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USE OF CORN STALK WASTE IN THE MANUFACTURING OF COMPOSITES: A REVIEW

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Abstract: The global increase in demand for natural resources raises urgent concerns about environmental sustainability. The transition to renewable natural materials, such as lignocellulosic fibers, is a promising strategy to mitigate environmental impacts. These fibers, derived from renewable sources, have low density and unique mechanical properties, making them attractive alternatives to synthetic materials. Composites reinforced by natural fibers have gained prominence, providing mechanical resistance and reducing costs. Waste such as corn stalk, abundant throughout the world, has been studied as reinforcement in composites. The use of these fibers not only offers environmental advantages, such as biodegradability and lower energy demand in production, but also contributes to the promotion of sustainable practices. Additionally, research shows that waste corn residue can be turned into valuable resources. Studies conducted with corn stalk husk revealed superior performance in composites, indicating its potential as a reinforcing material. Other research involving sliced culm demonstrated promising results, highlighting the economic viability and possibility of developing a new low-density engineering material. Therefore, the use of natural fibers, such as those from corn stalks, in composites represents not only an environmentally friendly solution, but also an opportunity for innovation in the production of sustainable materials, which will be the reason for this review.

Keywords: Composites; Residue; Corn stalk.

INTRODUCTION

The growing global demand for natural resources has led to increasingly urgent concerns regarding environmental issues and sustainability (1,2). The increase in consumption of natural resources has generated challenges related to the depletion of materials and the preservation of environmental sustainability (3). As the world's population continues to grow and consumption patterns intensify, it is critical to understand the implications of this increase in global resource use (4). These issues draw the attention of researchers, policy makers and society in general, driving the search for innovative solutions that promote the preservation of natural resources and the promotion of sustainable practices(5–8).

There is growing interest in replacing synthetic materials with natural alternatives as a strategy to mitigate environmental impacts (9–11). The use of renewable and biodegradable natural materials is a promising approach, as it reduces dependence on non-renewable resources and contributes to reducing the accumulation of solid waste (12,13). This transition to natural materials not only addresses environmental concerns, but can also offer additional benefits such as improving quality of life and promoting more sustainable economic systems (14). Given this context, the study and development of sustainable alternative materials arouse great interest in scientific, industrial and governmental areas, driving research and technological advances in this field (14,15).

Lignocellulosic fibers have attracted considerable attention due to their low density compared to synthetic materials(16,17). Natural fibers are derived from renewable sources, such as plants, animals and minerals, and have unique mechanical properties. Their low density, combined with good resistance and rigidity, makes them attractive alternatives to replace synthetic materials. Furthermore, these fibers have significant environmental advantages, such as biodegradability and lower energy demand during production. These characteristics make natural fibers particularly relevant in applications that seek to reduce environmental impact, promoting sustainability and the development of more environmentally friendly products (18–20). This review work sought to present positive points for the production of corn stalk as reinforcement in composites.

LITERATURE REVIEW

COMPOSITES

Composites, by definition, are considered the combination of two or more materials, with the matrix phase responsible for uniting and protecting the dispersed phase. This phase plays a crucial role in determining the mechanical strength of the material. Figure 1 presents in detail the matrix and dispersed phase of the composite.

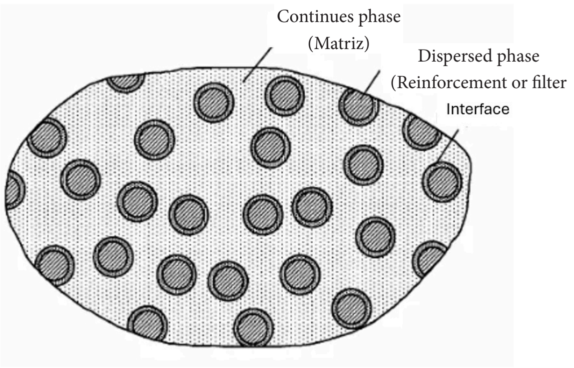

Figure 1- Phases of a composite material (21).

Reinforcement in composite materials provides mechanical resistance, including tensile strength and stiffness. Covering organic or inorganic fibers, ranging from elongated fibers to continuous or particulate fibers (22,23). The widely used fiberglass is known as E-glass fiber, accounting for more than 95% of applications. Furthermore, aramid fibers, such as Kevlar, are also widely used (24). Generally, in composite structures (which are anisotropic), fibers perform favorably when subjected to tension parallel to the fibers, while performance is proportionally lower when the tension is applied at 90° to the fibers.

FIBER-REINFORCED COMPOSITE MATERIALS

Natural fiber composites offer a considerable cost advantage compared to synthetic fiber reinforcements, are biodegradable, widely available, renewable and have low density. These natural fibers derive from three main sources: plants, animals, and minerals (25). Table 5 presents the advantages and disadvantages of using composite materials.

Advantages	Disadvantages
They are environmentally friendly;	High moisture absorption capacity;
Biodegradable;	Incompatibility with some polymer matrices;
Available in large quantities;	
Renewables;	Low moisture resistance, which causes fibers to swell;
Low cost;	Restricted maximum processing temperature;
Low density;	
They are used in structural applications;	In some cases, they cannot be used as a direct reinforcement without chemical treatment.;
High performance.	

Table 1 - Main advantages and disadvantages of using FNL as a reinforcing material in composites compared to synthetic fiber (26).

Polymer matrix composites, reinforced with natural fibers, present an increase in mechanical properties and a reduction in costs. From the point of view of mechanical performance, natural fibers are highly valuable reinforcement materials for the development of polymer composites, due to their high strength, low density and specific modulus (27,28).

Density plays a crucial role in end applications, as low-density materials are ideal for producing lightweight components. A big advantage of natural fibers is their lower density compared to artificial reinforcements. The low density of Kusha fibers, for example, increases their suitability for applications in low-density materials (25). *Scutellaria barbata* fiber, due to its low density, has the potential to be applied as a substitute for synthetic fibers (29).

WOOD PANELS

Wood composites constitute an expanding field of products that have gained increasing applicability in several areas, maintaining an uninterrupted upward trend for several decades. It is imperative to initially establish a precise definition of what is strictly considered a wood composite, given that there are several products that, although they can be categorized as such, fall outside the definition established in the professional wood vernacular (30). Therefore, corn stalk is a material that can be used in the production of wood panels, due to its low density (31) and relative mechanical resistance (32).

Several types of wood panels intended for a variety of applications are currently manufactured. The summarized definitions of these panels are presented below, however, for a more in-depth and detailed understanding of the manufacturing technology of these products, the reader is referred to specialized reviews (33). Figure 2 shows the types of wood composites.

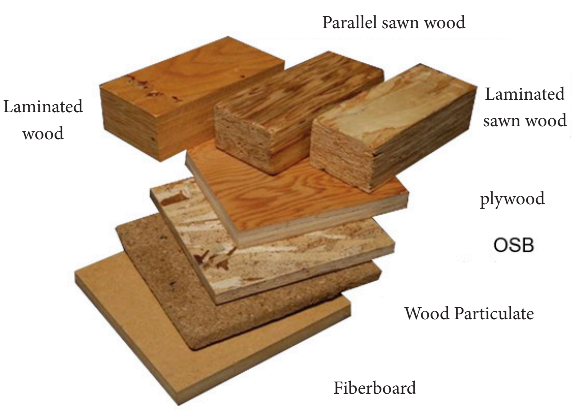

Figure 2- Some examples of wood composites (33).

These types can be understood as (33):

PARTICLE BOARD

- Definition: Flat hot-pressed wood composite panel, composed of randomly oriented wood chips joined by hot pressing, using thermosetting adhesive resins, mainly urea-formaldehyde (UF), melamine-urea-formaldehyde (MUF), phenolic resins (PF and TF) and isocyanates (pMDI).
- Structure: Generally has three distinct layers, with the surface layers composed of finer wood chips than the thicker core layers. Some processes result in a plate continuously graded in chip size throughout the thickness.
- Properties: Density typically ranging from 650 to 700 kg/m^3, with an average resinous solids content in the core section between 6% and 12% in dry wood.

ORIENTED STRAND BOARD (OSB)

- Definition: Three-layer hot-pressed flat wood composite panel, composed of oriented wood wafers glued together by hot pressing using thermosetting adhesive resins.
- Structure: Very thin wafers, oriented in a specific way, provide remarkable strength to the panel, being oriented in the same direction within the same layer and at 90° to each other in adjacent layers.
- Applications: Low-cost alternative to plywood, with lower wafer surface area, resulting in the need for only 4 to 5% of adhesive solids on dry wood.
- Being more suitable for corn stalk residue, where its processing involves just crushing and mixing in the resin, finally pressing the material.

MDF

- Definition: Hot-pressed flat composite panel, composed of wood fibers obtained by thermomechanical pulping of wood, traditionally glued with adhesive at a density of around 750–800 kg/m³.
- Applications: Mainly used for furniture and internal applications, bonded predominantly with urea-formaldehyde resins.

HARDBOARD (HIGH DENSITY FIBER)

- Definition: Composite panel of flat pressed wood, composed of randomly oriented wood fibers, obtained by thermomechanical pulping, and traditionally glued without any adhesive by hot pressing, due to the very high density (900–1100 kg/m³).
- Variation: Panels containing a small number of adhesives (2-3% dry fiber adhesive solids), usually PF resins, are often produced today to improve panel properties.

PLY WOOD

- Definition: Flat panel of hot-pressed multilayer wood, composed of oriented wood veneers, glued together by hot pressing using thermosetting adhesive resins.
- Structure: The veneered wood grains are oriented at 90° to each other in adjacent layers, giving the panel exceptional strength.
- Properties: Better strength/weight ratio compared to OSB, however, it is generally more expensive.

CORN STALK IN THE PRODUCTION OF COMPOSITES

Thatch is a specific type of stem found in grasses such as bamboo, corn and sugar cane. These stems are often hollow and have distinct nodes and internodes. Grass thatch is known for its strength and lightness, being used in various applications, such as construction and paper production (34). Figure 3 shows the different parts of the corn stalk.

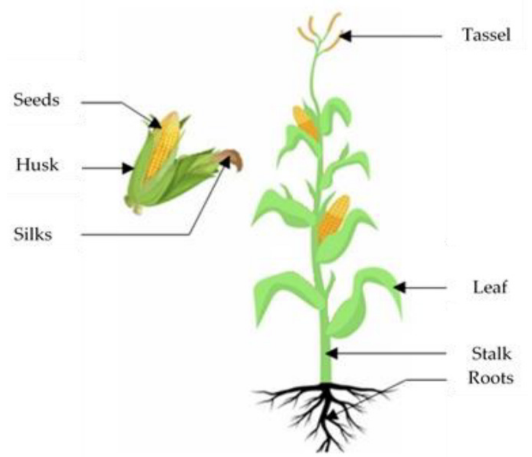

Figure 3- Different parts of corn (35).

Annual corn production in China reaches approximately 250 million tons (36). However, more than half of this material is inappropriately discarded or burned by local farmers, resulting in considerable waste of renewable biomass and resources derived from that biomass. This practice not only represents a potential loss of valuable resources, but also contributes to air and water pollution, as highlighted by previous studies (37).

Global corn production is around 1.13 million tons per year, second only to sugar cane with data collected from 2000 to 2022 (FAOSTAT, 2022) (38). Corn waste poses serious environmental concerns as it is the second largest source of greenhouse gas (GHG) emissions from landfills and the largest source of (GHG) emissions from biomass burning in 2017 (FAOSTAT, 2022), (38). Until now, few attempts have been made to reuse corn waste as a source of reinforcement in polymeric matrices.

In a study conducted by Rocha Júnior et al. (39), the research involved the use of corn stalk husks in volumetric fractions of 10%, 20%, and 30%. The composites were subjected to characterization using the Charpy and Izod impact tests. The results obtained revealed superior performance in relation to the epoxy matrix, with a gradual tendency to increase resistance proportional to the increase in volume fraction.

In another study carried out by Rocha Júnior et al. (40,41), the research involved the use of sliced corn stalks in volumetric fractions of 50, 60, 70, 80 and 90%. In this study, polyurethane resin derived from castor oil was used. They were subjected to Charpy and Izod impact tests in addition to residue characterization. In their results, the density of the residue was 0.295 g/cm³. The Charpy and Izod impact resistance of the composite was lower than resin.

FINAL CONSIDERATIONS

Considering the few articles published on the subject, this review highlights that:

- The use of corn stalks for the production of composites will provide savings in manufacturing, due to its low cost;
- It is a low-density material;
- The abundance of waste around the world, with Brazil, China and the United States as major producers;
- And will provide the development of a new engineering material.

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