Review of natural fiber composites

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Abstract. Development of new alternative materials to the existing traditional metals, alloys and synthetic materials is the new buzz in recent research activities at the academic and industrial level taking place all over the world. Earning carbon credits by minimizing the atmospheric pollution is getting an increase in attention by industries. One small step to conserve the atmosphere around us is to use natural resources in making fully bio degradable or partially bio degradable composite materials. Such prepared alternative materials can find applications in interior housing, automotive, marine, domestic, and other applications. Composites made by using appropriate natural fibers as reinforcements is a possibility that ensures such a reality as they can be well received in multiple disciplines of engineering. Results published from various research activities illustrates that natural fiber composites can successfully be adapted for non-structural, moderate load bearing indoor applications. Further, the few deficiencies in the natural fibers can be overcome by subjecting them to morphological changes by various physical or chemical treatment methods. The overall objective of this paper is to provide a comprehensive overview of the property profiles of Natural Fiber Composites.

1. Introduction

Bio based fibers as a reinforcement in the composite materials is getting more attention now a days. The benefits of using natural fibers as reinforcing media are many. Some of these are biodegradable properties which eases disposal problems, low investment, possibility of thermal recyclation, user friendly conditions, light weight structures, adequate specific strength properties[1,2,3,4] etc. Composites are basically, the sandwiched structure of two or more materials, maybe different in characteristics and composition combined with certain resins which maybe man made or synthetic based on the application, where the composites are used. Fibre properties are determined by the physical, mechanical and chemical properties of its constituents and their interfaces. Several studies have claimed that fibre’s mechanical properties are determined by the secondary wall’s middle layer [3, 5, 6].

There are certain disadvantages of using natural fibers in composites like moisture absorption, fast degradation, and low resistance to higher temperatures. Many of these problems can be overcome by modifying the fiber structure by physical or chemical treatments. In this study, we try to review some of the research activities carried out on natural fibers, their processing into composites, their characterization based on mechanical, thermal, acoustic, fire retardancy and shock absorption properties, etc.

2. Natural fibers as a reinforcement

Natural fibers are categorized into animal fibers and plant cellulose fibers. Plants that produce natural fibers can be divided into primary and secondary depending on the utilization. Primary plants are grown for their fibers while secondary plants are plants where the fibers are extracted from the waste product. There are six major types of fibers namely; bast fibers, leaf fibers, fruit fibers, grass fibers, straw fibers etc. Generally, much higher mechanical strength and stiffness can be obtained by using plant fibers, but before that, it has to be conditioned mechanically and should undergo certain chemical treatments. Fiber selection as reinforcement in the composites basically dependent upon the application, where it’s going to be implemented.
In several research works, Banana fiber has been characterized for mechanical properties [2, 3, 4, 5] and it is concluded that usage of alkali treatment shown the improvement in tensile and flexural strength. In a study involving pineapple leaf fiber (PALF) [6], green composites were prepared using twin screw extruder. Tensile properties of composites with pineapple leaf fiber and poly lactic acid (PLA) were increased significantly with fiber percentage of 40%.

Vakka, Sisal, Bamboo and Banana fibers were tested in a research work [7] for different mechanical properties, and the researchers claimed that extraction of Vakka fiber is simple. The processing of fibers results into an excellent quality, quantity and lengthy fiber useful for fabrication of large composite components. The extra light weight of the Vakka fiber makes it suitable for designing of lightweight materials.

3. Manufacturing processes

Suitable manufacturing process must be utilized for transformation of the basic materials to the final shape without causing any defect in the product. For the proper fabrication selection process with biodegradable polymer related composite, design and manufacturing engineer focuses on a number of criteria, including desired properties, size and shape of the resultant composites, processing characteristics of raw materials, production speed and the manufacturing cost. For small to medium sized components, injection and compression moulding are preferred because of their simplicity and fast processing cycle. However, for large structures, open moulding and autoclave process typically manufacture them.

In a study involving mechanical characteristics of unidirectional sisal / glass fiber reinforced hybrid polyester composites [1], hand lay-up technique was used for the creation of composites. In processing natural and wood fiber composites [8], Thermoset mat compression moulding, and Thermoset injection moulding were adapted for the production of green composites. In Mat compression process, a fiber mat is used which was made of natural fibers. In the compression moulding, the mat is sprayed, with resin and compressed into its final contour in a hot tool; with the use of air permeability, the parts could be covered easily in a vacuum covering process.

In Analysis of the deformability of flax fiber non-woven fabrics [9], Resin transfer moulding process (RTM) was used for composite production. It’s one of the main manufacturing process to produce composite parts for the transport industries [10] [11]. It is an increasingly common form of moulding using liquid composites. It’s primarily used to mould components with large surface areas, complex shape and smooth finishing.

4. Natural resins

The process of resin secretion occurs in special cavities or passages in most of the plant species. It is formed in the specialized structures called “ducks”. Resins come out from the bark of the trees and gets hardened when exposed to air. Natural resins of importance to the furniture coatings are rosin, damar, copal, sandarac, amber, and manila.

In studies of the medicinal plants, valuable resins with photochemicals and bioactive properties provided scientific information about tertiopenes that will be important for further research on the use of the various photochemicals found in resins and plants to sustain human health [12]. Ivica et al [13], proved in their study that the properties of the resins can be improved by treatment of the fibers with phenolic composition and antimicrobial process. Gram-positive bacteria were more susceptible to resin samples and different combination of pure phenolic, cherry bud samples had high amounts of naringenin and showed strong activity against Bacillus subtilis and Listeria monocytogenes. Chen et al [14], Wood resins are valuable natural products with wide utilisations resin-containing woods, natural wood resins are usually complex mixtures consisting of various compounds. Wood resin samples can be measured directly by Fourier transform infrared (FTIR) spectroscopy and principal component analysis can resolve the absorption bands of different compounds with respect to their positions in the resin containing woods.

5. Mechanical properties

In recent years, the mechanical performance of natural fiber composites seemed to be improved significantly. Enhancement in the overall properties in natural fiber composites has occurred due to improved fibre selection, extraction, treatment and interfacial engineering as well as composite processing [49]. Mechanical properties of sisal and glass fiber reinforced composites has been studied by Sanjay et al [1]. They’ve compared the properties like tensile, impact and flexural strength of both sisal and glass fiber reinforced composites and concluded that the tensile strength of 30% glass fiber – 70% sisal composition and flexural strength of 70% glass fiber – 30% sisal composition and impact strength of 50% glass fiber – 50% sisal composition was found to be better than the remaining two compositions.
Tara Sen et al [15], have studied properties of Sisal, bamboo, coir and Jute, and tried using them in the structural upgradation. In the study, strength of the material has been improved by the usage of Fiber Reinforced Polymers as a raw material. Different properties of these natural fibers like specific gravity, water absorption, and mechanical properties like tensile strength, modulus of elasticity, were studied and tested for their application into the structural upgradation. Mechanical behaviour of sisal / glass fiber reinforced polymer hybrid composite was studied by Sanjay, et al [16]. In this study, sisal fiber was hybridized with glass fiber with the hand lay - up process. They found that the tensile strength of 30 % GF- 70% sisal composition and flexural strength of 70% GF- 30% sisal composition and impact strength of 50% GF- 50% sisal composition were found to be better than the remaining two composites. In other study, mechanical properties of hybrid glass fiber – sisal jute reinforced epoxy composites were studied by Ramesha, et al [17]. The incorporation of sisal fiber with GFRP found to be having better properties than the jute fiber reinforced GFRP composites.

In a study involving the fracture and impact properties of short discrete jute-fiber reinforced cementitious composites (JFRCC), by Xiangming Zhou et al [18] they concluded that jute fiber had less deterioration in pulverized fly ash (PFA)/PC matrix than in ground granulated blast furnace slag (GGBS)/portland cement (PC) matrix upon impact failure. Sisal fiber glass fiber hybrid nano composite were tested by Nataranjan, et al [19]. It has been found that the tensile strength of nano sisal composite is relatively more than sisal/nano sisal composite and much higher when compared with sisal composite. They’ve also found that the percentage elongation of single fiber in tensile testing is less than that of the hybrid composite. In a study involving banana fiber, by Santhosh, et al [20], they’ve taken both treated and untreated banana fiber for the development of the hybrid composite material. In this study, the untreated banana fiber was treated by NaOH to increase wettability. The untreated banana fiber and NaOH treated banana fiber were used as reinforcing material with both Epoxy resin matrix and Vinyl ester resin matrix. Coconut shell powder was used along with both untreated and treated banana fiber as a filler material. They’ve concluded that the alkali treatment of banana fiber improved the mechanical properties like tensile, flexural and impact strength of both the epoxy/vinyl ester and hybrid composite. In a study involving the study of bamboo natural fiber composite, by Kumar [21], the researcher evaluated the tensile strength, flexural strength and surface hardness of the bamboo – epoxy composites. The effect of fiber loading on tensile strength, flexural strength and surface hardness also was studied on the bamboo epoxy composite. In this study, with the hand layup technique it was found that maximum value tensile strength, flexural strength, and micro surface hardness of bamboo-epoxy composite was achieved at 25% wt of fiber loading.

In a study done by Bakare et al, [22], on flax and flax basalt reinforcement, by introducing reinforcement, it was found that the surface weight of the flax basalt reinforcement was less than the flax. The researchers found a noticeable improvement in mechanical and thermal properties. The mechanical properties of the kenaf fiber was studied by Saba et al [23]. They found that the kenaf fiber has good tensile strength and flexural strength which was proved by many mechanical tests which enables it to utilize in variety of applications, such as auto-industrial, light weight constructional applications, customary products like yarns, fabrics and ropes. He also found that kenaf/epoxy composites showed better mechanical properties in comparison with polymeric matrix. A fiber named Hibiscus sabdariffa has been studied by Singh et al [24]. In this study, they’ve done scanning electron microscope testing. The UF (urea formaldehyde) was used as the matrix. The tensile and compressive strength has been studied and from that, they’ve concluded that the fiber has a good scope in in the fabrication of natural fiber reinforced polymer composites, having vast number of industrial applications. A polymer composite involving sisal fiber which is reinforced with coconut spathe and ridge gourd has been studied by Girisha et al [25]. Hybridization of these natural fiber with coconut spathe and ridge gourd provided considerable improvement in tensile strength when compared to the individual reinforcement. The tensile strength was found to be increased to 65 %, which is maximum for the hybrid combination of sisal and ridge gourd. Low density of natural fiber composites lead to better comparison for specific properties. Applications of Natural Fiber Composites has extended in load bearing and outdoor applications such as automotive exterior underfloor panelling, sports equipment, and marine structures [50].

6. Vibration and noise absorption properties

Noise pollution is the major problem now a days in metropolis. It causes not only annoyance and sleep disturbance, but also leads to severe problems like heart attack, learning disabilities and tinnitus [10, 26, 27]
Currently, in many of the buildings, automobiles and other transport vehicles, sound absorbing materials are used to reduce the noise and vibration through absorption of acoustic waves, because noise or the sound waves has to propagate through the sound absorber and it’ll get absorbed into that later [11].

As most of the commonly used sound absorptive materials having their source as fossil fuel, it limits the usage of them at industrial level. To overcome this, some materials like Antheria toxicaria barkcloth were tested for sound absorption using type 4206 impedance tube according to ISO 10534-2 standard using two quarter inch condenser microphones type 4187 and it has been found that the Antheria toxicaria barkcloth had higher sound absorptive properties at higher frequencies [10].

Natural fibers were found to have ease in handling and good acoustic insulation properties. [28, 29, 30]

In a study of free vibration characteristics of composite beam, which was made of banana/sisal fibers[31], it’s been found that the chemical treatment improves the mechanical and free vibration properties of polymer composites due to the enhancement of interfacial bond between fiber and matrix as the result of chemical treatment.

In a research involving the sunflower composite which was made up of crushed stem particles and chitosan binder, with high porosity and low density, sound absorptive properties were found to be increased as in comparison with the previous composition when the material was highly compact and had low porosity [32].

In a study of damping properties of flax fiber composites [33], it’s been found that the damping properties of composites increased with the twist and crimp amount through enhanced intra-yarn and inter-yarn friction respectively.

7. Thermal properties

Rapid consumption of fossil fuel based resources is increasing and because of that, the problems like global warming and other environmental issues are also affecting the normal life. Hence, there is need for developing natural fiber composites and biodegradable polymers, as they have high specific strength and eco-friendly as well. But the main obstacle in developing and using natural fiber based composites at higher temperature is that they are less thermally stable and more flammable as compared to synthetic fibers.

In a study, thermos - mechanical properties of the bio based composites made from lactic and thermoset resin and flax and flax/ basalt fiber reinforcements [22], the mechanical and thermal properties were found better than the pure flax composite. It was established that with the PMLA, (pentaerythritol methacrylated lactic acid resin) upto 60 wt % fiber loading possible, while with flax fibers alone, composite could have upto 40 wt % fiber load.

In another study, Srinivasan et al [34] found that, hybrid composite of banana, flax with GFRP has better thermal stability and flame resistance than the flax, banana fiber composites.

In a study, Ramie fiber was applied with the thermal treatment by Jian-Min Yuan et al [35], and it has been found that, the thermal treatments are efficient in modifying the surface and inner structures of the ramie fibers, and the water absorption, oxidative decomposition and thermal degradation greatly affect the cellulose structure.

8. Bio degradability

Now a days, due to large amount of usage of synthetic fiber composites like glass, aramid, etc., it’s causing a problem to the environment as it’s not degradable as easily as compared to the natural fibers. The development of natural fiber reinforced biodegradable composites promotes the use of environmental friendly material. Use of green materials provide alternative way to solve the problems associated with agriculture residues. [7, 36]

Bio degradable materials, which are also bio based in nature are ideal for the sustainable development. It has the potential for use in recyclable products, which can be collected, processed and reused for animal feed or left in the environment to be degraded naturally, releasing the materials that can fertilize and condition the soil to increase crop yields. [37]

In the study of natural fiber reinforced biodegradable polymer composite, [10] Sahari et al did the analysis of polymer matrices which were derived from natural resources such as poly lactide (PLA), thermoplastic starch (TPS), cellulose and polyhydroxyalkanoates (PHAs).

In this work, they’ve found that, biodegradable composites are having competitive properties with the existing fossil plastic materials, but their present low level production and high cost restrict them to be applied in industrial application. In addition, it’s also having hydrophilic properties, which makes it difficult to design. Bamboo fiber, its extraction and its reinforced polymer composite material has been studied by Yu ying wang et al [38]. Firstly, they did the analysis of the bamboo structure and later they’ve extracted it. Basically there are three types of extraction methods of bamboo fibers, viz., mechanical extraction, and chemical extraction, combination of mechanical and chemical extraction. After the extraction process, the fiber was reinforced with the polymeric materials and then different mechanical properties as well as cost analysis, CO₂ absorption, recyclability, renewability, energy of extraction, biodegradability were studied. They’ve found that the bamboo fiber is very much comparable with the glass fibers, as it was lighter in weight, had low cost and the main advantage, biodegradable.
There are mainly five types of biodegradable bio-based polymers commercially available: starch based polymer, polylactic acid based polymers (PLA), cellulose ester based polymers, bacterial polyhydroxyalkonate based polymers (PHAs) and protein based polymers.

In a study involving the composites of biodegradable matrix corn gluten meal material in wood fiber reinforced [39,40], and used water, glycerol, octanoic acid and polyethylene glycol and tested them as plasticizers for corn gluten meal (CGM). Also, they’ve found that water helped to get down the glass transition temperature. Mechanical properties were seemed to be the best for modest structural applications and has the good bio degradability.

In the study including starch based biodegradable reinforced composites with date palm and flax fibers [41], hybrid composites containing date palm and flax fibers, 25% wt. each, were examined. In that, it had been concluded that thermoplastic starch (TPS) composites are biodegradable and hydrophilic. The water uptake and rate of biodegradation was reported as inversely proportional to the fiber content.

9. Fire retarding properties

Basically, natural fibers are preferred over the synthetic fibers because it has several advantageous properties as mentioned below:

1. Low specific weight, which results in higher specific strength and stiffness than glass.
2. It is a renewable resource.
3. Producible with low investment at low cost.
4. Friendly processing.
5. CO₂ used while oxygen is given back to the environment.

But, natural fiber reinforced composites also has some disadvantages like high flammability, hydrophilic nature, etc. Because of the poor internal contact between hydrophilic natural fiber and hydrophobic PP matrix. Compatibilizers can be added to improve the compatibility between fiber and matrix which results in the enhancement of mechanical properties of the composites [42].

In studying the flame retardant, mechanical and thermal properties of sial fiber composites, [42], it was added with some flame retardants like Ammonium polyphosphate (APP), Mg(OH)₂, Zb, APP/Mg(OH)₂ and APP/Zb. After incorporating these flame retardants into the composite, it resulted in the improved flame retardant and thermal stability of the Polypropylene (PP) composites.

In a study involving the PP/wood fiber composites, by Zhen Xiu Zhang et al [43], firstly, they produced the composite with the help of twin screw extruder and later they treated these with the Ammonium polyphosphate (APP) as a flame retardant. They found that as the percentage of APP in the composite increases, its tensile strength decreases but the tensile strength was observed to be increased up to certain limit when the composites were treated with silica as a fire retarding agent.

Natural fiber polypropylene composites containing magnesium hydroxide were analysed by M Sain et al [44]. In this study, flame retardant properties of boric acid or zinc borate and magnesium hydroxide were studied with natural fiber PP. And they found that 25% magnesium hydroxide could reduce the flammability effectively (almost 50%) of natural fiber filled polypropylene composites.

Bamboo chopsticks fiber-reinforced poly green composites were tested for their flame-retardant properties by Yu-Ying Wang et al [38, 45, 46]. In this study, recycled bamboo chopsticks fibre were used with poly lactic acid (PLA). Later, the surface of chopstick fiber and nano clay surface were modified with coupling agents. They concluded that the composites achieve a good grade according to the different composition of the flame retardants. Also, the scanning electron microscope analysis showed that the inner face adhesion of the composites was effectively enhanced after the surface modification of the fiber. Results also showed that the resulting such green composites were not only flame retardant, but also had good thermal and mechanical properties.

In a study involving kenaf / PP fiber composites, the ammonium polyphosphate as flame retardant were used [47, 48] under 3 different compositions. In the thermal analysis of compounded PP/kenaf composites showed lesser rate of decomposition as compared to those of pure PP and PP/kenaf compounds. Also, the results showed the flame retardant property of PP/kenaf composites could be improved with increased APP content, irrespective of their type.

10. Conclusion

Innovations taking place worldwide on alternative materials are shedding light on feasibility of using natural resources such as plant fibers for reinforcing the base matrix materials. Many cellulosic fibers such as flax, sisal, Jute, bamboo have excellent specific strength and low density. As all the natural fibers are biodegradable, safe disposal of the materials at the end of their service life is assured. Natural fiber reinforced materials possess some inherent advantages such as better
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acoustic and damping properties due to their porous structure. Certain disadvantages such as poor mechanical, thermal, moisture resistance and fire resistance properties can be overcome by modifying them suitably with chemical treatments or by adding suitable additives. If such naturally available resources are processed and used selectively, much burden on fossil fuels can be reduced and value addition to the locally available natural fibers can be achieved.
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