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Biocomposites: An Overview

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ABSTRACT

Now a days, different industrial sectors such as aerospace, automotive, and civil applications are extensively using polymer matrices based composite materials. Due to rising environmental awareness, the usage of synthetic fibers such as glass fibers have been drastically reduced and the trend of using natural fibers to prepare biocomposites have been widely employed. The natural fibers are low-cost, recyclable, eco-friendly and bio-degradable materials. This paper provides the first time readers an insight into the domain of biocomposites. It aims at briefing the readers about the classification, natural fibers, natural/synthetic matrices, various fiber treatment methods, prevalent processing techniques, performance testing, potential and challenges of biocomposites.

Keywords

Biocomposites; Natural fibres; Green composites; Biopolymer; Biomatrix

1. Introduction

Biocomposite is a composite material formed by a matrix (resin) and a reinforcement of natural fibers. These materials often mimic the structure of the living materials involved in the process keeping the strengthening properties of the matrix that was used, but always provides biocompatibility. The matrix phase is formed by polymers derived from renewable and non-renewable resources. The matrix serves in protecting the fibers from environmental degradation and mechanical damage to hold the fibers together and so as to transfer the loads on it. In addition, biofibers are the principal components of biocomposites, which are derived from biological origins, for example, fibers from plants/crops (cotton, flax or hemp), recycled wood, waste paper, crop processing byproducts or regenerated cellulose fiber (viscose/rayon) or animal based fibres such as wool, silk and feathers.

The interest in biocomposites is rapidly growing in terms of industrial applications in automobiles, railway coaches, aerospace, military applications, construction, and packaging and fundamental research, due to many potential benefits such as renewability, cheaper in cost, recyclability, and biodegradability, light weight, high specific strength and ease in availability. Biocomposites can be used alone or as a complement to standard materials such as carbon fiber and glass. Advocates of biocomposites state that the use of these materials improves health and safety in their production, lighter in weight, have a visual appeal similar to that of wood and are environmentally superior. However, biocomposites have their inherent share of disadvantages such as hydrophilic nature, poor dimensional stability, low heat and fire resistance [1]. Green composites are a specific class of biocomposites where a bio-based polymer matrix is reinforced by natural fibers, and they represent an emerging area in polymer science. This means that both fiber and matrix are obtained from renewable resources [2]. Hybrid Biocomposite is another class of biocomposite that contains different types of fibres in a single matrix. A combination of natural fibers or a mix of natural and man madefibres can be used for the purpose.

2. Natural fiber reinforcement

Natural fiber can be classified into plant based and animal based. Plant based fibers can be further sub-classified into bast fibers (jute flax, hemp, ramie and kenaf), leaf fibers (abaca, sisal and pine apple), seed fibers (coir, cotton and kapok), core fibers (kenaf, hemp and juite), grass and reed fibers (wheat, corn and rice) and wood fibers commonly used in pulp form. Animal based fibres containing proteins include silk, wool and feathers [3].

2.1 Matrix

The shape, appearance, protection from the environment and durability of the composite depends on the matrix. Matrix can be categorized into 1) Petroleum based 2) Biobased. Natural fibres have been extensively used with thermoplastics and thermosetting matrixes. Thermoplastics matrixes include polypropylene (PP), polyethylene (PE), polystyrene (PS), and polyvinyl chloride (PVC), whereas Polyester, epoxy resin, phenol formaldehyde and vinyl esters are commonly used thermoplastics matrices. PP and PE are widely used thermoplastics in natural fibre reinforced composites (NFC). Modulus and strength of thermosets are higher than thermoplastics but the former's use is limited due to its non-recyclability. Environmental concerns and rapidly depleting fossil fuels have been the factors that have motivated researchers to work on bio-based polymers as a viable alternative for petroleum based products. Starch, PLA (polyactic acid) and PHA (polyoxyalkanoate) are polymers developed from renewable resources [1, 3].

2.2 Treatment of Natural Fibers

The main disadvantages of natural fibers in respective composites are the poor interface adhesion between fiber and matrix and their relatively high moisture absorption. Therefore, natural fibers are modified so as to change fiber surface properties to improve their adhesion with different matrices. A strong interface, very brittle in nature with easy crack propagation through the matrix and fiber imparts high strength and stiffness. A weaker interface reduces the efficiency of stress transfer from the matrix to the fiber. Extensive research was carried out and reported in the literature, showing the importance of the interface and the influence of various types of surface modifications on the physical and mechanical properties of natural fiber reinforced composites [3].

The observed trend indicate a preference for the chemical modification (alkaline, silane,acetylation, benzoylation, acrylation and acrylonitrile grafting, maleated coupling, permanganate, peroxide, and isocyanate treatment) [3,4] compared to physical modification (corona and plasma treatment). It has also been illustrated that maleated and silane treatment is being preferred due to favourable results [5-7]. Additive suppliers improved the quality of additives with higher amounts of anhydride functional groups than previous grades (used in 1980s and 1990s), which create more sites for chemical links, resulting in significant performance improvement at low additive contents. The usage of coupling agents reduced the tendency of water absorption of the composites. Enzyme treatment to modify surface of natural fibers is gaining momentum as it is environment friendly. Also, it is cheap and performs better as compared to frequently used maleated and saline methods for fiber treatment [1, 3].

3. Processing Methods

Moisture content, fiber type and content and fiber orientation are factors that affect processing of composites. Fiber drying is essential before processing. Fiber geometry (short or long, length to diameter ratio) and type of fiber also have an impact on processing. Majority of natural fiber composites are manufactured by injection moulding, extrusion, compression moulding, sheet moulding and RTM. However, new equipments such as unique heating system, single or dual venting system for in-line drying and variety of feeding mechanisms have come up that can improve the processing of composites. Choice of manufacturing process primarily depends on the product size. Small to medium components are manufactured by injection and compression moulding while large components are open moulded. Manufacturers are exploring pultrusion method for making natural fiber composites [3].

3.1 Performance

Tensile, bending and impact properties of natural fiber composites are usually studied. Natural fiber composites have low impact strength. In addition thermal, erosion properties [8, 9], creep, compressive properties, dynamic loading responses [3] are also investigated by scientists and researchers. Kumar and Das [10] used carding and compression-moulding processes for preparing fibrous biocomposites using nettle and

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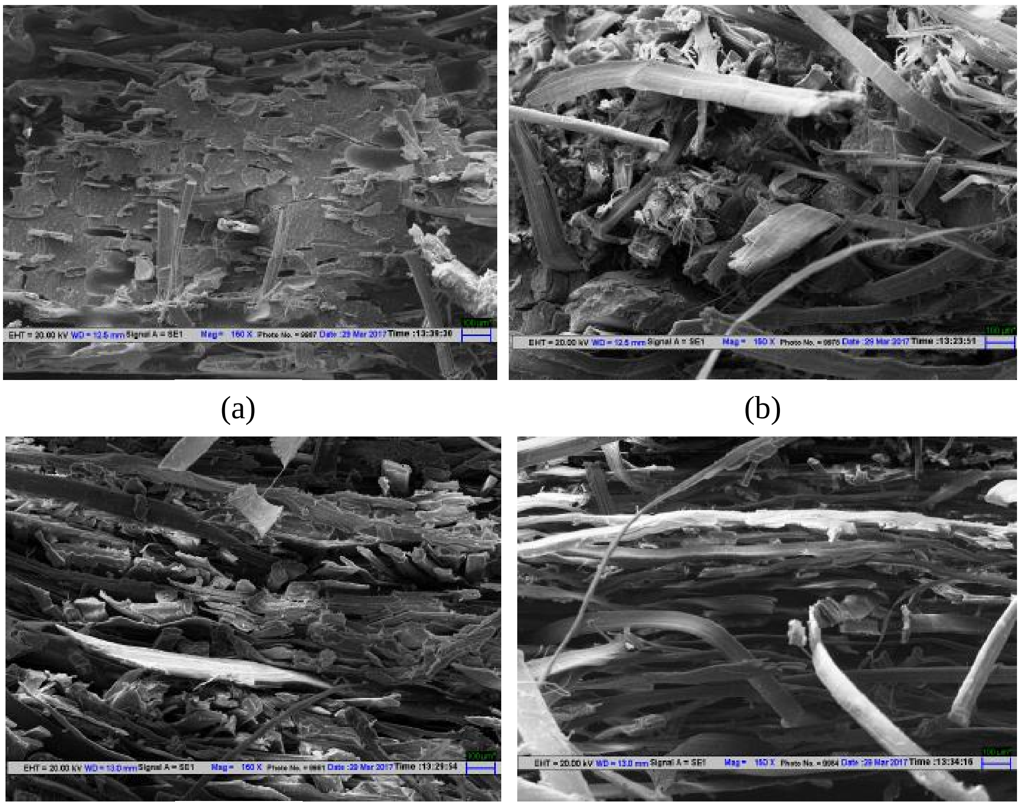
poly (lactic acid) fibers. It was found that the tensile, bending and impact properties of the biocomposites increased in the beginning with increase in content of nettle fibers up to 50 wt% and then, they decreased (Fig. 1). It is seen that when the weight percentage of fiber increased beyond 50 wt% of nettle fibers, the fiber accumulation amplified in the structure. Thus, more number of failure points were generated thereby decreasing the tensile strength with increase in fiber weight percentage. The thermo-gravimetric analysis showed that the biocomposite's thermal stability boosted with increase in nettle fiber content. The dynamic mechanical analysis revealed that the biocomposites displayed high storage modulus, low damping factor and low loss modulus. It was further found that the biodegradability of the biocomposites increased with increase in nettle fiber content. Finally, it was concluded that the biocomposite made from equal weight proportion of nettle and poly (lactic acid) can be successfully used for automotive dashboard panel application.

Wu at al [11] used flax-fibre weaves as reinforcement on plasticised wheat gluten so as to improve the strength and crack-resistant property of biocomposite. The composites were prepared by dip-coating of the flax-fibre weave into a wheat gluten/glycerol (WGG) solution, or by compression moulding technique. It was found that the bond between the fibres and the matrix augmented with increase in glycerol content, and compression moulding produced biocomposites having lowest porosity and the most extensive wetting property of the yarn. Horizontal dip-coating technique formed more homogeneous composite and yielded considerably stiffer and stronger materials (Fig 2). However, it was found that the samples produced by dip-coating demonstrated only a slightly lower stiffness and strength similar to that of the compression-moulded samples at comparable flax and plasticiser content. The main advantage of this process is that the biocomposites can be formed plastically under ambient conditions with increased strength and crack resistance.



(a) (b)

(c) (d)

Fig. 1. SEM images of cryo-fractured biocomposites prepared with (a) 10 wt % (b) 25 wt% (c) 50 wt% (d) 75 wt% nettle fibers

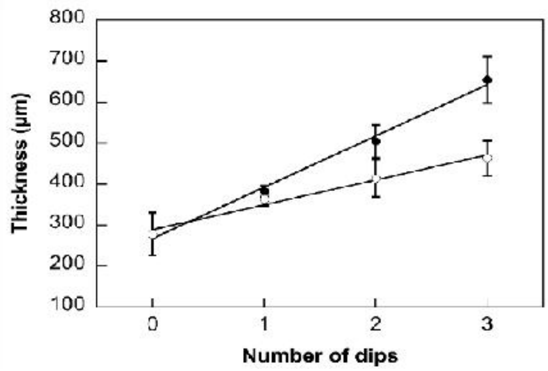


Fig. 2. The sample thickness as a function of the number of dips using the horizontal (●) and vertical (○) methods.

Porras et al [12] prepared green composites manufactured with poly-lactic acid (PLA) matrix reinforced with Manicaria Saccifera fabric (MF) and studied the tensile strength and elastic modulus. The processing parameters, compression moulding parameters, fabric chemical treatment parameters and fiber content were studied concurrently to yield optimum biocomposite properties. The experiments were planned as per Taguchi's L18 Orthogonal array. The optimum combination of input process parameters to generate optimum tensile properties was found to be low chemical treatment concentration, high chemical treatment time, high compression moulding temperature, high compression moulding pressure, high compression moulding time and medium fiber-weight ratio. The statistically significant process parameters were found to be processing pressure, processing temperature and fiber content, respectively. The tensile-fractured surface of both the untreated fabric composite and the optimized composite at different magnifications are shown in Fig. 3.

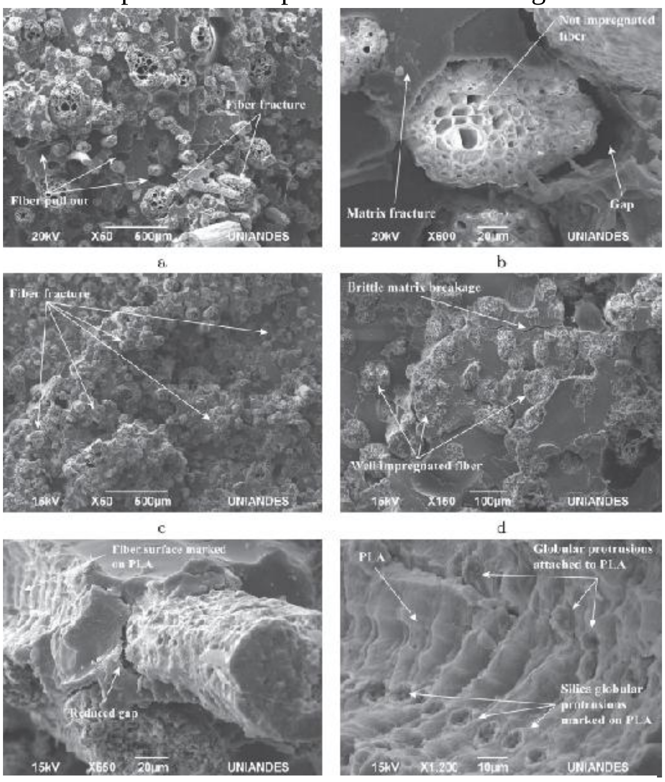


Fig. 3. SEM micrographs of tensile fractured surface. (a and b) Untreated fabric composite and (c–f) optimized composite.

The chief failure mechanisms recognized in both materials were found to be fiber pullout, fiber fracture and matrix breakage respectively. However, from Figs. 3a and 3b, it is clearly seen that fiber pull-out failure was prevailing in the untreated fabric composite indicating low fiber/matrix adhesion and the fibers were not well infused by the resin due to the presence of epidermis, cell wall and lumen of the fiber. Fig. 3c illustrates that the fiber fracture was the predominant failure mechanism in the optimized composite indicating strong adhesion and high fiber/matrix interfacial bonding. The fibers were found to be well permeated by the PLA matrix. The voids which comprised the microstructure of the fiber were packed by the matrix as evident from Fig. 3d. Fig. 3e shows that the gaps between the fiber and PLA matrix were decreased. The globular protrusions seen on the fiber surface were spotted on the resin (Fig. 3f) which indicates fine mechanical interlocking between the fiber and the PLA matrix. The tensile fracture analysis proved the causes for the improved mechanical properties of the optimized composite as compared to that of untreated fabric composite. Thus, the authors proved that MF is an effective reinforcement for building green composites for structural and non-structural applications.

3.2 Biocomposites-Potential and challenges

Biocomposites have come a long way forward from the mud and straw era and find diverse applications in automotive, construction, packaging and health care sectors. Natural materials can be innovatively used in making bicycles out of bamboo, marine crafts from flax, aircraft rudders made from hemp, wooden monitors for PCs and laptops [13]. Biocomposites have good specific properties but their properties often display large variations, reduced performance with time and low impact strength. New avenues can open up if bioproducts can have enhanced durability and dimensional stability along with being moisture proof and fire retardant. Nanotechnology has added a new dimension to biocomposite products by improvement of properties through coatings. Nanocrystalline cellulose is stronger than steel and stiffer than aluminium [2].

4. Conclusion

This review article is based on usage of natural fibers in preparing biocomposites, as natural fibers are low-cost, recyclable, eco-friendly and bio-degradable materials. These characteristics possessed by the natural fibers are making them as substitute to replace glass and carbon fibers. This paper unearths the key elements pertaining to biocomposites before the first time reader enabling him/her to channelize the searches for delving deep into the intriguing world of biocomposites.

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