***Opinion Article***

**Research progress of straw fiber reinforced cementitious composites**

**Abstract:** Sustainable development involves the use of sustainable materials as substitutes for traditional materials to avoid excessive consumption of natural resources. As a natural green material, plant fiber is gradually attracting the attention of researchers in the field of architecture due to its potential application value in composite materials. In order to promote the development of natural plant fiber composites, based on the analysis of the characteristics of natural plant fiber materials, and based on the role of natural plant fiber composites in crack resistance and toughening, internal maintenance, heat preservation and energy conservation, this paper comprehensively reviews the application of plant fiber cement based composites in building projects, hoping to provide some reference for the development and application of new building materials.

**Key words:** plant fiber; mechanical property; fiber reinforced cement, composite materials; durability

**Introduction**

**1. Current Research Status of Plant Fiber Cement-Based Composites**

**1.1 Research Status at Home and Abroad**

Nowadays, bio-composite materials have attracted widespread attention from many scholars due to their characteristics of light weight, high strength, low cost, biodegradability, and sustainability. With economic globalization and the pursuit of sustainable development, awareness of environmental pollution issues has been increasing. In traditional fields such as civil engineering, green and eco-friendly new composite materials are gradually being used to replace conventional construction materials.

Against this backdrop, fiber-reinforced construction materials have emerged. Fiber-reinforced cementitious composites refer to building composite materials that use cement as the matrix and fine sand as the aggregate, with the optional addition of other mineral admixtures or additives and an appropriate amount of fibers mixed in. This material possesses both high strength and high toughness, playing a crucial role in the development of new construction materials in China.

Compared to synthetic and artificial fibers, natural fibers offer excellent mechanical properties, recyclability, and renewability, making them not only economically and environmentally friendly but also reducing environmental pollution. Additionally, as an affordable reinforcement component, natural fibers exhibit good thermoplastic and thermosetting properties, making them widely applicable in aerospace, packaging, automotive, construction, railway carriages, and other fields. They can serve as a cost-effective alternative to traditional expensive glass fibers, offering vast application prospects.

**1.2 Mechanical Properties**

Ramakrishna et al. [1] conducted impact resistance tests on mortar boards reinforced with sisal, coconut shell, jute, and hibiscus fibers. The test results showed that the impact resistance of plant fiber mortar boards was 3 to 18 times higher than that of non-fiber mortar boards. Regardless of the type of fiber used, the impact resistance of the boards increased significantly with the increase in fiber volume fraction and length. Among them, the reinforcing effect of adding 1.5% to 2.0% (by volume) of sisal and coconut shell fibers was the most significant.

In addition to impact resistance, more scholars have studied the quasi-static mechanical properties of plant fiber-reinforced concrete, mostly through three-point or four-point bending tests to explore the flexural performance of plant fiber-reinforced concrete [2]. Ranjbar et al. [3] emphasized that when the fiber content is below 8% (by mass), the flexural strength of plant fiber-reinforced composites increases with the fiber content. However, when the fiber content exceeds 8% (by mass), the flexural strength decreases with further increases in fiber content, indicating that the fiber content usually has an optimal upper limit.

**1.3 Influence of Plant Fibers on the Microstructure of Concrete**

The interface between concrete and natural fibers is porous and cracked, and it is rich in calcium hydroxide crystals, resulting in relatively weak interface interlocking strength. Li et al. [4] pointed out that the interfacial transition zone (ITZ) between plant fibers and the cement matrix is characterized by high porosity, and gaps are often formed around the plant fibers. An SEM image of the coconut shell fiber–concrete interfacial transition zone is shown in Figure 1. Similar to ordinary concrete, the thickness of the transition zone increases with the water-cement ratio. The high porosity can be attributed to the high initial water absorption of the fibers, while the gaps between the fibers and the matrix can be explained by the high drying shrinkage rate of plant fibers.

Bonnet-Masimbert et al. [5] demonstrated through pull-out tests of oil palm fibers embedded in concrete that treated oil palm fibers exhibited higher interfacial bond strength with concrete compared to untreated fibers. This improvement was attributed to the formation of a rougher and more porous fiber surface after sugar removal.



Fig.1 SEM image of coconut shell fiber-concrete interface transition zone

**1.4 Improvement Measures for the Performance of Plant Fiber-Reinforced Concrete**

Improving the durability of plant fiber-reinforced concrete and enhancing the bond strength between plant fibers and the concrete matrix are the primary methods for improving the performance of plant fiber-reinforced concrete. Currently, researchers at home and abroad have adopted two main approaches:

1. **Modification of the concrete matrix** – The aim is to consume the alkaline substance Ca(OH)₂ produced by the hydration reaction.
2. **Modification of plant fibers** – This involves using physical or chemical methods to improve the stability of fibers within the concrete matrix.



Fig. 2 Diagrammatic sketch of natural fiber's alkaline degradation process

**1.4.1 Matrix Carbonation**

Research has shown that carbonation can enhance the performance of plant fiber-reinforced concrete by promoting a rapid reaction between Ca(OH)₂ produced during hydration and CO₂ to form CaCO₃, thereby reducing the alkaline Ca(OH)₂ content. Tonoli et al. [6] reported that accelerated carbonation increased the strength of sisal fiber-reinforced concrete, with test results showing that the toughness and tensile strength of the concrete increased by 80% and 25%, respectively. In addition, carbonation reduced the apparent porosity and water absorption rate of the specimens.

Soroushian et al. [7] also observed that carbonation curing reduced the porosity of concrete, thereby improving the flexural strength of fiber-reinforced concrete. However, carbonation has certain limitations in enhancing the performance of plant fiber-reinforced concrete. Neves et al. [8] pointed out that early carbonation effectively reduces the porosity of sisal fiber-reinforced concrete, but the residual mechanical properties after wet-dry cycles fluctuate significantly and cannot be stably maintained within a certain range. Therefore, the effectiveness of accelerated carbonation, especially under long-term service conditions, still requires further verification.

**1.4.2 Fiber Modification**

Currently, fiber modification methods can be broadly classified into physical and chemical approaches, including heat treatment, steam explosion treatment, plasma treatment, high-energy radiation treatment, mercerization, alkali treatment, and silane coupling agent treatment.

* **Physical modification** alters the structure and surface properties of fibers without changing their overall properties. It enhances the interfacial bond strength by improving the mechanical interlocking between the fibers and the matrix.
* **Chemical modification** involves the removal of fiber components such as hemicellulose, lignin, pectin, fats, and waxes, thereby exposing the cellulose and increasing the surface roughness and surface area, which improves the interfacial bond strength.

**2. Straw Fiber Cement-Based Composites**

**2.1 Mechanical Properties of Straw Fiber Cement-Based Materials**

The incorporation of straw fibers usually reduces the compressive strength of cement-based materials. This is because straw fibers themselves have relatively low strength and exhibit weak interfacial bonding with the cement matrix, affecting the overall load-bearing capacity. However, an appropriate amount of straw fibers can improve the material’s resistance to crack propagation, thereby enhancing its crack resistance to some extent.

The addition of straw fibers can significantly enhance the tensile strength of cement-based materials. The fibers act as bridges within the cement matrix under tensile stress, delaying the formation and expansion of cracks, thereby improving the material’s tensile performance. Optimizing fiber length and dosage can further enhance this reinforcing effect.

The reinforcement effect of straw fibers is particularly prominent in flexural performance. Studies have shown that an appropriate amount of straw fibers can significantly improve the toughness of cement-based materials, allowing them to withstand greater deformation under bending without brittle failure. Moreover, the uniform distribution of straw fibers has a considerable impact on flexural strength, as evenly distributed fibers contribute to improved material ductility.

Aldaood et al. [9] studied the reinforcement of clay with different amounts of straw fiber and cement. Their experiments showed that the addition of 0.5% straw fiber resulted in the highest improvement in the compressive strength of cement-stabilized soil. They also found that the toughness of the soil samples increased with the addition of straw fibers.

Al-Oraimi et al. [10] investigated the effects of glass fiber and palm leaf fiber on high-strength concrete through tests on compressive strength, splitting tensile strength, and impact resistance. The results showed that the addition of fibers increased both toughness and impact resistance. Moreover, palm leaf fiber exhibited similar performance to glass fiber, indicating that straw fibers have the potential to partially replace synthetic fibers.

Farooqi et al.[11] treated wheat straw with different methods (soaking, boiling, and alkali treatment) at mass fractions of 1%, 2%, and 3%, and prepared concrete specimens reinforced with wheat straw. The experiments showed that the pretreated specimens exhibited superior energy absorption ability and increased toughness. In particular, the specimens with 1% wheat straw soaked showed the best performance. The study suggests considering the application of this material in civil engineering fields such as rigid pavements, bridges, and buildings.

**2.2 Durability of Straw Fiber Cement-Based Materials**

Straw fibers are inexpensive and exhibit a certain degree of corrosion resistance. To enable their widespread use in construction materials, their durability is a crucial factor. Relevant studies have demonstrated that straw fibers exhibit excellent durability performance in cement-based materials.

Nguyen et al.[12] pretreated rice straw with NaOH solution to prepare rice straw reinforced alkali-activated cement-based composites. After testing the properties of the products, the study found that the treated straw exhibited increased effective surface area and surface roughness, improved density, and enhanced mechanical properties. The water absorption and drying shrinkage rates were reduced, and the durability of the material under dry-wet cycles was improved.

Mst. Sadia Mahzabin et al.[13]studied the effect of modified jute fiber on the durability of foamed concrete. The results showed that soaking jute fiber in a 6% NaOH solution for 12 hours was the optimal treatment, as it effectively cleaned and chemically modified the fiber surface. This treatment increased the surface roughness of the fibers, enhancing their adhesion to the cement matrix and improving the bonding, hydration process, and internal curing process.

Sarada Prasad Kundu et al.[14] studied the durability of jute fiber modified with mild alkali (0.5% NaOH, 24h) and diluted polymer emulsion (0.125% carboxylated styrene-butadiene rubber (SBR)) in alkaline media (saturated lime solution, NaOH solution) and a cementitious environment. The results showed that after 360 days of immersion in saturated lime solution, NaOH solution, and cement slurry, the alkali- and polymer-modified jute fiber exhibited a high tensile strength retention rate. This was attributed to the carboxylated SBR coating on the jute fiber surface, which formed a protective polymer layer. The effective polymer coating restricted the direct deposition of mineral ions on the fiber surface, eliminating direct interactions between the exposure medium and the fiber. As a result, the degree of fiber mineralization was reduced, thereby improving the tensile strength and durability of the jute fiber.

Wang Jibo et al. [15] investigated the chloride ion penetration resistance of concrete mixed with wheat straw fibers. They found that the chloride penetration resistance of the concrete specimens initially increased and then decreased with the increasing content of wheat straw fibers. The improvement at low fiber content was attributed to the enhancement of the pore structure and the inhibition of crack growth. However, when the straw fiber content became too high, it adversely affected the setting and hardening of concrete, thereby reducing its resistance to chloride ion penetration.

The addition of straw fibers can enhance the continuity of cement-based materials, improve their pore structure, and inhibit crack growth, thereby increasing their durability. However, due to the water absorption properties of straw fibers, prolonged exposure to water may impair their performance to some extent. Furthermore, the durability of straw fibers decreases under alkaline conditions. This issue can be addressed by replacing part of the alkaline cement with alternative cementitious materials or by pre-treating the fibers to improve their resistance to alkaline conditions and reduce harmful reactions.

**2.3 Thermal Insulation Properties of Straw Fiber Cement-Based Materials**

Straw fibers have a naturally low thermal conductivity, making them ideal components for thermal insulation building materials. In addition to their lightweight and renewable nature, straw fibers also provide benefits such as heat insulation and noise reduction.

Pachla et al. [16] investigated the effect of dry-wet cycle treatment of rice straw on the sound absorption performance of porous concrete. The study found that the addition of 15% rice straw with a length of 3 cm significantly improved sound absorption and thermal insulation properties. The cyclic treatment method enhanced the axial compressive strength, but the bending strength was reduced by 52%.

Mittal et al.[17] prepared straw fiber-epoxy resin composites using a manual lay-up method and conducted thermal stability tests on both untreated and 3% alkali-treated composite specimens. The results showed that the exothermic peak temperature of the treated straw specimens increased, indicating that chemical treatments such as alkali solutions can enhance the thermal stability of the material.

Chen Bing et al.[18] studied rapeseed stalks and discovered that their unique porous and hollow structure significantly reduced the thermal conductivity of straw fiber concrete. This ensured that the green concrete exhibited excellent thermal insulation properties.

Zhan Xiangyu et al.[19] used rice straw and cement to produce solid bricks made of rice straw fiber cement-based materials. These bricks demonstrated a certain level of mechanical strength while being lightweight and offering effective thermal insulation. They were found to be suitable for use in non-load-bearing walls.

Wang Chunhong et al.[20] analyzed the effects of expanded glass beads on the properties of cement-based materials using a response surface design model. The results showed that when the dosage was 10% and the particle size of the expanded glass beads was 600 μm, the optimal process conditions of the model were achieved. Notably, the material’s thermal conductivity reached 0.28 W/(m·K), which was reduced by 35.98% compared to the original sample, promoting the application of waste bottom ash from straw-fired power plants in the field of building insulation.

Straw fibers have low density, a porous internal structure, and lightweight properties, making them a natural insulating material. Their eco-friendly and pollution-free characteristics enhance the thermal performance of building materials while contributing to a comfortable and natural indoor environment.

**3. Summary and Conclusion**

**Straw fiber-reinforced cement-based composites** are an environmentally friendly building material. Incorporating fibers made from crop straw into cement-based materials can address the issue of rural straw waste disposal, while also reducing material costs and harnessing the various advantages of straw fibers.

**Enhancing the mechanical properties** of straw fiber cement-based materials relies on modifying straw fibers to improve their compatibility with cement. When modified straw fibers are added to cement-based composites at low dosages, they can enhance multiple mechanical strengths, improve impact resistance and toughness, and help prevent the formation of microcracks in the cement matrix.

In terms of **durability**, incorporating straw fibers into cement-based materials helps improve pore structure and enhances crack resistance, thereby increasing overall durability.

A **high content of straw fibers** in cement-based composites can improve their thermal insulation properties, enabling the production of lightweight insulating materials.

The application of straw fiber cement-based materials in actual construction projects is feasible and practical. They have the potential to partially replace high-cost fiber-reinforced concrete and serve as insulating materials. However, large-scale, standardized, and cost-effective processing of straw fibers remains a challenge. Since straw fibers are inherently low-cost, economic efficiency is a key advantage. Therefore, it is essential to develop an economically efficient production process for straw fiber cement-based materials. Future research should focus on developing effective fiber modification methods and production processes to enhance performance while maintaining cost-effectiveness and environmental sustainability, facilitating large-scale production and application.

Plant fibers are a green, eco-friendly, and cost-effective renewable fiber reinforcement with many advantages. However, in the alkaline environment of a cement matrix, they are prone to degradation and mineralization, exhibit poor compatibility with cement, have weak interfacial bonding properties, and tend to swell after absorbing water. Therefore, pretreatment is necessary.

Currently, there are various pretreatment methods. Among them, physical methods such as coating and water treatment are more environmentally friendly and can reduce the hydrophilicity of plant fibers, thereby enhancing interfacial bonding strength. Chemical methods, such as silane coupling agents and alkali treatment, can improve the mechanical properties and durability of composites. However, these pretreatment methods have not yet achieved optimal results and require further research.

Other high-performance organic fibers have broad application prospects in reinforcing and toughening cement-based composites. At present, research mainly focuses on improving the mechanical properties of cement-based composites. However, there is a lack of fundamental theories and microscopic mechanisms supporting other performance aspects and the role of fibers, highlighting the need for further studies in this area.

**COMPETING INTERESTS DISCLAIMER**:

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

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