Manufacturing Process of Recycling Corn Fiber, A Low-tech Materials for Modular Construction

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Abstract. The research demonstrates a novel approach to using various parts of maize plants (leaves, fruits, and kernels) to create building materials that can be modularized for construction purposes. Corn is widely grown as an agricultural crop, but after the removal of the fruit, the remaining parts are often discarded and contribute significantly to environmental pollution. Currently, only a few companies are engaged in the recycling of maize into building materials. However, existing methods of recycling corn have various limitations such as high energy consumption, a requirement for skilled workers on-site, and extensive equipment needs. In this project, we aim to reduce reliance on equipment, skilled craftsmanship and material resources to make the design compatible with traditional building methods for low-income areas. We first analyzed the material properties of each part of the corn and found corn husks to be the most efficient for extraction. Additionally, we obtained adhesives from the waste fruit. Finally, we designed assembly units and assembled two sturdy and reliable chairs to verify the feasibility of our workflow. The low technical, equipment, and cost requirements of this material make it possible for modular construction to be replicated in local communities, thus promoting community participation and self-management in construction.

Keywords: Corn fiber · Recycled materials · Modular architecture · Low-tech construction

1 Introduction

1.1 Background

Maize is a staple cereal, having been cultivated and improved by humans for 9,000 years [1]. In 2022, over 1 billion tons of corn were produced worldwide, accounting for 5% of the world's total food production [2]. Despite its widespread use, a significant portion of the maize plant including the stalks, leaves, and husks often goes to waste through burning or illegal open landfill practices, accounting for 30% of total corn production [3]. This phenomenon leads to severe environmental pollution and resource waste [4]. It is crucial to find a more sustainable and efficient way of recycling these agricultural waste materials.

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1.2 Problem Statement

The need for recycling maize waste has led to the development of two main methods for processing maize fiber. The first method involves modifying the Wood-based Fiberboard (WBF) technique to produce maize fiberboard. The second method uses maize fiber as an aggregate for eco-friendly or bio-based concrete. However, both methods have significant drawbacks [5]. However, both processes have major drawbacks.

The first approach, producing maize fiberboard, contributes to pollution during the fiber hydrolysis process [6]. It requires expensive, technically demanding hot-pressing equipment and experienced workers for the resin and fiber mixing process. Additionally, the synthetic resin used is non-degradable and the resulting products are not strong enough for structural use [7].

While the second approach, using maize fiber in bio-based concrete, improves concrete strength, reduces cost, and enhances sound and thermal insulation properties, compared to conventional concrete [8]. However, it has unstable mechanical properties due to the uneven distribution of fibres inside the concrete. In addition, concrete materials are difficult to be recycled [9].

1.3 Research Aim

This paper aims to develop an environmentally friendly and low-tech process for producing corn fiber with structural strength. In order to minimize that pollution and energy waste, we use corn husks and a small number of corn leaves as raw materials and make a bio-based glue from corn starch. This low-tech approach can also promote community involvement in construction in economically disadvantaged regions, improving the recycling rate of local agricultural waste.

2 Literature Review

2.1 Why Maize?

Maize fiber has several distinct advantages compared to other types of fibers. Firstly, maize leaf fibre is the second most produced in the world, with an annual production of over 9 million tonnes [10]. Secondly, compared to other plant fibres, maize fibre is more durable and and can withstand high tensile forces [11]. Thirdly, maize fibers have a pore structure that reduces their bulking density, making them an effective composite material [10]. In contrast to fibres such as hemp and coconut, maize fibres are easier to separate. This means that in breaking down the same amount of fibre, maize fibre requires a lower concentration of lye and a lower heating temperature. It does not require particularly high concentrations of sodium hydroxide when extracted with alkaline reagents [12].

2.2 Existing Mothods of Processing Maize Fibre

Almost all existing processes require the pretreatment of maize fibre, which is generally divided into five steps: crushing materials, adding lye (10–12% sodium hydroxide), heating lye, rinsing and drying. Different levels of pretreatment is used to obtain raw materials with different fibre impurities [11].

In the existing WBF-based process, thermosetting resins (UF and MF) are generally used as binders, and the mixed material is then added to a hot press for hot pressing [7]. Fibreboard from this processing is a lightweight material; it has the advantages of being environmentally friendly, low carbon, and good thermal and acoustic insulation [13]. However, its binder is non-degradable and it produces pollution during the fibre hydrolysis process [6]. Therefore, it is essential to develop a clean and sustainable process for transforming corn fibres into valuable products to make the best use of agricultural waste. On the other side, Its products are also not strong enough to be used as structures [7].

Corn fiber can be used as an aggregate to strengthen the concrete, called Bio-based concrete. It can effectively reduce the cost of concrete and improve sound and thermal insulation properties [8]. Bio-based concrete is also more environmentally friendly and helps to dispose of agricultural waste. However, compared with conventional concrete, it has unstable mechanical properties due to the uneven distribution of fibres inside the concrete [9].

So far, no buildings have been constructed using maize fibre as a structure, and most maize fibre products are in the experimental stage. The few lightweight maize panels are similar in structure to wooden Oriented Strand Boards (OBS boards). For example, a company called Corn Board Manufacturing produces a line of corn board products. Our research tries to explore a cleaner and easier way to produce corn fibre boards that are fully degradable and recyclable with a certain structural capacity.

3 Methodology

3.1 Overall Framework

Figure 1 illustrates the production process associated with maize. After harvest, the maize is processed by a local factory, where a majority of the pulpy part is distributed as food, while some is utilized as raw material for various industries. The excess waste is either collected by local farms for use as feed or for landfill purposes. However, a significant portion of the waste remains unutilized. The recycled waste discussed in this paper comes mainly from the waste from raw material processing in the local factories.

The process of utilizing corn residue is outlined as follows: 1. Assessment of corn fiber properties and extraction of shatter corn fiber. 2. Simultaneous production of bio-based adhesive and material sample boards. 3. Design of assembly units. 4. Structural strength validation by making chairs. 5. Simulation of modular building forms utilizing corn-based materials.

3.2 Analysis of Corn Fiber Properties

In this step, we analyzed the fibre properties of the waste collected from local corn husks and leaves. We found corn husks and leaves are easily separated by the lye solution. Our findings align with previous studies which have shown that the husk has the highest

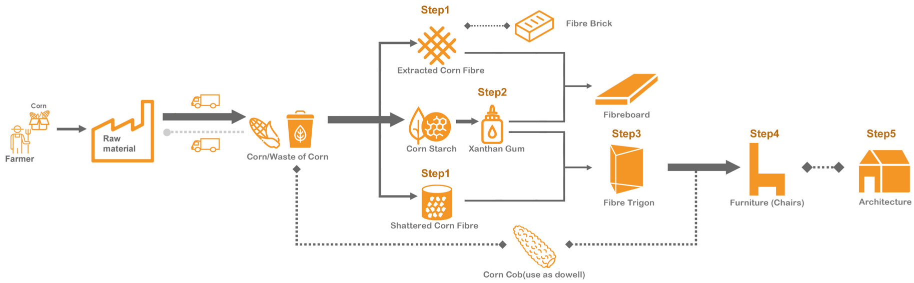

Fig. 1. The overall framework of recycling corn fiber

cellulose content among the stalk, cob, leaf, husk and ears of maize [14] and the highest water uptake suitable for separation with alkaline solutions [15]. The following is our detailed operation procedure.

According to available fibre extraction techniques, we treated the raw corn material (corn husk, corn leaves) with physical and chemical methods respectively to improve their fibrillation [16].

First, in the pre-treatment, we manually shred the corn husks into long strips 17–20 cm long and 3–5 cm wide. In the physical method, we further mechanically crush the corn leaves to 7–10 cm fibrous silk. And in the chemical method, we add the 17–20 cm corn silk to a boiling hot lye solution for fibre separation, after which we finish rinsing and drying to obtain the raw corn fibre. The characteristics of corn husk do not require a particularly high concentration of lye (Sodium bicarbonate) to complete the separation. The pictures show the characteristics and physical properties of the various fibres, of which boiled fibre and shattered fibre are the main raw materials for production (Fig. 2).

Fig. 2. Comparison of fiber properties by different techniques

3.3 Making Bio-Based Glue and Material Sample Boards

The second step of our process involves extracting bio-based glue from the maize starch. This is achieved by using xanthan gum [18], which is produced from bacterial fermentation of sugars [17] obtained from maize starch. However, due to low yield in self-extraction, we have mostly relied on commercially available xanthan gum in our experiments. To enhance the water resistance and strength of the structure, we have added Polyvinyl Alcohol (PVA) and other natural resinous materials to the xanthan gum mixture.

We have conducted multiple tests to determine the optimal combination of materials for the bio-based glue. These tests involved using different materials, ratios of xanthan gum and PVA, and even combinations of maize kernels and binders (Fig. 3).

The final blend of xanthan gum and PVA, combined with mechanically crushed maize fibres, resulted in boards with good mechanical properties, water resistance, and ability to withstand certain pressures.This mixture of xanthan gum and water in a mass ratio of 1:10 and aqueous xanthan gum to PVA in a mass ratio of 1:1, together with extracted maize fibres and mechanically crushed maize fibres (0.5:1 mass ratio), offers the desired properties for a sustainable and environmentally friendly bio-based glue. In other experiments, xanthan gum alone has been used as a load-bearing material and can be re-moulded with water, but its water resistance is not as strong as the blend of xanthan gum and PVA.

Fig. 3. Different combination of maize kernels, fibres and binders

3.4 Modular Building Form Simulation Using Corn Materials

Our team designed a series of shapes of assembly units (flat, curved, minimal surfaces, prisms) and test their structural performance relatively. All shapes of assembly units are made of xanthan gum and maize leaf fibre (1:5 mass ratio). To evaluate their structural performance, we conducted preliminary assessments of various properties such as strength, weight, flexibility, porosity, and recyclability. The results showed that most shapes had low weight, high flexibility, and were less likely to break, but more susceptible to deformation under vertical pressure. Flat shape of fibres board are tough and have a nice texture, but they can easily bend and can't handle high pressure. Curved and minimal surfaces shape fibers are better at handling pressure, but they're not as tough. Prism-shaped fibers can handle the most pressure and are easy to make with molds (see Fig. 4).

Additionally, we explored the architectural forms of each unit shape and assessed their compatibility with the glue mixes discussed in the previous step. Our team also experimented with various methods of joining parts to optimize assembly. After evaluating all options, we selected the trigonal prism as the preferred design for future development.

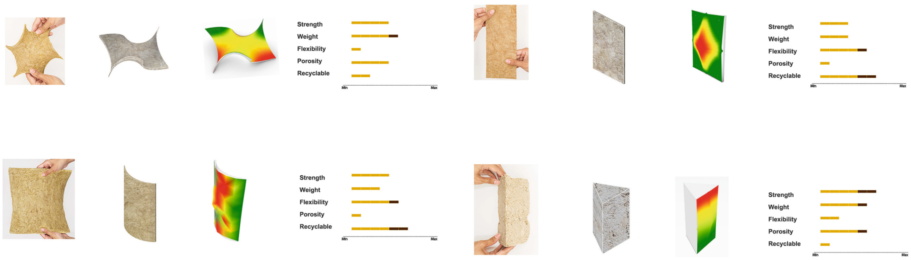

Fig. 4. Samples of different shapes

4 Case Study-Chair

4.1 One-piece Molded Chair

To validate the structural soundness of the trigonometry unit produced by this work flow, we designed and assembled two chairs, each with different compositions and molding techniques. The first chair was comprised of a 50:50 blend of mechanically crushed maize fibre and chemically extracted maize fibre, while the binding solution consisted of a mixture of xanthan gum solution (1:10 aqueous solution) and bio-plastic (CA, Cyanoacrylate-structural hybrids) in a 6:5 mass ratio [19]. Regarding mould plasticity, the team used CNC cutting technology to cut the Foam Board. The first chair was made with a one-piece infusion mould. The mould of the chair was cut longitudinally into eight pieces to obtain the rectangular shape of each piece that needed to be hollowed out, and the CNC technology was used to remove the parts that needed to be hollowed out on the eight different PVC Foam Boards. The eight PVC Foam Boards were then glued together and moulded. After 36 h of drying, the moulds were removed, and the first chair was made.

4.2 Modular Chair

For the second chair, we used 65% mechanically crushed maize fiber and 35% chemically extracted maize fiber as the material and reduced the use of bio-plastic, which is not environmentally friendly, by replacing part of it with PVA in a ratio of 5 (PVA):5 (bio-plastic):12 (xanthan gum solution). To improve the production process, the research team aimed to produce the chair in a modular form. As the chair can be divided into 12 finished trigonal components, we divided it into two groups, one consisting of four trigonal pieces spliced together to form the back of the chair and the other connecting two back trigonal pieces. Polished corn cobs are used as the dowel to connect these components. CNC was used to make these 6 moulds in the meterial of PVC Foam Board (Fig. 5). In fact, many of the moulds for the components are the same and they could eventually be reduced to 2 different moulds. The finished components were then joined together using polished corn cobs and perforated joints after 36 h of drying.

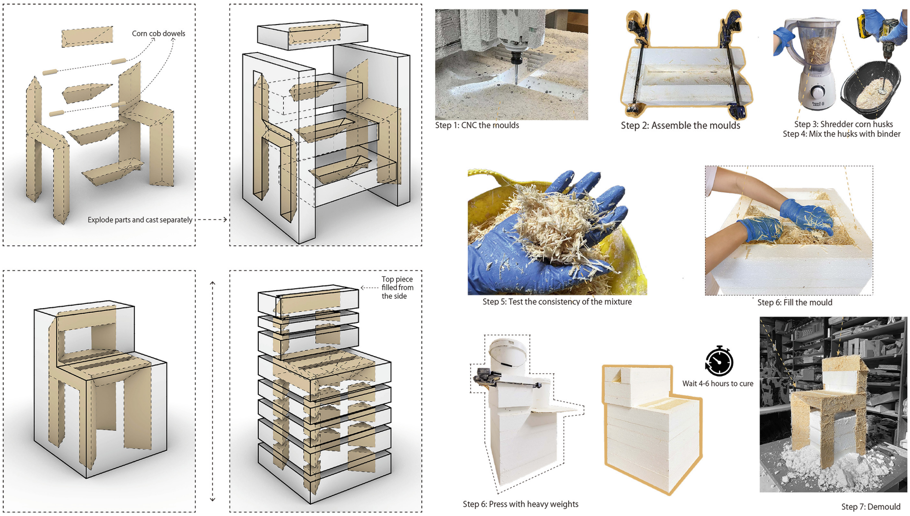

Fig. 5. Proceing of making

4.3 Use Test and Comparison

Both chairs boast strong and durable design, able to comfortably support the weight of an average adult (Fig. 6). However, the first chair is susceptible to cracks and moisture due to the different moulding materials, which are caused by the high level of chemically extracted fibres, and the lye has damaged the structure of the fibres to some extent. In terms of moulding, the first chair is much simpler and quicker, and the mould saves space. However, the integrated design makes it challenging to remove and dispose of the mold. On the other hand, the second chair may take longer to mold but its design allows for easy removal and reuse of the mold.

Fig. 6. Two chairs and imagine picture

5 Conclusion

This paper verifies the feasibility of using agricultural waste corn to create modular building materials. After performance tests via making two chairs, we found that the material has potential as a building surface and interior material (Fig. 6). Compared to existing recycling processes, the process presented in this paper is more cost-effective, requires less equipment and has a lower environmental impact, enabling fast construction and community involvement.

However, due to research condition constraints, there was a lack of experimentation in terms of architectural dimensions. The size of the model was only up to the size of the furniture, Besides, no rigorous testing methods were used for the mechanical testing of the samples. In addition, as no long-term tests have been carried out, it is not known whether the chairs will swell or deform when exposed to moisture over a long period of time.

Despite these limitations, the proposed method has the advantage of being less expensive, requiring less equipment and faster, making it ideal for local self-construction projects. The technology is open-source, providing the potential for communities to develop their own local building material and construction companies through a peer-to-peer collaboration model [20]. In this model, the government grants land development rights to the community for public welfare, the local construction materials companies recycle corn waste from farmers at a low price, employ local residents to manufacture building components and build them locally [21], and the architect establishes a platform to provide technical support [22]. By promoting a participatory, co-productive housing framework, architects are converted from former environmental designers to platform system providers, and community residents, formerly pure consumers, are converted to producers [23].

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