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3 Production of biodegradable composites from agricultural waste

A review

Abstract: The development of biodegradable composite as an alternative to nondegradable composite continues to wax stronger. Composite materials are materials popularly formed from the combination of matrix and reinforcements, where one of these is commonly from renewable sources. However, biodegradable composites are produced from the combination of matrix (resin) and reinforcement solely from natural fibers unlike ordinary composites that do contain synthetic polymers which are not biodegradable. Thus, studies are continued to produce biodegradable composites using different biodegradable materials and techniques. Recent activities have led to the development of biodegradable composites with reasonable tensile and flexural characteristics. However, there are shortfalls with regard to some of the biodegradable composites when they come in contact with moisture, which affects their performance under certain conditions as in aqueous medium or under high humidity. Notable works have come up with biodegradable composite materials from common agricultural wastes. Among the common materials that have been studied in the development of biodegradable composites are rice husk, soybean, sugarcane bagasse, and cassava peel. This chapter discusses some of the literature available on biodegradable composites developed mainly from common agricultural products, their properties, production method, challenges, and sustainability.

Keywords: Agricultural waste, biodegradable, composites, matrix, reinforcement

3.1 Introduction

Agricultural wastes or residue is a term used to describe all organic materials that are produced as by-product from harvesting and processing of agricultural crops. Agricultural crops provide food for both humans and animals for their energy. Recently, the waste generated during the harvesting and processing of these crops has

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been deemed to be very beneficial to other industries or sectors. For instance, agricultural waste material has been exploited for heavy metal remediation based on the fact that research has found it to be highly efficient, it is of low cost, and it is a renewable source of biomass [1]. Another example is the use of rice husk, which is one of the most common agricultural wastes to generate clean energy. Precisely, rice husk can be used to provide electricity due to its high calorific value. Furthermore, rise husk ash, which is a by-product of rice husk power plants, can be used in the production of cement for construction purposes [2]. Agricultural wastes can be broadly classified into two major categories based on the time of generation such as primary and secondary wastes or residues.

Primary residues are wastes generated during the time of harvesting agricultural crops such as sugarcane top, maize stalks, coconut empty bunches and frond, paddy straw, and palm oil bunches and fronds. On the other hand, secondary residues are wastes generated during the time of processing and they include, but not limited to, maize cob, coconut shell, paddy husk, coir dust, sawdust, bagasse, palm oil shell, wastewater, fiber, and empty bunches. In general, secondary residues are produced in large amounts; hence, they cannot be exhausted by reusing or recycling for a particular application, which is the motivating factor for investigating its usage in the production of composites in the manufacturing industry rather than just dumping on the landfill sites. Some of the most common agricultural waste materials are shown in Figure 3.1.

Figure 3.1: Images of rice straw, rice husk, corn cobs, and wheat husk.

It is important to note that agricultural wastes are part of crop residues originating from different sources. For example, cereals are from rice, maize or corn, sorghum, barley, and wheat; millet is from straw, leaves, stalk, husk, peel, and stubbles. Other agricultural wastes originate from cotton, legumes, coffee, tea, groundnut, fruits, and palm oil.

Research has found that various agricultural wastes can be used as raw materials in various sectors such as energy, construction, and manufacturing. More recently, investigations are ongoing in channeling these wastes to produce more biocomposite materials.

3.2 Classification of composites

Composites can be broadly classified into three major categories, namely, particle reinforced, fiber reinforced, and structural. These three categories can also be subdivided into various categories as shown in Figure 3.2.

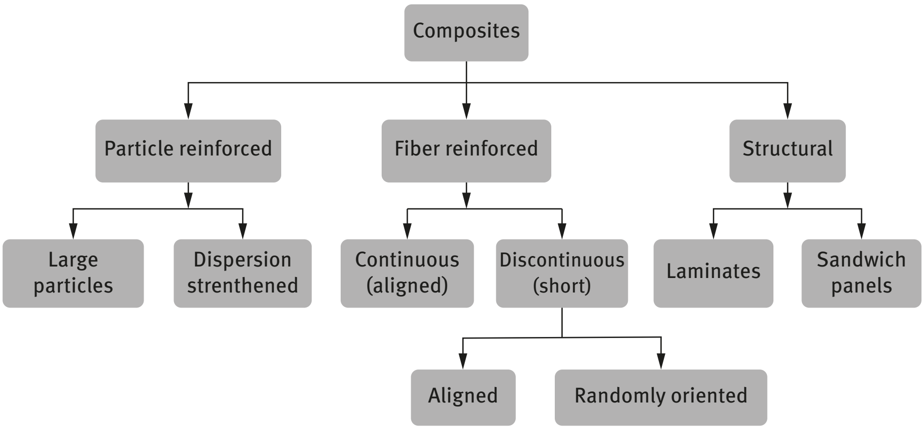

Figure 3.2: Composite classification [3].

3.3 Structural and nonstructural composites

Composite materials can further be classified into structural and nonstructural composites. Structural composites are load-bearing composites and as the name implies they are manufactured in order for them to carry loads. Also, their performance ranges from high to low depending on the purpose they are to serve. Structural composites performance can be improved by chemical modification techniques to modify the fiber properties. On the other hand, nonstructural composites are not designed to carry loads; as a result, they could be made from materials such as thermoplastics, textiles, and wood particles. The manufacturing process also varies but most common processes include and not limited to thermopressing, sheet and injection molding.

3.4 Biodegradable composites from common agricultural products

Composites are combination of at least two distinct, different materials that are combined together to provide an engineering performance that far exceeds that of any individual component [4]. Also, composites are artificially produced multiphase materials having a desirable combination of the best properties of the constituent phases [3]. In other words, a composite is made up of a primary constituent element and embedded in it is the another constituent element which serves as a reinforcement as shown in Figure 3.3. Composites have been found to be the most advanced and adaptable engineering materials. Despite the fact that composites are capable of meeting diverse design requirement with significant weight savings and high strength to weight loss, the composite industry is still faced with some challenges such as health and safety, emission of volatile organic compounds, energy consumption, and toxicity from manufacturing. The use of composites cuts across many sectors across the world; hence, its importance cannot be overemphasized. In 2011, the world's composite market was estimated to be worth $19.6 billion, and in

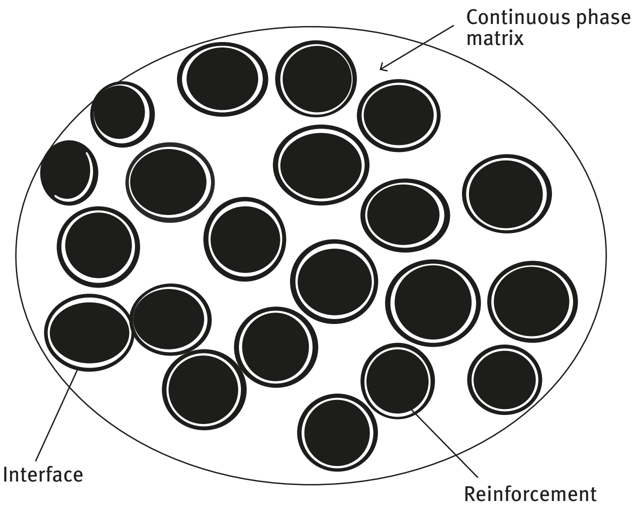

Figure 3.3: Constituent materials of a composite.

2017, the composite industry was estimated to be worth $29.9 billion [5]. It is important to stress that the usage of composite is fast growing and the end products made with composite materials are also growing sporadically.

The production of composites has dated over many centuries especially in the automobile industry. In 1940, Henry Ford began the experimentation of composites using compressed soybeans to produce plastic-like components for cars [6]. At that time, petroleum-based chemicals were very cheap and soy-based plastics were not economical for production [7]. Over a very long decade, manufacturing of components using the conventional methods has contributed immensely to the development of societies and the world at large started receiving global attention due to the depletion of petroleum resources, global awareness, and campaign to make the world more environmentally friendly and sustainable. These led researchers to investigate on more innovative ways of manufacturing composites from biodegradable materials. Biodegradable composite known as "biocomposites" are a new distinct composites, which are generally defined as biocompatible and ecofriendly composites [8, 9]. Several researchers have defined biocomposites based on their research interests such as combination of biodegradable polymer and biodegradable fillers usually biofibers [10]. Composite materials comprise one or more phase(s) derived from biological origin [11]. Biocomposites have also been defined as a resin-based composite [12]. In general, the aim of producing biocomposites is basically to improve basic mechanical properties and functionality of materials while ensuing they are ecofriendly.

3.5 Properties of biodegradable composite from common agricultural products

Generally, agricultural products or wastes have gained more usage in the production of biocomposites because they have a good biodegradability especially when subjected to various atmospheric conditions. Also, agrobased composite resources such as fiber, labor, water, energy, and processing equipment are well managed. Nevertheless, more emphasis is placed on the production of biocomposites from nonfood crops. This is done in order not to create a negative impact on food supply. As a result, agro-based composites are products of sustainable agriculture, which creates a balance between conservation and utilization of agricultural lands to serve both social and economic needs from local, national, and global vintage points [13]. Basically, properties of biocomposites are a function of the intrinsic properties of the constituent materials that can broadly be classified into thermal and mechanical properties. Although fiber-reinforced plastic composite has played a major dominant role for a long time in the manufacturing sector because of their utilization in various application as a result of their specific strength and Young's modulus [14], agro-based composites or biocomposites now have more advantages over it. Among such advantages include the following:

1. Acceptable specific strength properties
2. Reduction in weight and cost
3. Good thermal properties
4. Enhanced energy recovery
5. Ecofriendliness as a result of biodegradability

Several research works have been carried out and published on biocomposites, and their various properties among such works are biocomposite properties based on lignocellulosic fillers [15], mechanical properties of poly(butylene succinate) biocomposites reinforced with surface-modified jute fiber [16], the effect of fiber content on mechanical and thermal expansion properties of biocomposites based on microfibrillated cellulose [17], thermal and mechanical properties of biocomposites using additive manufacturing [18]. Nevertheless, very few findings have been reported on the properties of biocomposites from agricultural by-products.

3.6 Classification and production methods for biodegradable composites

Various factors that can influence the classification of composites are densities, uses, manufacturing methods or other systems [13], and these factors help easily classify composites into three major categories as stated earlier. Also, biocomposites can be broadly classified into two major categories, namely, matrix and natural fibers as shown in Figure 3.4. Matrix types of biocomposites are made up of biodegradable homogenous and monolithic materials, where the fiber system of a composite is embedded while natural fibers are derived either directly from agricultural sources or as processing or production residues when crops are processed for their primary uses such as nutrition [19].

There is no generic way of producing biocomposites due to the fact that various biocomposites are produced to meet several demands or purposes. However, there are several types of biocomposites just like we have many types of composites such as wood–plastic composite, glass fiber epoxy composites, cement composites, filament–wound composites square tubes, carbon nitride/titania nanotube composites, and ZnS–ZnO composites.

Many biocomposites have been produced using various techniques such as biodegradable composites produced from polylactic acid and polyhydroxybutyrate, which contains 40 wt% of paper pulp and mixing them with short and long fiber pulps using torque rheometer [21]. Biocomposites are produced from biodegradable starch and jute strands fabricated using injection molding process [22].

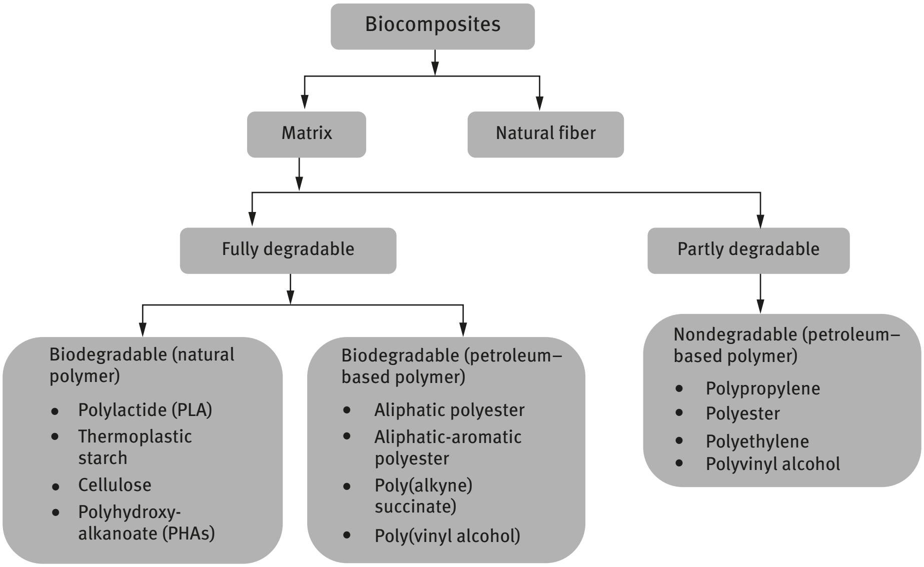

Figure 3.4: Biocomposite classification [20].

3.7 Applications of biodegradable composites

Biodegradable composites have found a drastic increase in its usage due to the fact that they offset significantly the use of fossil fuels and reduce greenhouse gas emissions when compared to the conventional petroleum-based composites. There are various applications where the use of biocomposites is gaining momentum such as in the aeronautical space, automotive industry, packaging, marine, construction, and furniture. Biocomposites have also been used majorly in the medical field as in the case where it was used as a bone-regenerative implant [23]. The reason behind the general acceptability of biocomposites globally is not far-fetched, especially when performance is the key criteria for utilization as illustrated in Figure 3.5.

Ong et al. [25] evaluated the effectiveness of treated and untreated palm kernel shell as filler in a polypropylene matrix at various filler loadings to create biocomposite materials. The analysis was carried out to assess the water absorbability, surface morphology, and tensile and flexural properties. The findings revealed that the treated palm kernel shell possesses more desirable mechanical properties with reduced water absorption as compared to nontreated palm kernel shell. The morphology of the treated palm kernel shell composites also revealed a better filler–matrix interaction because of surface modification. In conclusion, the inclusion of amino silane–palm kernel shell as a filler into the matrix provided an improved biocomposite with better flexural, tensile, and water absorbability properties. In a similar work

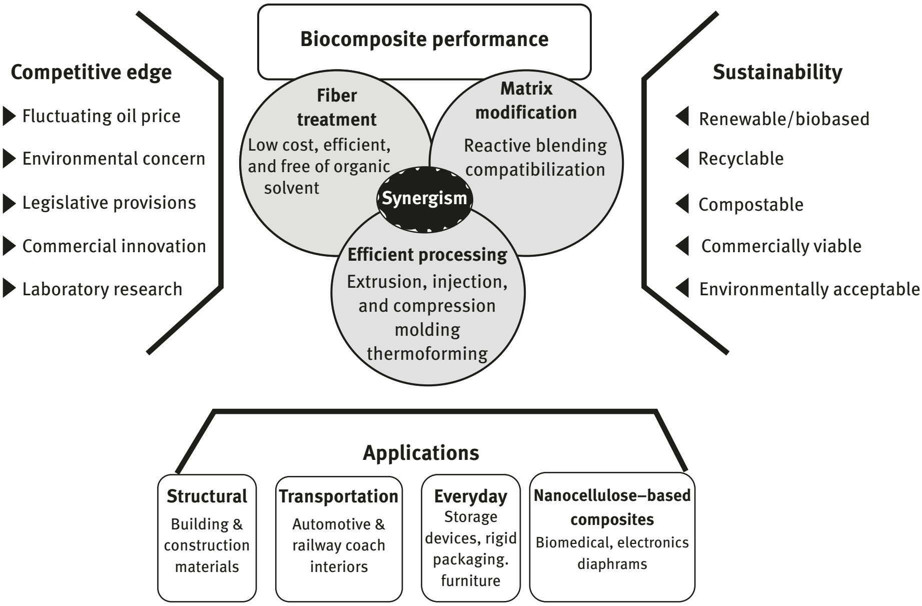

Figure 3.5: Biocomposite performance, competitiveness, sustainability balance, and applications [24].

carried out by Safwan et al. [26], the Brabender internal mixer was used to produce biocomposites of palm kernel shell/nanosilica-filled and palm kernel shell-filled maleated polypropylene biocomposites. The thermal analysis revealed an improved mechanical property of the biocomposites. The research on the produced composites also recorded minimal water absorption percentages as compared to palm kernel shell/polypropylene composite.

3.8 Sustainability and future work in biodegradable composites

The use of agro-based composite has been proven to be sustainable considering the fact that biocomposites are renewable, recyclable, compostable, commercially viable, and environmentally acceptable [24]. The rate at which technologies are disrupting the business world, especially in the manufacturing sector globally is paramount to produce biocomposites that find application in all sectors of life and eradicating the shortcomings of conventional or ordinary composites. Research is ongoing to improve the properties of existing biocomposites and increase its utilization. Also, campaign for more effective and environmentally friendly way of manufacturing will continue to be encouraged.

3.9 Summary

Considering the fact that the world is revolutionizing and transiting into the Fourth Industrial Revolution (Industry 4.0), it is important to start replacing conventional materials (composites) that contribute greatly to environmental waste with biodegradable composites or natural composites that have been tested and proven to have displayed low environmental impact and a low cost across a wide range of applications. However, researches are ongoing to improve on the properties of biocomposite materials and make them more suitable for engineering applications. The use of agricultural by-products provides an alternative raw material to some food crops currently being used in the development of biocomposites, thereby easing the effect of food shortage supply.

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