d}, M.R. Sanjay\textsuperscript{e,*}, Suchart Siengchin\textsuperscript{e}, Mohammad Jawaid\textsuperscript{j}, Khalid Alamry\textsuperscript{a,b}, Abdullah M. Asiri\textsuperscript{a,b}

\textsuperscript{a} Chemistry Department, Faculty of Science, King Abdulaziz University, Jeddah, Saudi Arabia.
\textsuperscript{b} Center of Excellence for Advanced Materials Research, King Abdulaziz University, Jeddah, Saudi Arabia
\textsuperscript{c} Department of Production Engineering, National Institute of Technology, Tiruchirappalli, Tamil Nadu, India
\textsuperscript{d} Department of Mechanical Engineering, Presidency University, Bengaluru, Karnataka, India
\textsuperscript{e} Natural Composites Research Group Lab, King Mongkut’s University of Technology North Bangkok, Bangsue, Bangkok, Thailand
\textsuperscript{j} Department of Biocomposite Technology, Institute of Tropical Forestry and Forest Products, Universiti Putra Malaysia, 43400 UPM Serdang, Selangor, Malaysia

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\textbf{A B S T R A C T}

The study deals with the mechanical characterization of vetiver grass fiber and kenaf fiber reinforced epoxy-based hybrid composites. Five types of composite laminates were developed through the hand lay-up process by varying the percentage of vetiver grass and kenaf fibers. The tensile, flexural, compression and impact tests were conducted as per ASTM. The fractured surfaces of the tested specimens were studied using a scanning electron microscope. From the results, it was shown that properties of epoxy composites were improved by hybridization with vetiver grass and kenaf fibers. The improved mechanical properties of fiber-reinforced composites were noticed in increment of percentage composition of kenaf fibers.

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1. Introduction

Environmental conditions and search of new materials are motivating researchers, scientists, and engineers to propose more modern and biodegradable materials for automotive, aerospace, construction, marine and packaging applications.

In this context, the lignocellulose fibre reinforced polymer composites are preferred due to their biodegradability, availability, ease of production, low cost, appreciable properties and lightweight [1–3]. Ramakrishna et al. studied the mechanical and water absorption properties of jute fiber reinforced epoxy composites. The effects of fiber length, fiber weight fraction and nano-clay addition on the aforementioned...
properties were determined. It was concluded that composites reinforced with 5% of NaOH-treated fiber and 5 wt.% of nano-clay exhibited higher tensile, flexural and impact strengths of 103.05 MPa, 162.8 MPa and 0.35 8 kJ/mm² respectively and lower water absorption rate [4]. Jothisabu et al. investigated the stacking sequence effect of areca sheath fibers and jute fibers on the mechanical properties of the pure and hybrid epoxy composites. It was shown that jute fibers with core layer of areca sheath fibers showed higher tensile, flexural, impact and compression strength compared to pure and other hybrid composites [5]. Sathishkumar et al. worked on sisal and cotton reinforced polymer matrix composites. It was shown that if content of lamina increases, there was an increase in the mechanical and damping properties [6]. Sepea et al. studied on treated and untreated hemp fiber, and analyzed characteristics of composites using Fourier transform infrared spectroscopy and scanning electron microscopy, and mechanical test. It was shown that the treatment of hemp fibers improved properties of the composites [7]. Kaur et al. worked on smoke treated bamboo fiber, and analyzed that the resistance of smoke treated increased when compared to degraded control samples [8]. Kaur et al. performed on physical and chemical characterization of different bamboo fiber, and observed that region-wise, the chemical composition varied [9]. Sharba et al. worked on woven kenaf/glass reinforced unsaturated polyester composites, and considered laminate sequence method to fabricate laminates, different layered composites showed different mechanical properties [10]. Vijay and Lenin Singaravelu et al. investigated the mechanical performance of stacking sequence-based Cyperus pangorei and jute fibers in the epoxy composites developed by hand lay-up process. It was found that C. pangorei at the core with jute fibers at the skin layer showed better mechanical strength compared to other three composites [11]. Naveen et al. studied the mechanical strength behavior of partial replacement of plain-woven Kevlar with naturally woven cocous nucifera sheath (CS) waste at various weight fraction of 100/0, 75/25, 50/50, 25/75, and 0/100. The results showed that the hybrid composites (75/25) declined the tensile strength by 19% compared to Kevlar fabric reinforced epoxy composites. But, the hybrid composites (75/25) exhibited highest flexural strength (175 MPa) with good impact toughness than pure Kevlar-reinforced epoxy composites [12]. Anidha et al. studied the dynamic mechanical behavior of treated and untreated 5% Aramid fiber (AF) treated with bagasse/epoxy (BG/E) resin, a bio-degradable composite fabricated using hand lay-up process. Three different types of composites with different BG to epoxy (40:60, 50:50, and 60:40) ratios were prepared. It was shown from the test results that 40 wt.% of treated bagasse with aramid and epoxy fiber composites showed enhanced dynamic mechanical properties compared to those of untreated fiber-based composites with less moisture absorption [13]. Ramlee et al. characterized properties like tensile strength, water absorption, thickness swelling, density, void content, and micrographs for oil palm empty fruit bunch (OPEFB) and sugarcane bagasse (SCB) fiber-based hybrid composites by hand lay-up technique by maintaining total fiber loading 50 wt.% The experimental results found that hybridization of OPEFB/SCB fiber composites had better performance and properties comparing with pure fiber composites. It was shown from the obtained results that 70OPEFB:3SCB hybrid composites displayed highest tensile strength and modulus, 5.56 MPa and 661 MPa, respectively with less porous and voids area compared to pure composites. While 30OPEFB:7SCB hybrid composites showed lower water absorption and thickness swelling after 24 h analysis [14]. Sezgin and Berkalp investigated on jute fiber and that fiber was reinforced with carbon and glass fiber, incorporating high impact resistant fibers to the outer layers of the composites leads to higher impact resistance, and placing high tensile strength fibers at the inner layers results in higher tensile strength at the hybrid composite laminates [15]. Vinod et al. worked on jute reinforced epoxy composites and there composites were also filled with Calotropis gigantea stem powder, the results revealed that the composites with Calotropis gigantea stem powder showed higher mechanical and thermal properties compare to other [16]. Yu et al. studied on ramie based polylactic composites, water absorption and hygrothermal behavior were observed, and Ramie/PLA composites showed higher saturation weight gains and diffusion coefficients [17]. Arpitha et al. studied on sisal glass epoxy-based hybrid composites; the results showed that filler material can reduce the voids and can increase the physical properties [18]. Sanjay and Yogeshika stated that green materials are most widely used research topics in recent years because they are environmentally friendly, low cost and have better mechanical properties [19].

The present scenario has concerned about the use of naturally available materials to replace synthetic materials, so this work has a concern about natural fiber-reinforced composites and the use of new kinds of plant fibers as reinforcement of polymer composites. So the main objective of this study is to evaluate the mechanical properties and characterization of vetiver grass fiber and kenaf fiber reinforced epoxy based hybrid composites.

2. Materials

Vetiver (Chrysopogon zizanioides) grass fiber and kenaf fibres usually grow in the regions of India, Bangladesh, China, Nepal, and Thailand were taken for fabrication of laminates. The commercially available epoxy resin LY556 and an amine-based hardener HY951 were used as the matrix system for preparing the composite specimens. Preparation of die was done by coating it with polyvinyl alcohol. Fig. 1 shows the morphology of the vetiver fibre and kenaf fiber. Fig. 1(a) and (b) shows higher roughness; it increases the bonding area between the fibre and matrix leading to improve the mechanical properties of the composites.

2.1. Fabrication of composites

The composites were developed by hand lay-up process. The preparation of mold was done by coating it with polyvinyl alcohol and allowing it to dry in the hot sun. To develop C1 composite, 30% of vetiver grass fibers were taken and evenly dispersed in a die of size of 300 mm × 300 mm × 5 mm. Then the epoxy resin was mixed with hardener in the ratio 10:1, and 70% were considered and filled in the mold which already
contains the above fibers mixture. Finally, a weight of 25 kg was placed over it and left for curing in the room temperature conditions for 24 h. In the case of C2 composite, 22% of vetiver grass fibers were mixed with 7.5% of kenaf fibers, C3 composite was made of 30% kenaf fibers, C4 composite of 22.5% kenaf fiber and 7.5% vetiver fiber. In C5 composite consisted of 15% kenaf fibers and 15% vetiver fibers. In this work, the mechanical properties like tensile, flexural, compression and energy absorption properties were also determined to suggest the possibilities of eco-friendly hybrid composites for day to day applications.

2.2. Testing methods

Mechanical properties were analyzed for composites according to ASTM. The five samples were analyzed, and consistent results were reported for each test. Tensile tests were performed using the universal servohydraulic test machine (Model No: UTES-40, Brand: Fuel Instruments & Engineers Pvt. Ltd.) with a maximum capacity of 400 kN by ASTM D 638-14 with a loading speed of 2 mm/min. The specimen was cut to the shape of dog bone that had dimensions 165 mm × 19 mm, and the length of the middle section was 57 mm. The samples were kept between the UTM clamps, and the load was increased until a fracture occurred. Flexural tests were carried out following ASTM D790-10 using the universal testing machine with model and manufacturing, as indicated above with a loading speed of 2 mm/min. The dimensions of the sample were 165 mm × 19 mm. The three-point bending mode was applied to measure the final load and resistance to bending, with 30 mm diameter rollers. The load was applied until the fracture occurred. Compression tests were carried out in accordance with ASTM D695-15. The dimensions of the compression sample are 55 mm × 55 mm. Compression tests were carried out on the universal testing machine at room temperature until a fracture occurred. The machine is fixed with a pair of compression plates, with a diameter of 120 mm to compress the sample. Variations of stress with strain responses were obtained graphically for all previous tests. The absorbed energy was measured according to ASTM D256-10 in a Charpy impact test machine (Model No: IT-30 (D) and Make: Fuel Instruments & Engineers Pvt. Ltd.) using a notched sample. The dimensions of the impact sample were 76 mm × 20 mm, with a 90° notch angle. The fractured interface (sample) was cut in 15 mm × 15 mm with a diamond cutter, pulverized with conductive material (gold), and then analyzed in scanning electron microscopy (SEM) of Tescan VEGA 3LMU, Czech Republic to study the various morphologies of the specimen tested.

3. Results and discussions

3.1. Tensile properties

Tensile test for the three different sequences and pure vetiver fiber and kenaf fiber reinforced epoxy composites are performed and the tensile strength properties are shown in Fig. 2. It was observed that C3 composite possess higher tensile properties of 40 MPa compared to C1 because of reduced strength of vetiver grass fiber-reinforced composites, C3 composites were made of pure kenaf fiber and it is showing higher tensile properties. In between it is observed that hybridization effect of composite C4 of 22.5% kenaf fiber and 7.5% vetiver fiber also showing improved tensile results. From the other view it was noticed that composites made of kenaf fiber are showing excellent tensile properties compared to the composite made of vetiver fiber because of poor tensile strength of vetiver fiber [20–24].
3.2. Flexural properties

Fig. 3 shows the effect of fiber content and epoxy on the flexural properties of vetiver fiber and kenaf fiber reinforced epoxy composites. C3 composites show the increasing trend. It is clear that the C3 composite possesses higher flexural properties compared to C1 because of poor strength of vetiver fiber reinforced composites, increased properties because of pure kenaf fiber, and it is also because of cohesive forces exerted in between the fiber. Percentage improvement in flexural properties between the volume fractions of 30% kenaf fiber, and composite of 22.5% kenaf fiber and 7.5% vetiver fiber. C1 composite shows poor flexural strength because of poor flexural properties of vetiver grass fiber and it is made of altogether 30% of vetiver grass fibers and epoxy [25–28].

3.3. Compression properties

Fig. 4 shows compressive properties of vetiver fiber and kenaf fiber reinforced epoxy composites, it is observed that the addition of kenaf fiber in the composites showing improved compassion strength. It is also observed that the composite made of only vetiver fiber is showing less compression properties because of poor strength of vetiver fiber. Compression strength and modules are relevant design parameters because composites are frequently used in flexure, and the lower compressive strength will lead to high bending and instant failure [29,30].

3.4. Impact strength

Fig. 5 shows impact resistance of the composite laminates. It is seen that the composite laminate with kenaf fiber showing more impact resistance while vetiver fiber shows less. The effect of hybridization is examined, and it is seen that that composite C3 has the highest value of 11, while C1 has the lowest value of 4). Besides it is observed that although there is no much difference between other laminates but composite made of kenaf fiber showing good results compared to vetiver fiber. This unusual performance of composite laminates is because of void fractions, sudden impact, and mechanics of the sliding behavior of the laminates [31,32].

3.5. Morphology studies

Scanning electron microscopy study is carried out to study the fractured surfaces of tensile, flexural, compression and impact tested specimens. Fiber pull out, and voids are observed due to fibre pull-out and fibre debonding. It is because of untreated poor adhesion between the kenaf, vetiver and epoxy matrix [33,34]. It is also observed that the fiber failure mode gives an indication of good load transfer through fibers and matrix; it is shown in Fig. 6.

4. Conclusions

In this work, the mechanical properties like tensile, flexural, compression and energy absorption properties were determined to suggest possibilities of eco-friendly hybrid
composites for various day to day applications. From the results, it was noticed that the composites made of kenaf fiber showed good tensile properties compared to the composite made of vetiver fiber because of poor tensile strength of vetiver fiber. It was observed that C3 composite possessed higher mechanical properties when compared to all other composites. It was also observed that the fiber failure mode gives an indication of good load transfer through fibers and matrix. In future, these composites can be used when cost reduction is the prime consideration and for semi-structural applications. These composites may be suggested in potential applications like roofing sheets, bricks, door panels, furniture panels, interior paneling, storage tanks, pipelines, bath units, chairs, lampshades, partitions, roof, suitcases, trays, tables, and manufacturing of car doors, car interiors, dash boards, headliners, decking, parcel shelves, pallets, spare tyre covers, spare-wheel pan, seat backs, etc.

Conflicts of interest

The author declares no conflicts of interest.

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