2nd International Conference on Emerging Trends in Materials, Computing and Communication Technologies
International Journal of Scientific Research in Science, Engineering and Technology
Print ISSN: 2395-1990 | Online ISSN : 2394-4099 (www.ijsrset.com)

A Review of Natural Fibre Composites

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ABSTRACT

The majority of the research focuses on characterising natural fibres and comparing them to conventional composites in terms of mechanical behaviour and application performance. There are dozens of distinct varieties of natural fibres, each with unique qualities that influence whether or not they are used in various industrial applications. Because of the natural nature of these materials, they have a wide range of qualities that are mostly dependent on the harvesting location and conditions, making it difficult to choose the right fibre for a certain application. This research provides a thorough examination of the qualities of natural fibres utilised as composite material reinforcement. The goal of this work is to map where each type of fibre is positioned in numerous properties by providing a detailed assessment of the qualities of natural fibres used as composite materials reinforcement. A overview of recently published studies on emerging forms of fibres is also included. A future trend analysis of natural fibre applications, as well as the necessary developments to widen their applications, is also provided and explored.
Keywords: natural fibres; green composites, industrial applications.

I. INTRODUCTION

In particular, composite materials are being developed and redesigned aiming to improve and to adapt traditional products and introduce new products in a sustainable and responsible way. This study investigates and discusses recent advancements in the field of fiber-reinforced bio-composite materials, as well as offering information on natural fibres for bio-composites, with a focus on their qualities and applications. One of the problems with natural fibres is the lack of consistent information and claimed variances in mechanical properties. Furthermore, the lack of rules for both producers and users of these materials in terms of how to collect, treat, process, and post-process natural fibres complicates the selection process. These difficulties are, in fact, major deterrents to the widespread use of natural fibres in a variety of applications. To fill this void, this study presents a review of various mechanical properties of natural fibres and their applications.

II. NATURAL FIBRE-REINFORCED BIO-COMPOSITES

In general, depending upon the nature of the constituents, bio-based composites can be classified either as partly eco-friendly or green. Green composite implies that all its constituents are obtained from renewable resources, potentially reducing the carbon dioxide emissions and the dependence on petroleum-derived materials. While partly eco-friendly means that one of the constituents, either fibre or matrix, is not obtained from renewable resources [1].

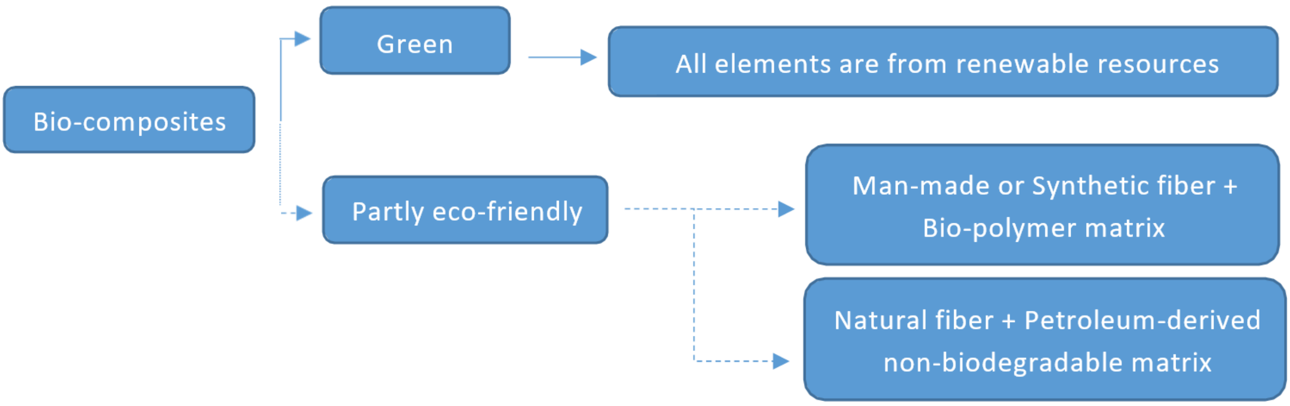

Figure 1. Classification of bio-composites

As shown in Figure 2, natural fibre reinforcement can be separated into three types based on length, dimension, and orientation. This can either be in the form of fibre or particle. The fibre itself is characterized as continuous or discontinuous (i.e., chopped) depending on its length-to-diameter (l/d) ratio. Commonly, the fibre-reinforced phase arrangement is classed as woven or non-woven. A woven fabric is characterized by continuous interlacing of perpendicular yarns, in a regular pattern. Yarns are stru made up of a number of interwoven threads. Up to a certain degree, the twist angle is responsible for the cohesion of the fibres and yarn strength; after that, the maximum fibre strength diminishes due to the increase in obliquity. Moreover, the increase of the fibre twist angle is correlated with a decrease of fibre-resin bond strength, lower permeability and consequently poor mechanical properties.[2,3] In the one-dimensional architecture, the twist angle and the level of alignment of continuous-filament yarns play a significant role in determining the maximum applied load. For this reason, unidirectional composites tend to be weaker in the transverse directions . Given these attributes, for a known state of stress, these anisotropic structures can exhibit at least 3 to 4 times better mechanical properties than their isotropic counterparts.

A non-woven arrangement is a flat structure without interwoven strands, consisting of a mat directionally or randomly oriented and placed together using heat, chemicals, pressure or combination of these thereof as adhesion promoter, the mat or woven can either be composed of continuous or chopped unidirectional fibres, randomly chopped fibres or suspended particles. Mats made up of randomly cut fibres (whiskers) in particular do not have a preferred stress direction, but they are the preferred choice for large-scale production due to their great availability, convenience, and cost effectiveness for producing complex isotropic sections.

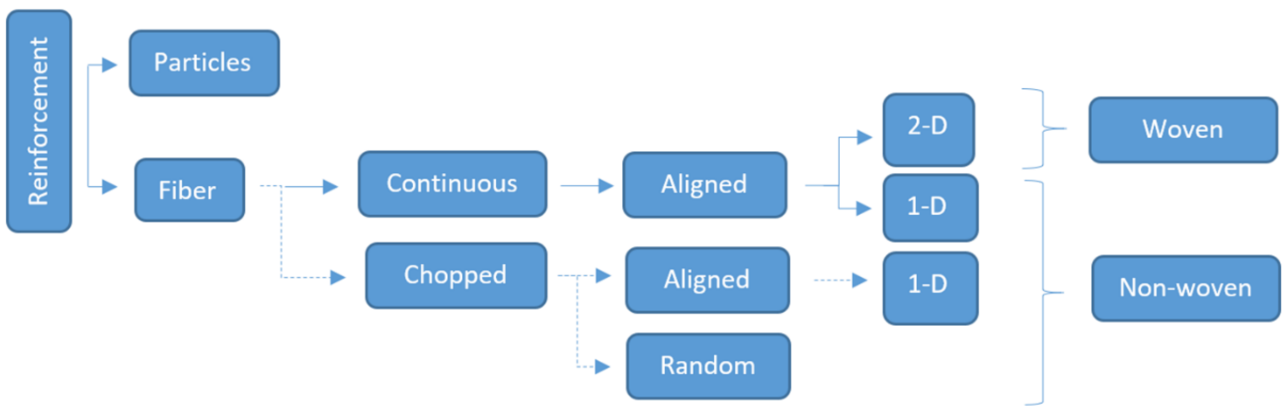

Figure 2. Type of natural fibre reinforcements.

2.1 Bio-Polymeric Matrix

The mechanical performance of a bio-composite also depends on the properties of polymeric matrix (thermoplastic or thermoset). The raw material to produce these polymers can either be from bio-based sources (plant or animal) or synthetic (oil by-product). In the literature the term bio-polymer has multiple and overlapping meanings, including but not limited to: bio-based, biodegradable or both Others expressions, though not incorrect, like “bio-based polymer” or “renewably-sourced polymer” are also used to refer a polymer that contains carbon sourced from a renewable plant source or biomass.[4,5] The selection of polymer materials necessitates a thorough examination of mechanical qualities, chemical resistance, dimensional stability, and manufacturing process, all with an eye on future recycling or biodegradability. The efficacy of end-of-life recycling is determined by the heterogeneous composition of its components.

2.2 Natural Fibres

Natural fibres can be classified based upon their origin into the following groups: animal, mineral and plant. Plant fibres are the most commonly accepted fibres by the industry and the most analysed by the research community. This is mainly due to the short growth period, renewability and wider availability. The vegetable fibres are composed of cellulose, hemicellulose and lignin, which can be extracted from bast, leaf, seed, fruit, wood, stalk and grass/reed. The focus of this research is on vegetable fibres because all others have limited use or are outright prohibited by law. In actuality, animal fibres are rarely utilised, and asbestos has been banned due to the dangers of exposure and the threats to human health.

Natural fibres provide a number of advantages over synthetic fibres, including availability, low cost, low density, acceptable modulus-weight ratio, excellent acoustic damping, low manufacturing energy consumption, low carbon footprint, and biodegradability.

The large variety of properties are mainly dependent upon plant species, growth conditions and method of fibre extraction. Moreover, properties depend on the fibre cell geometry of each type of cellulose and its degree of polymerization It should be noted that linear cellulosic macromolecules are linked by hydrogen bonds and are closely associated with hemicelluloses and lignin which confer stiffness to fibre. Not only holds fibres together but also the cellulose within the fibre cell wall . Extraction, processing, manufacturing, use, disposal, and recycling are the general phases of the natural fibre life cycle. A large-scale manufacture and use of fibres is constrained by a number of issues. These elements have an impact on numerous stages of the natural fiber's life cycle, including soil composition and shape, hydrophilic nature of the fibres, microbial degradation, service life, and sunshine. The physical and chemical properties of natural fibres are linked to plant source, cultivation location, climate conditions, harvest window, use of Genetic Modified Organisms (GMO), pesticides and fertilizers

Researchers are also paying close attention to fibres like coir, flax, hemp, and jute. Among the selected natural fibres, species such as abaca and ramie, on the other hand, have the fewest publications published. The factors influencing the significant differences in publication intensity are as follows: the origin and the amount of plant area available throughout the planet (cotton, bamboo vs. pineapple, abaca), the readiness to be used as composite reinforcement material (sisal, hemp vs. ramie, banana) and overall mechanical properties (flax, jute vs. eucalyptus, banana). In recent years, natural fibres have become increasingly popular among researchers due to their sustainability and renewability characteristics.

Various mechanical qualities will necessitate varied fibre mass, and different fibre quality and dependability will result in different wastes and scrap during composites manufacture, as well as different needs for part replacement over time. Nonetheless, multiple studies show that natural fibres are less expensive than synthetic fibres in general. Bamboo shows the lowest density while abaca, pineapple, hemp and ramie have some of the highest ones among the natural fibres. Jute and coir have the lowest average diameter and bamboo and ramie are on average the thickest ones. Moreover, ramie is on average the longest fibre. Contrarily, banana, bamboo and coir are usually short-length fibres. The tensile strength variation among fibres has low amplitude, being cotton the one with the lowest average value and pineapple the strongest one in this property.

Natural fibres' rising potential allows for constant growth in terms of knowledge and understanding, as well as the generation of data to support future research and the development of innovative techniques to tackle obstacles. The two recent studies included are extensive and based on a large number of references, as well as reflecting and incorporating findings from previous research.

Another important aspect regarding the comparison of natural fibres properties is related with the process of obtaining the fibres from the plants. Many extraction techniques have been reported such as mechanical, chemical or a combination of both, some of them are rudimentary processes and there is no scientific consensus or standards allowing a robust comparison. In addition, natural fibres require the modification of the roughness and the surface physio-chemistry of fibres to improve functional properties such as wettability and dimensional stability, therefore increase their adhesion with hydrophobic matrix. [6-10].Typically, these may consist of water or dew retting on stalks or decorticated fibres plus mechanical scutching and chemical processing.

There is an important variability in the properties of most of the fibres and there is a relevant amplitude of properties among fibres. There is not one type of natural fibre that can be considered better than the others, meaning that the selection of the proper fibre depends largely on the application requirements and type of composite to be produced, fibre availability to answer to the product demand volume and the guarantee of properties levelling among different crops or batches (depending on the fibre origin, plant processing and post-treatments).

Fibres like cotton, flax, hemp and ramie exhibit the highest price, being higher than the one of glass fibre. Contrarily, coir, abaca and kenaf prices are far lower. The usefulness of compiling this data is to have the relative level of cost for each kind of fibre.

Regarding tensile strength Pineapple fibres has higher tensile strength with a relative low price. On the other side, ramie, cotton and flax show lower mechanical behaviour with a much higher price. Regarding the specific strength pineapple fibres keep a good position but bamboo fibre shows a higher value for the same kind of cost. Sisal also have a good performance when combining these two characteristics. Regarding the Young modulus with price analysis ramie higher mechanical behaviour is impaired by its higher price, assuming pineapple and bamboo fibres exhibit a good combined behaviour in this analysis.

III. APPLICATIONS

Despite the fact that natural fibre composites are most commonly used in the automotive industry, they are also used in textiles, medical, healthcare, and pharmaceuticals, home and personal care, food and feed additives, construction and furniture, packaging, pulp and paper, and bioenergy and biofuels.

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