

# The Current State and Prospects of Using Composite Materials in Different Sectors of Industry

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**Abstract.** This research covers the most recent innovations and trends in sustainable composite materials, with an emphasis on design, manufacturing, and performance. The paper highlights the importance of renewable resources in accomplishing environmental sustainability goals and addressing high-performance material demand. It also points out the use of new techniques in material selection, manufacturing procedures, and performance optimization to meet sustainability issues. Finally, it discusses the prospective applications and benefits of sustainable composite materials in many industries.

## 1. Introduction

There has been an increase in demand over the past decade for materials that not only perform well but also support to environmental sustainability. Because of its unique combination of qualities, such as high strength-to-weight ratio, ability to resist corrosion, and design flexibility, composite materials have received a lot of attention. Traditional production procedures and material choices linked with composites, on the other hand, have prompted questions about their environmental effect and long-term sustainability.

Scientists and engineers have been exploring new approaches for the development of sustainable composite materials. The development of sustainable composite materials entails a strong emphasis on incorporating eco-friendly and renewable resources, including bio-based polymers and natural fibers. Furthermore, the integration of advanced modeling and simulation techniques plays a pivotal role in optimizing the material properties. The manufacturing processes have also been subjected to significant advancements in terms of sustainability, with the utilization of additive manufacturing, robotic-assisted manufacturing, and digital design tools. These methods enable the reduction of waste and energy consumption, while simultaneously enhancing production efficiency.

In addition, the optimization of performance is essential in guaranteeing the appropriateness and competitiveness of sustainable composite materials. This entails employing state-of-the-art characterization methods and computational modeling to assess and elevate the mechanical, thermal, and functional characteristics of composites. By customizing the composition and structure of materials for particular applications like aerospace, automotive, construction, and renewable energy, sustainable composites can provide enhanced longevity, energy efficiency, and overall efficiency. The purpose of this work is to evaluate the latest developments and prospects in this field, highlighting potential applications and advantages in various industries.

## 2. Theoretical foundations

Composite material is an inhomogeneous solid material that consists of two or more components, one of which is a reinforcing element that provides the necessary mechanical characteristics of the material, and the other is a matrix that ensures the joint operation of reinforcing elements [1].

### 2.1 Advantages of composite materials

Composite materials are very resistant to external influences, therefore they are suitable for use where resistance to high temperatures, corrosion or heavy loads is required. Composite materials are excellent electrical insulation materials when using both alternating and direct current. The use of certain fillers makes it possible to obtain composite materials resistant to various aggressive environments, including the effects of concentrated acids and alkalis.

### 2.2 Classification of composites materials

The development of increasingly more advanced composite materials and manufacturing technologies, as well as their widespread application, is quickly becoming one of the most important areas of economic and technological progress. As a result, in order to create high-quality products, composite materials are typically categorized based on matrix elements and reinforcement fillers.

**2.2.1 Matrix.** The matrix is a continuous phase that assures the material's solidity, aids in the preservation of the product's shape, and provides load distribution on the reinforcement. Matrices are divided into metal, polymer, ceramic [2]. A number of studies have revealed that selection of matrix type influences the process of producing the structure; as a result, the following restrictions have been set on the matrices:

- to possess enough stiffness, strength, heat resistance, and fracture resistance to ensure the composite's operability throughout operation;
- to promote good wetting of the fiber, to have low values of the parameters of final shaping, the possibility of pre-manufacturing prepregs, high-quality connection of composite layers to ensure a high level of manufacturability.

**2.2.2 Reinforcement fillers.** The two main kinds of fillers are dispersed fillers, which are powdered organic or inorganic components (kaolin, talc, mica, chalk, quartz, etc.), and fibrous fillers, which mostly look like threads (the most common are glass, carbonaceous, boron, and high-modulus organic fibers) [2]. Their physical and mechanical features are listed below (Table 1).

**Table 1.** Physical and mechanical features of fibrous fillers

Parameter	Glass	Boron	Carbon		Organic	Steel
			high modulus	high strength		
Density (kg/m <sup>3</sup> )	2.5·10 <sup>-3</sup>	2.5·10 <sup>-3</sup>	1.95·10 <sup>-3</sup>	1.76·10 <sup>-3</sup>	1.45·10 <sup>-3</sup>	7.8·10 <sup>-3</sup>
Elasticity Modulus (GPa)	89	400	400	260	120	210
Tensile strength (GPa)	3.5	3.5	2.1	3.3	2.8	2.9
Specific stiffness (m)	3.6·10 <sup>-6</sup>	16·10 <sup>-6</sup>	20.3·10 <sup>-6</sup>	14.7·10 <sup>-6</sup>	8.3·10 <sup>-6</sup>	2.7·10 <sup>-6</sup>
Specific strength (m)	140·10 <sup>-3</sup>	140·10 <sup>-3</sup>	108·10 <sup>-3</sup>	187·10 <sup>-3</sup>	193·10 <sup>-3</sup>	37·10 <sup>-3</sup>

## 3. Biocomposites and other environmentally friendly materials

Many industrial composites have a big issue, which is related to the fact that most of the existing materials are not environmentally friendly. They cannot be recycled or melted down like regular metal, plastic, or wood. To recycle the whole composite material or an old part of it in a sustainable approach,

the matrix must be separated from the reinforcement, which is an extremely difficult process. Materials consisting of organic resins and fibers called biocomposites are produced for this purpose. In some situations, they can be totally reused and are relatively inexpensive. The primary function of flax in biocomposites is to provide strength. Additionally, hemp, cotton, reclaimed wood, and waste paper can be used [3].

Researchers have been working on developing biodegradable materials these days, those materials that can degrade naturally in the environment. This is a result of the growing strict laws governing the release of greenhouse gases, mostly carbon dioxide, which are intended to mitigate the effects of human activity-related climate change.

Biodegradable binders for biocomposites and other environmentally friendly materials can be divided into three large groups [4]:

- polymer based on lactic acid called polylactic acid (PLA) is created when sugary compounds are fermented in lactic acid;
- polyhydroxyalkanoates (PHA) are byproducts of microbial digestion of vegetable sugar; they are found in starch-based polymers;
- starch-based materials.

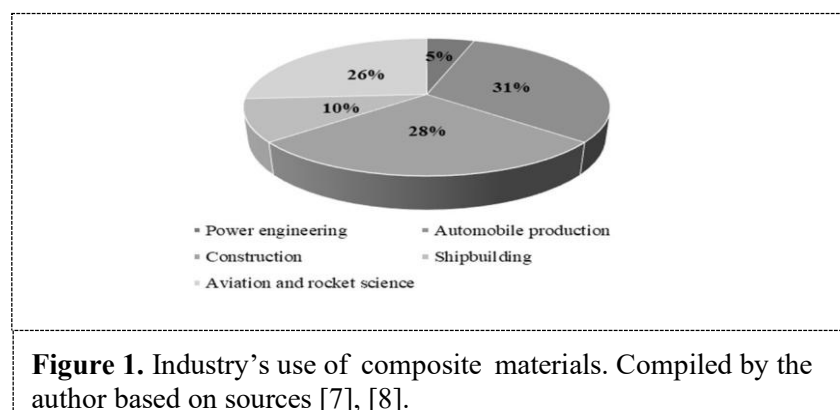
There are also products based on natural polymers like lignin, cellulose, and caprolactone as well as synthetic polymers like polyvinyl alcohol, polyvinyl acetate, and polyglycolic acid.

This approach highlights the progress in research on the conversion of non-renewable materials into renewable, degradable ones. This development results in the production of new materials with the appropriate structures and qualities [5]. Nowadays, biocomposites demonstrate improved heat resistance, increased durability, tensile and tensile strength, as well as a reduced tendency to water absorption. The classification of biodegradable composites is based on the systems of manufacturing, use, density, and others. These elements allow for the division of composites into two basic categories: matrix (biodegradable polymers) and natural bioresources (natural fiber and agricultural waste) [6]. Due to the demands of their general application, there is no one method for the synthesis of composites. Biocomposites come in a variety of forms, including those made of wood, plastic, cement, glass, etc. Numerous manufacturing processes, such as extrusion, injection molding, thermoforming, and others are utilized for making biocomposites. At the moment, research is concentrated on the invention and application of such biodegradable composites useful for resolving engineering issues.

#### 4. Applications for modern composite materials

In the industry, modern composite materials are becoming more and more significant. They are employed in many different industries, including construction, automobile manufacturing, and aviation.

As was already mentioned, the majority of contemporary environmentally friendly composite materials that are available and being developed, including biocomposites, are intended to address technical issues. The percentage of composites used in each industry is represented graphically below (



The figure 1 leads to the conclusion that biocomposites are being utilized more frequently in the field of aerospace as well as in sectors like automobile manufacturing, aviation, and construction. However, biocomposites are growing more frequent in the medical and military segment.

Bamboo composites and incredibly lightweight web-based materials are increasingly being used in rocket science, aviation, automobile manufacturing and shipbuilding [3]. Also, biocomposites, which are biopolymers (polylactide, polyhydroxyalkanoates and biodegradable polyamides) reinforced with natural fibers, are used in the automotive industry to create exterior body panels, hood parts and various structural elements [9]. Students from the Technical University of Eindhoven in the Netherlands were successful in creating a complete biodegradable electric vehicle prototype in 2018. Biocomposites based on flax and sugar were used to create the car's body panels, chassis, and interior details [3].

The combination of natural fibers, such as hemp and flax, and bio-base resins makes it possible to obtain biocomposites with good strength characteristics, high impact resistance and sound absorption. Such materials are widely used in the energy industry, for example, when creating wind turbine blades [10].

To lessen their negative environmental impact, experts in the field of construction manufacturing have recently tried to move to wood composite materials. The production of building materials using sawmill by-products, which are actively used in various construction works, has now increased greatly. However, the usage of wood as a building material in some cases is expensive, so in order to reduce manufacturing costs and meet environmental requirements [11].

In the last decade, new composite photocatalytic materials have been created, the main field of application of which is medicine. Antimicrobial coatings based on photocatalytic materials are environmentally friendly and effective for use in healthcare, in addition, they can be used in the food industry and in enterprises and service facilities [12]. At the moment, starch-based biocomposites are gradually being used for medical purposes. Due to its biodegradability, biocompatibility, non-toxicity and good mechanical properties, such a material can be used in bone tissues, where the biocomposite provides support for the structural framework [13].

Along with to the abovementioned industries, the food sector actively applies biodegradable composite materials when it comes to product packaging and storage. Research and attempts are being made to utilise starch- or clay-based nanocomposites [14], which have the potential to be used in mass production, to replace synthetic polymers.

## **5. Perspectives of using environmentally friendly materials**

The use of biocomposite materials offers promising perspectives in various industries, driven by the increasing demand for sustainable and environmentally friendly solutions. The objective of ongoing research and development is to discover new bio-based polymer, natural fiber, and additive combinations that will improve the characteristics and functionality of biocomposite materials. To increase the efficiency and scalability of the manufacture of biocomposite materials, innovations in manufacturing processes including 3D printing and advanced modelling techniques are also being analysed.

### *5.1 Innovations and potential projects*

The growth of biocomposite materials has been pushed by advances in production methods, material science, and knowledge of the characteristics of natural fibers and bio-based polymers. To create biocomposite materials with improved strength, durability, and other desirable qualities, researchers have been experimenting with new combinations of natural fibers. In the summer of 2023, researchers from the Ural Federal University collaborated with experts from the Malay Technological University and the Isra University to design an affordable and practical composite for radiation shielding [15]. Due to its total consideration for the environment, this new polymer composite may someday prove to be a viable replacement for plumbum. Due to the severe toxicity of plumbum and the potential dangers associated with its release into the environment, plumbum-based buildings pose a huge disposal challenge for nuclear power. Scientists created samples of a unique shielding substance using an epoxy resin composite filled with zinc oxide nanoparticles (ZnO). The innovative composite is fully eco-friendly in both production and use, and it will be particularly useful in nuclear power engineering.

The compositions of biodegradable composites that include polyolefins and organic fillers have been covered in a number of recent reports and patents [16], [17]. Based on the information available, it can be concluded that the mass production of polymers filled with lignocellulose biodegradable materials of natural origin, such as wood flour, straw, and cereal husk, will soon take place. This will increase productivity, lower the cost of polymer compositions, and greatly reduce the environmental impact of polymer use, which is crucial for packaging and disposable dinnerware [18].

Modern composite materials are widely used for surface hardening of parts of special machinery and industrial equipment. In this situation, composite electrochemical coatings are applied, specifically chrome coatings that are deposited using environmentally toxic electrolytes. Electroplating is currently moving in the direction of creating composite electrochemical coatings that are less hazardous to the environment. For instance, a composite electrochemical coating made of nickel and zirconium diboride was suggested as being both less harmful and more effective due to the coating's strong wear resistance and microhardness during testing [19].

Another pure natural biomaterial that can potentially receive huge development is bacterial cellulose, which generates some aerobic bacteria [20]. Bacterial cellulose has perfect mechanical strength, a nanofibrillar microporous structure, and biocompatibility. However, bacterial cellulose lacks antimicrobial activity, which makes it difficult to apply as early and burn-healing dressings since it cannot shield the wound from bacterial damage. The potential uses of bacterial cellulose for several biological applications are increased when it is modified with nanoparticles of active metals. Therefore, there is currently an enormous amount of interest in the implementation of functional composites made of bacterial cellulose and metallic nanoparticles, more particularly gold, in a variety of scientific and technological fields, such as biomedicine as antimicrobial and antitumor agents [21], the chemical industry as reusable catalysts, biotechnology for enzyme immobilization, and bioelectronic systems [22].

## 6. Conclusion

Biocomposite and ecologically friendly materials' mechanical, thermal, and chemical qualities will be enhanced by progress in material science, and processing methods, putting them on level with or even surpassing existing composite materials in terms of the characteristics.

The implementation of biocomposite and ecologically friendly materials will be aided by rising green laws and sustainability programs. Governments and regulatory agencies are expected to offer incentives and support to businesses moving to more beneficial ecological procedures.

Eco-friendly and biocomposite materials will become more cost-competitive with traditional materials as demand for them increases. This will be made possible by economical regulations and technical improvements.

The use of biocomposite and ecologically friendly materials has potential, supported by innovations and future initiatives. These materials respond to the urgent demand for environmental preservation across many sectors by providing a sustainable alternative to traditional materials. Biocomposite and ecologically friendly materials are in a prime position to fulfill an important role in establishing a more sustainable future because of continuous research, technical achievements, and cooperative efforts. By utilizing these materials, industries can lower their impact on the environment while preserving performance and contributing to the development of a more sustainable and greener environment.

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