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Research Article

Advanced Biocomposites: Processing, Characterization and Applications

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Abstract – Natural fibers are being viewed as an alternative to synthetic fibers as environmental management and sustainability gain relevance. Both renewable and biodegradable, natural fibers are. In this way, it makes synthetic fibers more affordable. Natural fibers have several beneficial qualities, including high strength and sustainability, low specific density, and low cost. Natural fibers can be used, however their utilization is constrained by weak characteristics such matrix/fibre interactions and water resistance. Despite having excellent mechanical qualities, synthetic fibers like glass, carbon, and aramid have negative effects on human health and the environment. Combining natural and synthetic fibers is an excellent way to get around the drawbacks currently present. A new class of materials called advanced biocomposites combines the advantages of natural and synthetic components to produce desired qualities including improved mechanical, thermal, and biological performance. The goal of this research project is to examine the state-of-the-art in advanced biocomposites' processing, characterisation, and applications. The study will concentrate on the most recent advancements in processing technologies for biocomposite materials as well as the numerous characterization and testing procedures. Finally, the study will look into how advanced biocomposites might be used in industries including automotive, aerospace, biomedicine, and environmental. Future study will show that increasing the usage of these eco-friendly composite materials across a wide range of industrial sectors will lower pollution and increase societal sustainability standards.

Keywords – Natural Fibers, Synthetic Fibers, Advanced Biocomposites, Processing Techniques, Characterization Methods.

INTRODUCTION

A rising number of people are now interested in creating sustainable materials to take the place of composites and traditional plastics. Advanced biocomposites are the subject of a flurry of studies as a result of the rising need for sustainable materials. Due to their renewability, biodegradability, and minimal environmental impact, biocomposites—materials constructed from natural fibers and matrices—have become a possible replacement for synthetic materials. Using biocomposites might also lessen reliance on fossil fuels, cut carbon emissions, and solve the expanding issue of environmental plastic waste [1,2].

Advanced biocomposites are made from natural and synthetic components and manufactured utilizing a variety of methods, including compression molding, injection molding, and extrusion. By changing the composition, production conditions, and additions of these materials, the characteristics can be adjusted to match certain requirements [3].

Based on the kind of reinforcement fibers and matrices employed, biocomposites can be categorized. Natural fibers like hemp, flax, sisal, and jute are the most popular types of reinforcing fibers, whereas matrices can be created from biopolymers including starch, cellulose, chitosan, and alginate. Nanocellulose, a nanomaterial made from plant cell walls that possesses excellent strength, stiffness, and aspect ratio, can also be used to reinforce biocomposites [4].

The kind and quantity of reinforcing fibers, the type of matrix, the processing conditions, and the location of the fibers and matrix contact all affect the properties of biocomposites. By enhancing these elements and creating novel processing methods, biocomposites' mechanical, thermal, and barrier qualities can be enhanced. Designing biocomposites with specific qualities also requires an understanding of the molecular interactions between the matrix and the fibers [5].

Biocomposites have a wide range of uses, including in the automotive [4], aerospace [5], building [6], packaging [7], and biomedical [8] sectors. Biocomposites can be utilized for light weighting in the automotive and aerospace industries, which can result in fuel savings and lower emissions. Biocomposites can be utilized in the construction sector for structural, flooring, and insulation purposes. Biocomposites can be utilized in the packaging business for single-use items including cutlery, glasses, and plates. Biocomposites can be employed for tissue engineering, medication delivery, and wound healing in the biomedical sector [4–8].

In spite of the potential advantages of biocomposites, there are still issues that must be resolved if they are to live up to their full potential. Increasing the production of biocomposites for industrial applications, lowering the cost of raw materials, and enhancing the compatibility of the reinforcing fibers and matrix are some of these difficulties. Interdisciplinary research including materials science, chemistry, and engineering is necessary to tackle these problems [9].
This proposal's goal is to analyze recent developments in the characterization, processing, and use of biocomposites in this context. This proposal will concentrate on the development of new characterisation methods, the use of alginate in biomedical applications, and the use of nanocellulose as a reinforcing agent. The suggested review would outline the present state of the art in biocomposites and point out any open problems and areas for further study.

Classification of biocomposites

The natural fibers that make up the biocomposites consist of wood and non-wood species. Figure 1 shows a classification for this. In addition, fibers with load-bearing properties, the most basic component of composite materials, are examined as natural and synthetic fibers (Figure 2). An overview of the composites reinforced with natural and synthetic fibers that make up the advanced composites is presented in Figure 3.

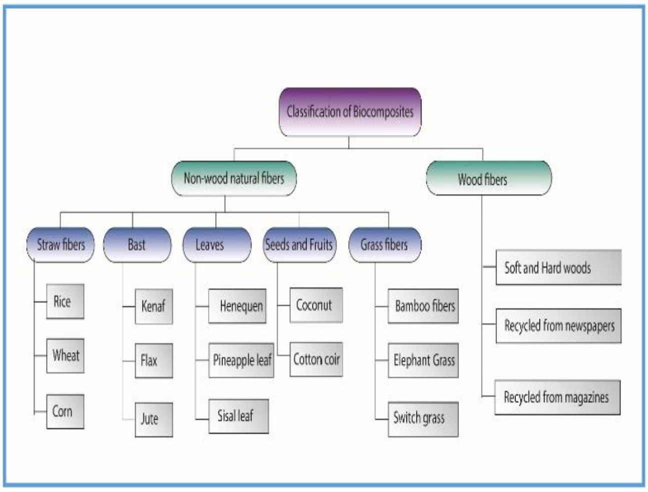

Fig. 1 Sorting biocomposites into categories [10].

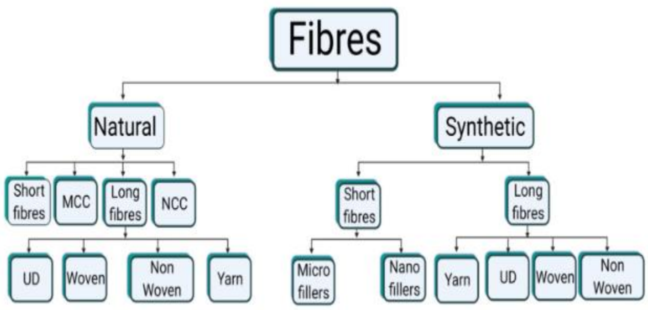

Fig. 2 Natural and synthetic fiber types [11].

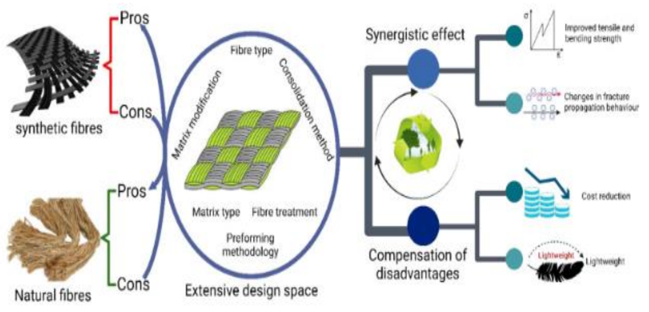

Fig. 3 General state of natural and synthetic fiber reinforced composites [11].

Materials and Methods

Based on the processing techniques, the investigations will be split into three main categories: hybrid biocomposites, natural fiber-reinforced biocomposites, and synthetic fiber-reinforced biocomposites. Some examples of natural fiber-reinforced biocomposites include cellulose, hemp, sisal, jute, and flax fibers [12]. Among the components employed in the synthetic fiber-reinforced biocomposites include carbon, glass, and aramid fibers [13–15]. Hybrid biocomposites are made by combining fibers from both natural and synthetic sources. These materials can be processed by extrusion, injection molding, compression molding, and 3D printing, among other techniques [16].

The research will be divided into four major areas based on their characterization and testing, including mechanical testing, thermal analysis, biological testing, and morphological analysis. Tensile, flexural, compression, and impact testing are all part of the mechanical testing [17]. Differential scanning calorimetry (DSC), thermogravimetric analysis (TGA), and dynamic mechanical analysis (DMA) are all included in the thermal analysis [18]. Studies on cell growth, cytotoxicity, and biocompatibility will all be part of the biological testing [19]. Microscopy and X-ray diffraction are included in the morphological analysis [20].

The investigations will be divided into four key application categories: automotive, aerospace, biomedical, and environmental. Dashboard panels, door trims, and body panels are only a few examples of the interior and exterior parts that will be used in automotive applications [21]. Wings, fuselage, and engine sections are only a few examples of structural components that will be used in aircraft applications [22]. Implants, scaffolds, and medication delivery systems will all be utilized in biomedical applications [23]. Water filtration systems and biodegradable packaging materials are two examples of environmental uses [24].

Processing of Advanced Biocomposites

Advanced biocomposites go through a number of processes throughout production, including choosing the raw materials, pretreatment, and composite construction. Natural fibers, nanocellulose, and biodegradable polymers are some of the raw materials used in biocomposites. To increase their compatibility and mechanical qualities, these raw materials are processed using a variety of techniques, such as chemical or physical alteration. There are several different methods used to manufacture composites, including manual lay-up, compression molding, injection molding, pultrusion, and extrusion. In Figure 4, various production methods are displayed. In addition, Figures 5-8 provide detailed illustrations of a few of these techniques.

The use of nanocellulose as a reinforcing agent in the production of biocomposites is a noteworthy development. The mechanical, thermal, and barrier properties of biocomposites can be improved by using the renewable and biodegradable ingredient known as nanocellulose. Because of their superior mechanical qualities and biocompatibility, nanocellulose-reinforced composites have prospective uses in the packaging, automotive, and biomedical industries, according to some researchers analysis of the features and uses of these materials.

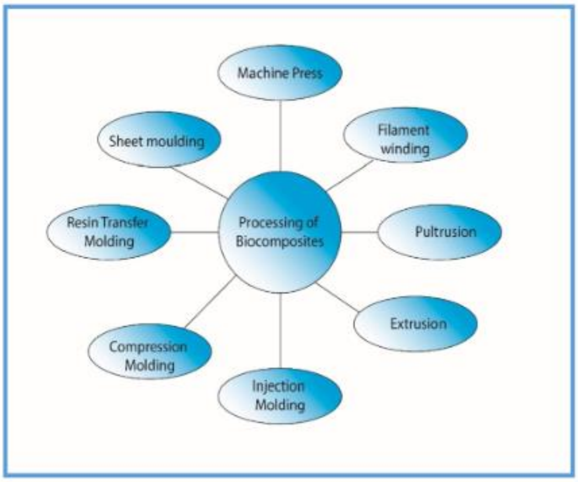

Fig. 4 Production processes [25].

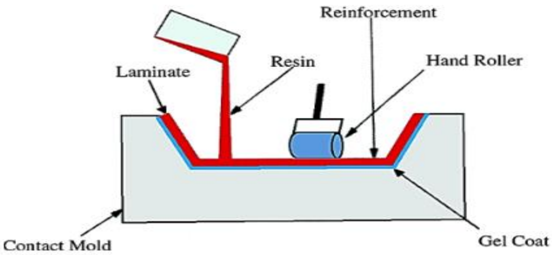

Fig. 5 Hand lay-up [26].

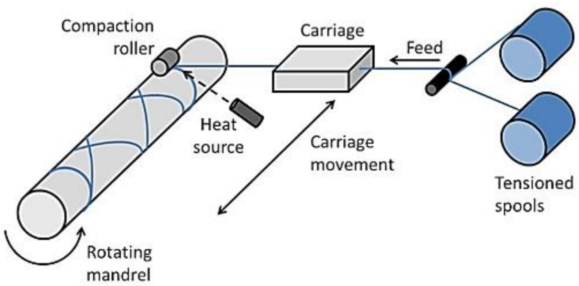

Fig. 6 Filament winding [26].

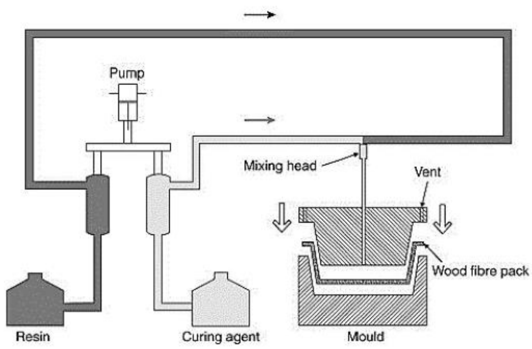

Fig. 7 Resin transfer moulding [26].

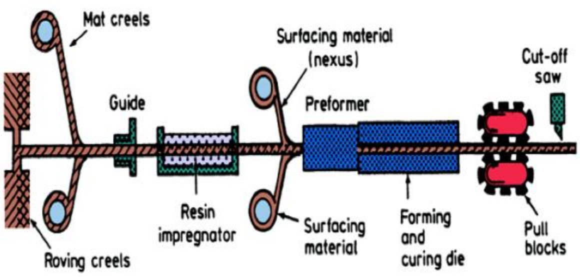

Fig. 8 Pultrusion process [26].

Characterization of Advanced Biocomposites

Understanding advanced biocomposites' structure, morphology, and characteristics requires their characterization. Thermal analysis, Fourier transform infrared spectroscopy, scanning electron microscopy (SEM), and others are used to characterize biocomposites. These methods offer important insights into the degree of crystallinity, thermal stability, and interfacial interaction between components in biocomposites.

The use of Raman spectroscopy is one recent advancement in the characterisation of biocomposites. Raman spectroscopy is a non-invasive, non-destructive method for learning about the molecular makeup and structure of materials. Raman spectroscopy was used to study the interface contact between chitosan and cellulose nanofibers, and it was discovered that it could be a useful tool to learn more about the molecular interactions between different parts.

Applications of Advanced Biocomposites

Advanced biocomposites are used in a wide range of sectors, including the automotive, packaging, and biomedical ones. These uses are made possible by their special qualities, including biodegradability, renewability, and mechanical strength. In automotive applications, biocomposites are utilized to reduce weight, increase fuel efficiency, and cut carbon emissions. Table 1 provides examples of how natural fiber reinforced composites are used in the automobile sector. Biocomposites in packaging provide greater barrier qualities, increased shelf life, and little environmental effect. Due to their biocompatibility and biodegradability, biocomposites are employed in biomedical applications for tissue engineering, wound healing, and drug delivery systems. Figure 9 lists some applications for natural fiber reinforced composites.

The use of alginate in biomedical applications represents a significant advancement in the utilization of biocomposites. In order to create hydrogels, alginate, a naturally occurring polysaccharide obtained from seaweed, can be cross-linked with different divalent cations.

Table 1. Components manufactured of natural fiber composite materials for the automotive sector [26].

Car Brand	Model(s)	Manufactured Components
Audi	A2, A3, A4, A6, A8, Coupe	Tire-lining, boot-lining, back and side door panels, hat rack and seat back
BMW	3 series, 5 series and 7 series	Boot-lining, seat back, headliner panel, noise insulation panels and door panels
Mercedes Benz	C class, S class, E class, and A class	Trunk panel, door panel, seat backrest panel, head-lining and noise insulation panels
Opel	Astra, Vectra and Zafira	Door panels, pillar cover panel, head-liner panel and instrumental panel
Volkswagen	Bora, Passat and Golf	Boot-lining, door panels, seat back, and boot-lid finish panel
Peugeot	406	Rear and front door panels, parcel shelf and seat backs
Volvo	S40, C70	cargo floor tray and seat padding
Ford	Focus and Mondeo	Floor trays, door inserts, door panels, B-pillar, and boot-liner
Fiat	Romeo, Brava, Punto and Marea	Door panels
Citroen	C5	Rear parcel shelf
Toyota	Brevis, Corolla, and Harrier	Seat backs, door panels, tire cover and floor mats
Renault	Megane and Clio	Interior door panelling

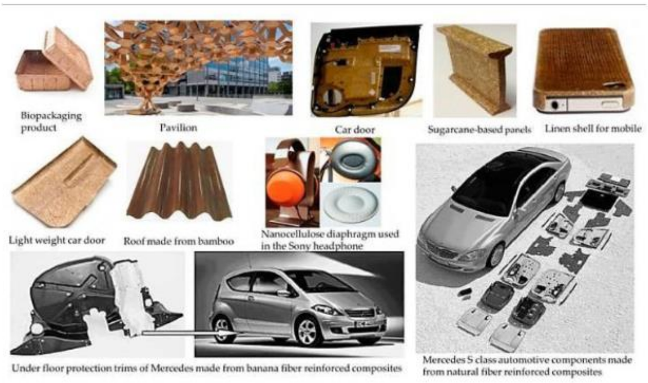

Fig. 9 Various applications for natural fibre reinforced composites [26].

RESULTS and DISCUSSION

A viable replacement for conventional petroleum-based composites has evolved in the form of advanced biocomposites. These materials have drawn the attention of both academics and business due to their potential for sustainability, biodegradability, and renewability. Recent advancements in biocomposites' processing, characterisation, and applications present substantial prospects to create new materials for a variety of industries. Advanced biocomposites can offer a wide range of features and possible uses in many industries, such as automotive, packaging, and biomedical, by utilizing various natural and synthetic components, such as natural fibers, nanocellulose, and biodegradable polymers.

The characteristics of biocomposites have been enhanced, and important new insights into their molecular interactions have been gained, thanks to the use of nanocellulose as a reinforcing agent and the development of new characterisation techniques like Raman spectroscopy. Alginate's usage in biomedical applications has also created new opportunities for tissue engineering, medication delivery, and wound healing.

The creation of biocomposites must, however, also contend with a number of difficulties. These difficulties include enhancing the compatibility of various parts, lowering the price of raw materials, and increasing the production of biocomposites for industrial uses. Interdisciplinary research including materials science, chemistry, and engineering is necessary to tackle these problems.

The creation of sophisticated biocomposites has the potential to significantly lessen the environmental effect of composite materials and offer sustainable substitutes for a variety of sectors. To create new materials, enhance processing methods, and comprehend the molecular characteristics of biocomposites, more study is required.

CONCLUSION

This research sheds light on the most recent advancements in advanced biocomposites, including their properties, production methods, and possible applications. The study included recommendations for future research as well as pointed out gaps and difficulties in the field. Advanced biocomposites have been processed, characterized, and used in many ways using current technology. The latest advancements in biocomposite materials and their processing methods are described in general. Advanced biocomposites' morphological assessments, mechanical, thermal, and biological capabilities were assessed. Advanced biocomposites may find use in a number of industries, including aerospace, biomedicine, automotive, and environmental applications.

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