Research on Product Design of Agricultural Waste Wheat Straw Material Based on Material Driven Design

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Abstract. At present, environmental pollution is becoming increasingly serious and resources are becoming increasingly depleted. To solve environmental and ecological problems, gradually replacing petroleum-based plastics with renewable and degradable green polymer materials is important to improve the ecological environment. The transformation of product design concepts from "cradle to grave" to "cradle to cradle". The idea of sustainable design has been deeply rooted in people's hearts. This paper focuses on the product design application of agricultural waste material straw, explores the product design method of ecological material, and makes ecological materials better suitable for product design innovation research through material-driven design theory.

Keywords: Materia driven design; agricultural waste; wheat straw; sustainable design

1 Introduction

1.1 Research Background

With the continuous growth of the global population and the acceleration of industrialization, the ecological environment is facing unprecedented challenges. Climate change, resource depletion, and waste management have become core issues of global concern. Especially in agricultural production, the huge amount of agricultural waste has caused serious pressure on the environment [1]. As a by-product after the wheat harvest, agricultural waste represented by wheat straw produces hundreds of millions of tons yearly worldwide [2]. Traditional methods of wheat straw treatment, such as incineration and landfill, not only lead to waste of resources but also bring negative environmental impacts such as air pollution and greenhouse gas emissions. Therefore, how to transform wheat straw into valuable resources has become the key to solving the problem of agricultural waste. As a natural and renewable biomass material, wheat straw has rich fiber and chemical components, has great resource potential, and can provide innovative solutions for sustainable material design.

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1.2 Research Motivation

At present, most product designs still rely on traditional material choices, such as wood, plastic, and metal, which, although superior in some aspects, have certain limitations in terms of sustainability, environmental impact, and resource consumption [3]. The production process of traditional materials often involves high energy consumption, carbon emissions and consumption of limited resources, resulting in an increased environmental burden during the product life cycle [4]. Therefore, finding alternative materials, especially the use of renewable, low-carbon, and resource-rich agricultural waste materials, has become an urgent need for sustainable design. As an ecological material with degradability and low carbon emissions, wheat straw's renewable properties make it an ideal alternative material [5]. By applying wheat straw materials to product design, we can not only reduce the use of traditional materials, but also promote the efficient use of agricultural waste, reduce the environmental burden, and achieve green and sustainable development.

1.3 Research Questions and Objectives

Research question 1: How to design optimized product solutions based on the physical, chemical, and mechanical properties of wheat straw?

Research question 2: How do the fiber structure, plasticity, strength, toughness, and other properties of wheat straw affect the function, durability, and sustainability of the product?

Research question 3: How to enhance the performance of wheat straw in composite materials and promote its application in green design by combining it with other materials?

1.4 Research Objectives

Research objectives 1: Explore product design strategies for wheat straw based on the material-driven design approach.

Research objectives 2: Analyze the unique material properties of wheat straw and develop a product design framework with material properties as the core.

Research objectives 3: Explore the combination of wheat straw with other materials to enhance its application potential in composite materials.

2 Literature Review

Wheat straw, as a high-quality original ecological material, has received extensive attention in recent years. Ashby argues that ecological materials refer to materials with low environmental load and high regeneration rate, including original ecological materials and artificial ecological materials [3]. Wheat straw is an original ecological material that can be directly obtained and used from nature, while artificial ecological materials are obtained by processing original ecological materials [6]. Therefore, the research and application of original ecological materials are crucial to promoting sustainable design.

In modern product design, the selection of materials runs through the entire process of design, production, manufacturing, and recycling [7]. In the context of global ecological environment challenges, the development and application of ecological materials have become the key to achieving a circular economy. As a by-product of wheat harvest, wheat straw has huge resource potential, but if it is not handled properly, it will cause pollution to the environment. Therefore, the effective use of wheat straw can not only reduce the burden of waste on the environment but also provide sustainable raw materials and promote the development of a green economy. As a natural fiber material, wheat straw has unique physical, chemical, and mechanical properties, which give it the potential for wide application in many fields. Its strong hygroscopicity and hydrophilicity are related to the void structure of the fiber. The toughness varies with maturity and water content, and the toughness is significantly improved after absorbing water [8]. The tensile strength of wheat straw is related to the fiber length, and longer fibers increase its tensile strength [9]. Although the tensile strength is not as good as that of wood, its good plasticity and flexibility are more advantageous in specific applications.

In terms of chemical composition, wheat straw is rich in cellulose, hemicellulose, and lignin [10]. Wheat straw, like wood, is highly biodegradable and environmentally friendly. It can be combined with degradable plastics to prepare environmentally friendly biomass composites, which has become a research hotspot in materials science [11].

Through the Straw performance and design intervention application matrix analysis (Figure 1), the study found that the characteristics of wheat straw in green building materials, packaging, composite materials, and other fields have been deeply explored, but there is less design intervention, and most of the applications are traditional methods. There is a lack of systematic design optimization, which leads to its potential not being fully released. In the field of design, due to the limitations of mechanical properties and environmental adaptability, the application of wheat straw has not yet formed a scale, and the innovation potential has not been fully explored.

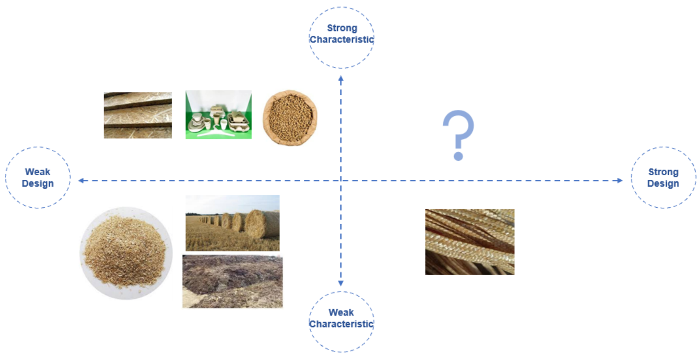

Fig. 1. Straw performance and design intervention application matrix analysis (drawn by the author)

This study aims to explore new applications of wheat straw in modern product design through a gap study of literature review, focusing on material-driven design, combining its natural fiber characteristics, optimizing design, improving functionality, breaking through performance limitations, expanding its application in high-performance composite materials and green consumer products, and promoting its widespread application in sustainable design.

Material-driven design is an innovative design method that emphasizes the core role of material properties in the design process. Unlike traditional design methods, material-driven design focuses on how to use the physical, chemical, and mechanical properties of materials to promote product innovation [12].

This method has important advantages in sustainable design and green manufacturing, especially in the application of agricultural waste materials. By deeply understanding and utilizing the essential properties of materials, more efficient and environmentally friendly design solutions can be achieved. The MDD method is divided into four steps: understanding the technical and experience characteristics of materials, creating a material experience vision, creating a comprehensive material experience model, and designing and developing products or concepts based on the material [13]. This method takes material research as the starting point, material experience as the main content, and ends with product output or the next step of material research and development.

The key to the material-driven design is that through a deep understanding of materials, designers can fully consider the material life cycle, environmental impact, and performance requirements during the design stage, thereby optimizing product design and improving product functionality and sustainability. In practical applications, this method has been widely used in aerospace, automotive, construction, and other fields, promoting the application of a variety of new environmentally friendly materials.

3 Research Methods and Analysis

The core of the ecological composite material design method based on material-driven design is to promote design innovation through multi-dimensional factors such as material experience characteristics, physical properties, processing technology, and final application form. Material-driven design not only focuses on material experience but also covers multiple aspects such as hardness, texture, mechanical properties, processing technology, etc [14]. This method expands the design vision, enabling designers to stimulate diversified innovative ideas under limited material experience, thereby enhancing the diversity, feasibility, and innovation of design, which is particularly suitable for materials such as ecological composite materials that have not been widely studied and applied.

Based on material-driven design, this study proposes a more refined design method model, particularly suitable for ecological composite materials. Through multi-dimensional analysis, the model deeply explores the application potential of materials and provides precise guidance for designers to help explore the design potential of materials and effectively apply them to innovative design. The model consists of four main steps:

Build Material Awareness, Creating Material Conversion, Creating Material Application Mode, and Design Outputs (Figure 2). These four steps are gradual and have inherent logical coherence. Firstly, only when designers are truly familiar with materials and establish a keen awareness of materials can they lay the foundation for subsequent creative work; Next, based on a deep understanding of the material, perform transformation operations to explore new possibilities for the material; Then, based on market and industry demands, create application models to ensure the practicality and feasibility of the design; Finally, by designing the output, the previous efforts are concretized, completing the transformation from conception to finished product. This interlocking process ensures the efficient and high-quality output of the design.

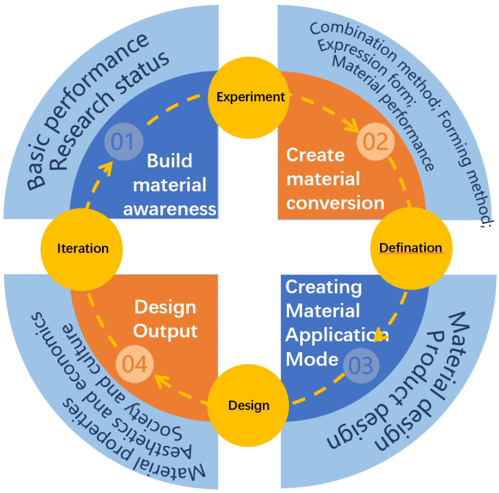

Fig. 2. Eco-composite material design method model (drawn by the author)

4 Conclusions

This study adopts the material-driven design method proposed by Elvin Karana to explore the application possibility of agricultural waste straw as a recycled material in product design. This study not only provides new ideas for agricultural waste management but also contributes new material application cases to the field of environmental design, demonstrating the important role of interdisciplinary cooperation in promoting resource recycling and environmental protection practices.

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