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Mechanical and Wear Properties of Natural Fibers Reinforced Composites and its Applications - A Review

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Abstract

In considering sustainable and eco-friendly society, few ecological legislations drive material engineers and automakers to exploration for green based materials. Naturally available green particulates and fibers might find a significant role in future generation materials. Moreover, the steep rise in demand for high-damped material with good mechanical strength for the under-hood structure of automotive end applications and other applications like soundproof require newly designed lightweight materials. Plant resource-based polymer composites have an enormous impact on today's global market. This is not only for its environmentally friendly nature, but also for its technical credibility and commercial viability to dominate the market. Moreover, there are many other attractive features including aesthetic appeal and decorative appearances. It has become one of the most popular composites available in the market in modern times.

Keywords

Natural fibers, Mechanical properties, Wear properties, Industrial applications

Introduction

With the increasing awareness of environmental concerns, demand for environmental sustainability and progress in the composite industry has catalyzed an attraction and ever-increasing interest in bio composites [1]. Recently, there has been rapid growth and innovation in bio-composites owing to their renewability, availability, better properties, and light weight products to the research and industrial applications [2, 3]. For the same weight, natural fiber composite is 25% to 30% stronger than glass fiber. The density of the natural fiber (1400 kg/m^3) is better than the glass fiber (2540 kg/m^3). The reduction in weight of the component leads to lower total energy consumption. The production cost of the molding process of NFRC's (Natural Fibers Reinforced Composites) saves up to 10% than glass fiber molding process [4]. In connection with mechanical properties, the characterization of some plant fibers such as bamboo, banana, cotton, snake grass, areca, kapok, flax, jute, coir, African teff, pineapple leaf, palmyra, and kenaf with tensile properties is comparable to the E-glass fiber [5]. The different categories of bio-reinforcements such as bast, leaf, seed, fruit, grass, and reed are widely used in the NFRC's. Thermoset/thermoplastic is a type of polymer which protects the reinforcement material from environmental damage while holding the fiber position and orientation in the composites [6]. It is also used to shift the load to the fibrils in the composites. In general, polymer materials can be categorized into two types namely thermoplastic and thermosetting plastic. Thermoset polymers cannot be recycled and reused once cured while thermoplastics can be recycled and reused [7]. The presence of high cross-linked aromatic structure in polyester matrices possesses extraordinary adhesive properties, superior heat and fire resistance, high rigidity, and good dimensional stability. The versatility, availability, less density, and specific strength properties of eco-friendly natural fiber reinforcement composites finds its application in the field of aerospace, marine, electrical panels, electronic instruments, building, sports, biomedical implants, furniture, and music instrument industries [8-10]. However, the prospect of the growth of NFRC's has been hampered because of the drawbacks like moisture sensitivity, improper bonding with polymer matrices, dimensional instability [11]. Henceforth, NFRC's finds its applications in the field of biomedicals, sports, electrical panels, defense products, and household appliances such as roofing, wall linings, covers and bodies of mobile phones, the interior of car doors and dashboards [12]. Jagadeesh et al. [13] in their review paper highlighted the salient aspects of NFRC's, like their lightweight, low cost, non-toxicity, non-abrasive, biodegradable, and combustible properties. The authors reviewed bio-composites made from poly (lactic acid) and plant fibers like kenaf, jute, sisal, hemp, ramie, bamboo, and flax. They also discussed the problem associated with the processibility of composite and their remedies. Ashik et al. [14] analyzed the properties of renewable resources with respect to its absorbing capabilities of carbon dioxide (CO_2). For the past decades, the authors analyzed the impact of CO_2 on absorption characteristics for their efficient material design. The biodegradability of the natural fibers was analyzed with respect to various properties of capabilities. The authors designed their methodology for reinforced composites as an effective resource sharing technique. The use of various composite fibers used for different applications was also discussed in this work.

Mechanical Properties of NFRC's

Mwaikambo and Ansell [15] studied the effect of surface modification and hybridization on the adhesion property of coir fiber composites. They noticed that coir fiber with glass fiber improved their adhesion behavior owing to fiber treatment. Hariharan and Khalil [16] tested oil palm fibers for achieving glass fiber strength. They had a higher resistance when compared with other materials. Rao and Rao [17] checked the behavior of different filters which were highlighted poly materials for improving certain properties of CO_2 degradation. These materials were analyzed with respect to their various shapes and sizes. Monteiro et al. [18] performed the flexural strength of the various natural fibers. They analyzed the flexural strength of these natural fibers under different pressure. The results of this paper were compared with various existing methods in terms of flexural strength. Jacquemin et al. [19] studied micro and mechanical behavior by analyzing fiber strength and its matrix decomposition. The stability, as well as durability of these materials, was analyzed for enhancing the mechanical behavior of the enveloped products using epoxy materials with carbon components which were added as equivalent factors. Nilsson [20] developed composite products using sisal fibers as reinforced materials. The authors extracted 30 mm fiber leaf and tested for tensile strength behavior improvement. Different fibers with respect to different length were tested on various fiber materials. Bessel and Mutuli [21] applied sisal fibers as reinforced materials which were added to cement materials. The authors conducted a number of tensile tests on different sisal and cement composite products to prove the robustness behavior of these integrated components. Dinesh et al. [22] utilized the characteristics of the sisal fibers for producing durable materials for automobile manufacturing industries. The authors analyzed and tested their materials with respect to different ratios as 10% to 30% with step size of 10%. The compression test was conducted by the authors on these developed materials for analyzing the behavior and strength of the products with industrial standards. Ochi [23] developed a methodology for improving the functionality of the Bamboo Fiber-Reinforced Plastic materials based on different mat materials. The authors used bamboo fibers for unidirectional components. The performance of the proposed method was improved and analyzed with respect to fiber volume fraction parameters. Rajulu et al. [24] prepared the composites using bamboo as reinforcement and epoxy and polycarbonate as matrix. The authors used non-linear regression models to investigate the tensile strength of the fiber. The developed methodology was utilized by regression models for testing their products with respect to various design parameters. The mechanical behavior of these tested materials was finally considered and designed with polyester composite products. Okra fibers extracted from okra bahmia plant were analyzed for the tensile tests of single fiber at a gauge length of 10 mm [25]. Table 1 presents mechanical properties of NFRC's.

Wear Properties of NFRC's

Chand and Dwivedi [35] analyzed the sliding wear property of jute/polyester composites. The wear property of composites was determined for different fiber orientation and sliding load. The applied load increased the coefficient of friction was decreased. Mishra and Acharya [36] analyzed the abrasive wear properties of bagasse/epoxy composite in different orientation. The parallel orientation type composites were found to have better wear properties. Deo and Acharya [37] studied the abrasive wear properties of lantana camara fiber reinforced polyester composite. The increase in the normal load increased the wear loss. In 40 wt.% fiber content composite found the optimum wear resistance properties. Scanning Electron Microscopy described the wear mechanisms like a crank, plastic deformation, and adherence in composites. Yusoff and Jamaludin [38] concluded the wear properties of hybrid composite by Pin on disc apparatus. The analysis of variance is used to predict the various factors like sliding distance, velocity, load and % of reinforcement. Chand and Dwivedi [39] investigated the wear performance of agave/epoxy composites by varying the fiber length of 3 mm, 5 mm, and 7 mm. Sliding velocity, fiber length, and normal load are main factors to find the wear behavior of composites. The superior wear properties are observed in the 3 mm length of agave fiber than the other composites. Singh et al. [40] investigated the wet sliding wear behavior of kenaf/polyurethane composites. The results indicated that at high applied load, wear and frictional performance were improved by 59% and 90%, respectively. Nirmal et al. [41] analyzed the wear properties of sugarcane/polyester

Table 1: Effect of mechanical properties of NFRC's.

S. No.	Fibers	Key Parameters	Observations	Reference
1	*Pennisetum purpureum* stem fibers	Chemical Treatment (Alkaline)	Better mechanical properties were obtained.	[26]
2	*Prosopis juliflora* fiber	Fiber Content (20 wt.%)	Physical and mechanical properties were better at 20 wt.% of fiber content.	[27]
3	*Lygeum spartum* stem fiber	Fiber Diameter	Fiber diameter significantly influenced the thermal property.	[28]
4	*Elettaria cardamomum* plant fibers	Fiber Selection	Exhibited better thermal property.	[29]
5	Sisal fiber	Manufacturing Technique (Resin Transfer Molding)	Improvement of fiber/matrix interfacial adhesion resulting in enhanced tensile, flexural and impact strength.	[30]
6	Palmyra palm fiber	Manufacturing Technique (Hand Lay-up)	Improved mechanical properties.	[31]
7	Palmyra fiber	Fiber Length (30 mm)	Better mechanical properties were obtained.	[32]
8	Sun hemp fiber	Fiber Length z(30 mm)	Better mechanical properties were obtained.	[32]
9	Curaua fiber	Fiber Content (30 vol.%)	Higher mechanical and thermal properties were observed at 30 vol.% of curaua fiber.	[33]
10	Pineapple leaf fiber	Fiber Content	Increase the fiber content beyond optimum level, thermal stability was decreased.	[34]

composites. Sugarcane fibers were used in two different forms like chopped and unidirectional for preparing composites. The wear properties of unidirectional sugarcane fibers composite are superior to the chopped composites. Table 2 presents the effect of wear properties of NFRC's.

Industrial Applications of Natural Fibers and Its Composites

Hemp fibers are used in building and constructions, car interior and exteriors, textile machinery, defense parts, sport helmets, laptop casing, household products, paper, and packaging [50]. Ketty et al. [51] used natural fibers such as banana with coconut for composing botanical properties by heating them to 200 °C by means of nitrogen gas. The increased temperature changes the behavior of hybrid materials for the need of industrial applications. Shin et al. [52] stated that because of epoxy resin characteristics it is used as matrix material significantly in various applications like aerospace, ship building, automobile industry, and structural applications. The epoxy and glass fiber are mixed in the ratio of 1:1 to obtain the best mechanical properties. Palanikumar and Subbiah [53] contemplated the mechanical and vibration behavior of caryota fiber fortified with polyester matrix. Initially the caryota leaves are placed in water over a time of four days for the primary walls to soften easily and then the fibers are extracted. The

Table 2: Effect of wear properties of NFRC's.

S. No.	Fibers	Key Parameters	Observations	Reference
1	Bagasse fiber	Fiber Orientation (Parallel)	Improvement in wear resistance.	[42]
2	*Lantana camara* fiber	Fiber Content (40 wt.%)	Better wear resistance was recorded at 40 wt.%.	[37]
3	Kenaf fiber	Wet Sliding Condition	Increases the composites wear and frictional performance by 59% and 90%, respectively.	[40]
4	Jute fiber	Sliding Load	The coefficient of friction was improved by the optimum sliding load.	[43]
5	Coir fiber	Fiber Stacking Sequence	Four layers of coir fiber in the polyester exhibited better wear and frictional performance than neat polyester.	[44]
6	Bamboo fiber	Fiber Orientation	Fibers with anti-parallel direction exhibited better wear properties than other directions.	[45]
7	Palmyra fruit fiber	Chemical Treatment (Alkaline)	Alkaline concentration on palmyra fiber exhibited superior wear resistance than untreated fiber.	[46]
8	Date palm fiber	Filler Content	Graphite filler has significantly improved the wear properties of the composites.	[47]
9	Agave fiber	Fiber Length and Manufacturing Technique (3 mm and Hand Lay-up)	Better wear properties.	[48]
10	Sugarcane fiber	Fiber Orientation	Unidirectional sugarcane fiber composites have better wear characteristics than chopped composites.	[49]

composite specimens were manufactured by varying the volume fraction of the composites. Results showed higher mechanical properties for 40 wt. % of fiber content. Khalil et al. [54] in their book on bio-fiber reinforcements in composite materials stressed about the inclusion of sustainability as an important criterion which determines the construction and manufacturing of building materials. They focused on bamboo as the natural fiber that gained wide acceptance for many applications around the globe for three important factors, i.e., economic, ecology, and social needs. They concluded their article by declaring that due to the infinite variations that can be made by just changing the percentage composition of the reinforcement material, there can be much research carried out by just using bamboo as the reinforcement material. Figure 1 shows industrial applications of NFRC's.

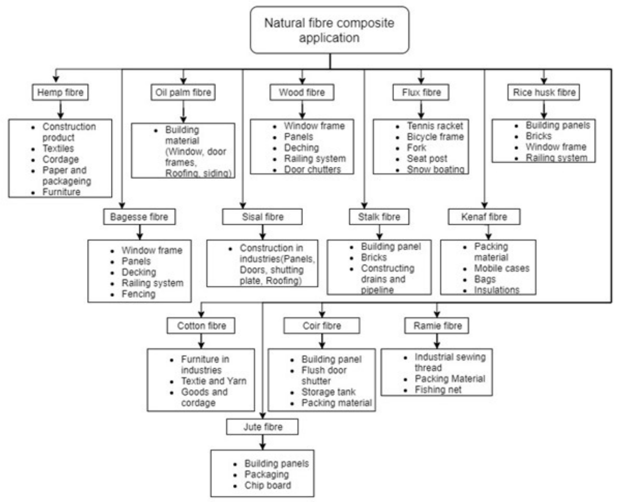

Figure 1: Commercial applications of natural fibers [55-57].

Conclusion

In the present time, scientists and researchers concentrate on the application of different natural fibers in polymer matrices to produce environment friendly composites. This is a vast area of research concerned with the fabrication and development of eco-friendly composites using a variety of plant resources. These composites are not only environmentally friendly, but also possess other attractive features like low density, electrical and thermal insulation property, sound abatement property and more importantly the low cost. These attractive features lead to the development of many plant resource-based composites which find extensive applications in various commercial sectors.

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None.

Conflict of Interest

None.

Credit Author Statement

S. Sathish: Supervision; M. Aravindh: Formal analysis, Investigation, Writing - review and editing; L. Prabhu: Resources; S. Gokulkumar: Writing - review and editing; M. Thejeshwar: Conceptualization, Methodology; R.K. Siva Visagan: Conceptualization, Methodology; K. Thiru Vikraman: Writing - original draft preparation; M. Yuvarajan: Writing - original draft preparation; Pottli Tulasi Kumar Reddy: Writing - original draft preparation; V. Kavipriyadharsan: Writing - original draft preparation; D. Kesavan: Writing - original draft preparation; M. Vijaya Sree: Writing - original draft preparation. All the authors read and approved the manuscript.

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