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Plant fibre based bio-composites: Sustainable and renewable green materials

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ABSTRACT

The abundant availability and accessibility of plant fibres are the major reasons for an emerging new interest in sustainable technology. While focusing on the composite materials, the main points to be considered are environment friendliness and light weight, with high specific properties. This century has witnessed remarkable achievements in green technology in the field of materials science through the development of high-performance materials made from natural resources is increasing worldwide. Plant fibres are a kind of renewable resources, which have been renewed by nature and human ingenuity for thousands of years. The greatest challenge in working with plant fibre reinforced composites (PFRCs) is their large variation in properties and characteristics. A PFRCs properties are influenced by a number of variables, including the fibre type, environmental conditions, processing methods, and modification of the fibre. A detailed systematic review on these sustainable and renewable green materials is presented in this paper. The overall characteristics of plant fibres used in bio-composites, including source, type, structure, composition, as well as properties, will be reviewed. Finally, the review will conclude with recent developments and future trends of PFRCs as well as key issues that need to be addressed and resolved.

1. Introduction

There is an urgency to address the environmental and economic concerns in the production of new materials and hence in this regard these new materials based on plant fibres and bio-resins are able to produce green material [1,2]. Petroleum is a fossil fuel which is estimated to last for only another 50–60 years at the current rate of consumption [3]. Elevated environmental consciousness in the general public and preservation of non-renewable petroleum based materials has resulted in an extensive use of PFRCs for commercial applications. Restricting the emission of greenhouse effect causing gases such as CO_2 into the atmosphere, and an increasing awareness of the finiteness of fossil energy resources, lead to the development of new materials that are entirely based on renewable resources. Excessive use of petroleum based polymers causes to a serious depletion of landfill capacities. Besides, the government's plastic waste control legislations and the growing interest among the users in sustainable and environmentally friendly products drive the retailers and manufacturers trending towards their investment on the development of sustainable materials with acceptable cost, to alleviate an impact from global warming. Therefore, the public awareness of increased un-decomposable solid wastes and their impact to the environment has awakened a new interest in the area of developing fully biodegradable materials with acceptable properties. Recently, biodegradable materials have continued attracting much attention worldwide.

Manufacture of currently used materials is quite difficult as regards consumption of energy, raw materials and cost. Therefore there are efforts for finding suitable alternative material resources, while local, easily renewable resources are to be the advantageous alternative, on the condition of consequent processing with low energy requirements [4]. The readily available renewable material resources are very important also from the point of sustainability of material resources. One of the methods of solution is using naturally available fibrous resources from agriculture. Another promising method is using industrial waste or industrial recycled materials. Use of high quality structural materials, energetic design of energy saving structures and thermal insulation of existing structures is of prime importance for reducing energy requirements of structures. In such types of structures, where plant fibres are used, further positive factors take place, like thermal regulation of structures, protection from weather, protection

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from direct sunlight and others, which is supported by many scientific studies and results. To use all advantages of these systems, it is necessary to consider suitability of the structures, type of plants and their location in the plant as well as for example questions of keeping the plants [5–14].

In recent years, plant fibres have become an important class of reinforcing materials [15–17]. The total consumption of biodegradable materials is forecasted to grow at an average annual rate of nearly 13%, which are accounted as the major global markets for materials' consumption [18]. However, high price and limited properties of the fully degradable materials hinder the diversity of the usage. Therefore, in order to tackle on these problems and retard the exhaustion of natural resources, different projects along the line of developing biodegradable materials have emerged recently and it is general believed that these are one of most key materials in all industries in coming centuries. PFRCs are defined as a type of materials which are generally composed of plant fibre and biodegradable polymer, as a matrix. PFRCs have recently received substantial attention due to their potential for replacing conventional fibre reinforced composites, specifically glass fibre reinforced composites (GFRCs). It is forecasted that by 2020 fibres derived from bio-based sources will represent up to 28% of the total market of reinforcement materials [19].

The properties of these composites can be tailored for various types of applications by a proper selection of fibres, matrix, additives and manufacturing methods. The pre-treatment process of fibre plays a key role it controls the overall interfacial bonding properties and thus, successful stress transfer of resultant composites. Garbage wastes such as plastic grocery bags, food packaging materials, bottles, containers etc. are mainly responsible for causing environment pollution in urban areas due to non-biodegradable nature. To keep our environment safe and green, it is compulsory to reduce the use of such pollution causing garbage [20]. That is why; many countries banned plastic grocery bags responsible for so called white pollution. Alternative usage of biodegradable plastics and their plant fibre bio-composites gained more popularity because they are degraded easily after landfill. Therefore, it may lead to one of the solutions for the issue of disposal ground depletion [21,22]. Keeping this target, recent research efforts are being harnessed in developing a new class of fully bio-degradable composites by combining plant fibre with bio-degradable polymers [23].

This review focuses the potentiality of plant fibre based green materials. Due to their properties including high mechanical strength and excellent biocompatibility, they have gained more attention and growing field in materials technology. A general review on plant fibre and its composites was done by several researchers. Several fibres, especially bast and leaf fibres, and its composites were reviewed previously [24–30]. Several researchers are exploring plant-based bio-materials in the form of sheets, strands, particles, microfibres and nano-particles for different applications. Although there is a good amount of literature available on plant fibre based bio-materials, there is an inadequacy of extensive review articles that specifically focus on properties of plant fibre based bio-materials. In this work an attempt has been made to highlight the research that has been carried out in the field of plant fibre based bio-composites. It aims to provide an overview of the advances that have been made and the future course available. It will provide an overview of the plant fibres and its bio-composites as well as may direct the researchers to the specific areas of application.

2. Fibre plants

2.1. History and background

Over the last few years, there has been a dramatic increase in the use of plant fibres for making a sustainable eco-friendly and biodegradable materials [1]. Fibres from plants such as cotton, hemp, jute, sisal, pineapple, ramie, bamboo, banana, etc., as well as wood and seeds of flax are used as the reinforcement in polymer matrix composites [31–33]. Among all the fibre plants, areca appears to be a promising reinforcing material because it is inexpensive,abundantly available and a very high potential perennial crop. It belongs to the family palmecea, originated in the Malaya peninsular, and cultivated in India and other countries in Asia. In India, areca nut cultivation is coming up on a large scale basis with a view to attaining self sufficiency in medicine, paint, chocolate, gutka, etc. The husk of the are cais a hard fibrous portion covering the endosperm, which constitutes 30–45% of the total volume of the fruit. Areca husk fibres are predominantly composed of hemicelluloses and not of cellulose. Are cafibres contain 13to 24.6% of lignin, 35–64.8% of hemicelluloses,4.4% of ash and 8–25% of water content [34]. Kenaf is one of the plant fibres used as reinforcement in polymer matrix composites (PMCs). Kenaf has been found to be an important source of fibre for composites, and other industrial applications. Kenaf is well known as a cellulosic source with both economic and ecological advantages. It is able to grow under a wide range of weather conditions, to a height of more than 3 m and a base diameter of 3–5 cm within 3 months. This statement is supported by previous studies, which mentions that growing speed may reach 10 cm/day under optimum ambient conditions. The kenaf plant is composed of many useful components (e.g., stalks, leaves, and seeds) and within each of these there are various usable portions (e.g., fibres and fibre strands, proteins, oils, and allelopathic chemicals). The yield and composition of these plant components can be affected by many factors, including cultivar, planting date, photosensitivity, length of growing season, plant populations, and plant maturity [35,36].

It is a well known fact that banana is one ofthe oldest cultivated plant in the world. It belongs to the Musaceae family and there are approximately 300 species, but only 20 varieties are used for consumption. Approximately 70 million metric tons of bananas are produced every year by the tropical and subtropical regions of the world. The nutritional facts of banana are as follows: carbohydrates-18.8 g; protein-1.15 g; fat-0.18 g; water-73.9 g; vitamins C1, B1, B2, B6, E, other minerals-0.83 g and 81 kcal. Banana plants generally produce 30 large leaves (almost 2 m long and 30–60 cm wide) [37]. Hemp is naturally one of the most ecologically friendly fibres and also the oldest crop. The Columbia history of the world states that the oldest relics of human industry are bits of hemp fabric discovered in tombs dating back to approximately 8000 BCE. Hemp is an annual plant native to central Asia and known to have been grown for more than 12,000 years. It probably reached central Europe in the Iron Age and there is evidence of its growth in the UK by the Anglo Saxons (800–1000 CE). It is now grown mostly in the EU, central Asia, Philippines, and China. According to Food and Agriculture Organisation (FAO), almost half of the world's industrial hemp supply is grown in China, with most of the remainder being cultivated in Chile, France, the democratic people's republic of Korea and Spain [38].

Bio-mass waste from palm plantation and palm industry are challenging as bio-pellet based material. The utilization of oil palm solid waste gives positive impact not only for the environment but also to the wellness and economical sector. By integrated waste management provide production process that more efficient in economic side. Solid waste that has been passed through in advance process could be used as a diversification product and give the economic value for oil palm industry. It could be assumed, 50% of solid waste materials used for energy consumption in process needs, so that for the excess one could be give an alternative eco-friendly fuel used for other industrial fuel, household, electricity, and also become potential export commodity [39].

Jute is a bast fibre originated from Tiliaceae family and takes nearly 3 months to grow to a height of 12–15 feet. Jute plant is cut and kept immersed in the water for retting process during rainy season. The inner stem and outer gets separated and the outer plant gets individualized to form fibres. Jute fibre is known as golden fibre, and is grown in Eastern India and Bangladesh [1,40]. Bamboo belongs to the grass family Bambusoideae, which consists of cellulose fibre