



Review

Biofibres and biocomposites

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Abstract

This review deals with a recent study of the literature on the various aspects of cellulosic fibres and biocomposites. Cellulosic fibre reinforced polymeric composites are finding applications in many fields ranging from construction industry to automotive industry. The pros and cons of using these fibres are enumerated in this review. The classification of composites into green composites, hybrid biocomposites and textile biocomposites are discussed. New developments dealing with cellulose based nanocomposites and electrospinning of nanofibres have also been presented. Recent studies pertaining to the above topics have also been cited. Finally, the applications of cellulosic fibre reinforced polymeric composites have been highlighted.

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1. Lignocellulosic fibres/natural fibres

Natural fibres are subdivided based on their origins, coming from plants, animals or minerals. All plant fibres are composed of cellulose while animal fibres consist of proteins (hair, silk, and wool). Plant fibres include bast (or stem or soft sclerenchyma) fibres, leaf or hard fibres, seed, fruit, wood, cereal straw, and other grass fibres. Over the last few years, a number of researchers have been involved in investigating the exploitation of natural fibres as load bearing constituents in composite materials. The use of such materials in composites has increased due to their relative cheapness, their ability to recycle and for the fact that they can compete well in terms of strength per weight of material. Natural fibres can be considered as naturally occurring composites consisting mainly of cellulose fibrils embedded in lignin matrix. The cellulose fibrils are aligned along the length of the fibre, which render maximum tensile and flexural strengths, in addition to providing rigidity. The reinforcing efficiency of natural fibre is related to the nature of cellulose and its crystallinity. The

main components of natural fibres are cellulose (α -cellulose), hemicellulose, lignin, pectins, and waxes.

Cellulose is a natural polymer consisting of D-anhydro-glucose ($C_6H_{10}O_5$) repeating units joined by 1,4- β -D-glycosidic linkages at C₁ and C₄ position (Neveall & Zeronian, 1985). The degree of polymerization (DP) is around 10,000. Each repeating unit contains three hydroxyl groups. These hydroxyl groups and their ability to hydrogen bond play a major role in directing the crystalline packing and also govern the physical properties of cellulose. Solid cellulose forms a microcrystalline structure with regions of high order i.e. crystalline regions and regions of low order i.e. amorphous regions. Cellulose is also formed of slender rod like crystalline microfibrils. The crystal nature (monoclinic sphenoidic) of naturally occurring cellulose is known as cellulose I. Cellulose is resistant to strong alkali (17.5 wt%) but is easily hydrolyzed by acid to water-soluble sugars. Cellulose is relatively resistant to oxidizing agents.

Hemicellulose is not a form of cellulose and the name is a misnomer. They comprise a group of polysaccharides composed of a combination of 5- and 6-carbon ring sugars. Hemicellulose differs from cellulose in three aspects. Firstly, they contain several different sugar units whereas cellulose contains only 1,4- β -D-glucopyranose units.

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Secondly, they exhibit a considerable degree of chain branching containing pendant side groups giving rise to its non crystalline nature, whereas cellulose is a linear polymer. Thirdly, the degree of polymerization of native cellulose is 10–100 times higher than that of hemicellulose. The degree of polymerization (DP) of hemicellulose is around 50–300. Hemicelluloses form the supportive matrix for cellulose microfibrils. Hemicellulose is very hydrophilic, soluble in alkali and easily hydrolyzed in acids.

Lignin is a complex hydrocarbon polymer with both aliphatic and aromatic constituents. They are totally insoluble in most solvents and cannot be broken down to monomeric units. Lignin is totally amorphous and hydrophobic in nature. It is the compound that gives rigidity to the plants. It is thought to be a complex, three-dimensional copolymer of aliphatic and aromatic constituents with very high molecular weight. Hydroxyl, methoxyl and carbonyl groups have been identified. Lignin has been found to contain five hydroxyl and five methoxyl groups per building unit. It is believed that the structural units of lignin molecule are derivatives of 4-hydroxy-3-methoxy phenylpropane. The main difficulty in lignin chemistry is that no method has been established by which it is possible to isolate lignin in its native state from the fibre. Lignin is considered to be a thermoplastic polymer exhibiting a glass transition temperature of around 90 °C and melting temperature of around 170 °C (Olesen & Plackett, 1999). It is not hydrolyzed by acids, but soluble in hot alkali, readily oxidized, and easily condensable with phenol (Bismarck, Mishra, & Lampke, 2005).

Pectins are a collective name for heteropolysaccharides. They give plants flexibility. Waxes make up the last part of fibres and they consist of different types of alcohols.

Biofibres can be considered to be composites of hollow cellulose fibrils held together by a lignin and hemicellulose matrix (Jayaraman, 2003). The cell wall in a fibre is not a homogenous membrane (Fig. 1). Each fibril has a complex, layered structure consisting of a thin primary wall that is the first layer deposited during cell growth encircling a secondary wall. The secondary wall is made up of three layers and the thick middle layer determines the mechanical properties of the fibre. The middle layer consists of a series of

helically wound cellular microfibrils formed from long chain cellulose molecules: the angle between the fibre axis and the microfibrils is called the microfibrillar angle. The characteristic value for this parameter varies from one fibre to another.

Such microfibrils have typically a diameter of about 10–30 nm and are made up of 30–100 cellulose molecules in extended chain conformation and provide mechanical strength to the fibre. The amorphous matrix phase in a cell wall is very complex and consists of hemicellulose, lignin, and in some cases pectin. The hemicellulose molecules are hydrogen bonded to cellulose and act as cementing matrix between the cellulose microfibrils, forming the cellulose–hemicellulose network, which is thought to be the main structural component of the fibre cell. The hydrophobic lignin network affects the properties of other network in a way that it acts as a coupling agent and increases the stiffness of the cellulose/hemicellulose composite.

The structure, microfibrillar angle, cell dimensions, defects, and the chemical composition of fibres are the most important variables that determine the overall properties of the fibres (Satyanarayana et al., 1986). Generally, tensile strength and Young's modulus of fibres increases with increasing cellulose content. The microfibrillar angle determines the stiffness of the fibres. Plant fibres are more ductile if the microfibrils have a spiral orientation to the fibre axis. If the microfibrils are oriented parallel to the fibre axis, the fibres will be rigid, inflexible and have high tensile strength. Some of the important biofibres are listed in Table 1.

1.1. Cellulosic fibres: advantages and disadvantages

The growing interest in lignocellulosic fibres is mainly due to their economical production with few requirements for equipment and low specific weight, which results in a higher specific strength and stiffness when compared to glass reinforced composites. They also present safer handling and working conditions compared to synthetic reinforcements. Biofibres are nonabrasive to mixing and molding equipment, which can contribute to significant cost reductions. The most interesting aspect about natural fibres is their positive environmental impact. Biofibres are a renewable resource with production requiring little energy. They are carbon dioxide neutral i.e. they do not return excess carbon dioxide into the atmosphere when they are composted or combusted. The processing atmosphere is friendly with better working conditions and therefore there will be reduced dermal and respiratory irritation. Biofibres possess high electrical resistance. Thermal recycling is also possible. The hollow cellular structure provides good acoustic insulating properties. The worldwide availability is an additional factor.

The inherent polar and hydrophilic nature of lignocellulosic fibres and the non-polar characteristics of most thermoplastics results in compounding difficulties leading to non-uniform dispersion of fibres within the matrix which

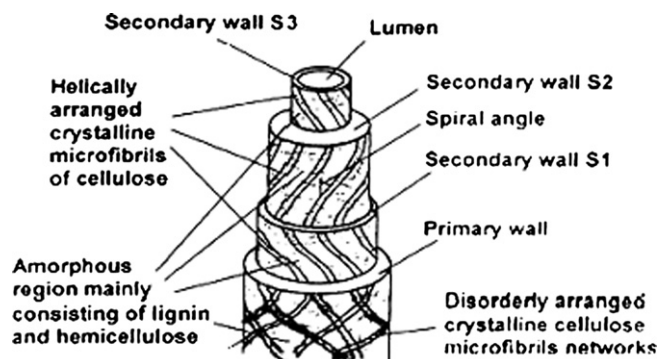


Fig. 1. Structure of biofibre.

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