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# Study on the Performance of Reinforced Concrete Blocks Treated by Styrene-Acrylic Emulsion

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This paper introduces a method of improving the performance of reinforced concrete blocks and reveals the reinforcing effect of fibers. It is pointed out that the plant fibers treated by styrene-acrylic emulsion can effectively improve the interfacial bonding conditions, for the modified straw fibers which were treated by alkali processing and acrylic coating, their performance has been significantly improved, which is conducive to absorbing energy and improving the strength of the material. This paper focuses on introducing three types of reinforced concrete blocks, it's known that the bridging effect can effectively prevent the development of micro cracks. The occurrence of cracks increases the macroscopic tensile strain of the material and increases the ductility and toughness of the matrix. Studying plant fiber reinforced blocks will help promote the application of this new wall materials.

## 1. Introduction

The aging and destruction of concrete blocks are mainly caused by the development of hidden micro cracks and micro cracks due to influence of environment and loads. The concrete blocks are not dense enough, which makes water and other soluble substances to penetrate, accelerating the destruction process. Improving the quality of concrete blocks and preventing the development of cracks are worthy of particular concern. In recent years, in developing countries and regions, the interest in reinforcing the concrete with relatively inexpensive plant fibers is increasing (Jr and Agopyan, 1999; Mwamilla, 1987; Filho et al., 2000). Plant fiber is the most abundant natural polymer material in nature. The total amount of cellulose grown in the natural world is as much as 100 billion tons per year, far exceeding the total reserves of existing petroleum on the earth (Xu et al., 2005). The research and development of plant fiber-reinforced concrete blocks not only avoids cracks, seepage, and leaks of the blocks, but also contributes to environmental protection and sustainable development, and the reinforced concrete blocks are expected to replace the clay bricks and concrete blocks, so as to optimize product performance and production costs.

## 2. Properties of plant fiber and its reinforcing effect

### 2.1 Room temperature properties of plant fibers

The chemical compositions of plant fibers are: cellulose, hemicellulose, lignin, pectin, waxiness and so on. Among them, cellulose is the main component, which acts as a skeleton, the strength and hardness of the fiber are determined by the cellulose content, and the rotation angle formed by the microfibrils and the fiber axis in the inner cell wall (Pan and Ren, 2010). Hemicellulose is a substance that is tightly bound to cellulose and acts as the binding agent. Lignin content determines the structure and properties of plant fibers. Plant fibers have not much differences with the traditional reinforcing fibers in the performance, which is of great market potential and development prospects.

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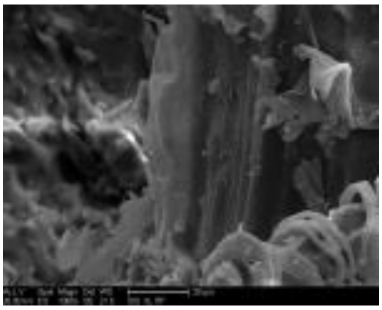
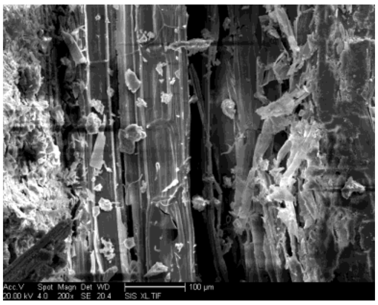
The main function of adding fibers into blocks is to inhibit and stabilize the development of micro-cracks and to mitigate the degradation of blocks. As the fibers are closer to each other, the length-diameter ratio is larger, the surface area is large, the adhesion strength and the tensile strength are larger, which has larger restraints on the cracks, and the key is the balance between the adhesion strength and the tensile strength. Cellulose fibers have thin diameters and strong surface hydrophilicity, which does not affect the compaction of cement particles and has a good uniformity (Yang et al., 2007; Yang, 1996; Zheng and Zhu, 2013).

### 2.2 The reinforcing effect of plant fibers

The lignin in the plant fiber binds together the single fibers, which results in that the wheat straw and the matrix cannot effectively complement each other (Zheng et al., 2005). Alkali extraction and acid-alkali extraction method can be used to extract the single fibers in the wheat straw and make the fibrils closer to the fiber axis, which is conductive to increasing the modulus and strength of wheat straw fiber, improving the interface binding, and increasing the contact area with the matrix.
Destruction of cementing materials can effectively prevent the development of microcracks through the bridging effect of fibers (Li, 2006; Li et al., 2017; Moriconi, 2003). When the matrix cracking load is reached, the fibers passing through the crack surface are constrained by the surrounding matrix and bear the tensile stress at the crack opening, which restricts the development of cracks, as a result, the stress of the matrix near the cracks is increasing, resulting in new cracks. Therefore, multiple cracks increase the macroscopic tensile strain of the material and increase the ductility and toughness of the matrix.
The SEM analysis results after high temperature show that (Filho et al., 2003): when the temperature is between 20°C and 400°C, the sawtooth structure of the wheat straw in the matrix is closely meshed with the matrix of the material, and is well compatible with the matrix; after 600°C high temperature, the straws still have a relatively complete morphology (Fig. 1), but appear few narrow cracks, indicating that the straws still have some pulling effect, and still have a certain toughness-reinforcing effect on the blocks (Zhu and Zheng, 2012;).


*(a) 20°C*


*(b) 400°C*

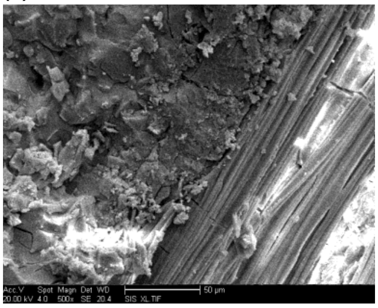

*(c) 600°C*

*Figure 1: SEM pictures of fiber reinforced concrete blocks at different temperatures*

## 3. Research status of plant fiber reinforced blocks

### 3.1 Plant fiber reinforced gypsum slag hollow blocks

In 2003, for the “Special Topic for the Research and Development of Green House Industry Technology for Small Cities and Towns”-the “Tenth Five-Year” scientific and technological breakthrough plan, its main task was to develop and utilize plant fiber reinforced gypsum slag hollow blocks. These blocks take straw, wheat straw, chaff, cotton stalks and other agricultural straw and sand as the basic aggregate, cement and gypsum slag as the cementing agent, fly ash, expanded perlite, and polystyrene granules as the admixtures, these

materials are mixed and condensed to form these hollow blocks. With the advantages of small unit weight, low cost, low thermal expansion rate and low water absorption expansion rate, they can be used as substitute products of clay bricks, and they are a new type of wall material that is energy-saving and environment-friendly. At present, in the formulated industrial standard *Technical Specification for Application of Plant Fiber Reinforced Gypsum Slag Hollow Blocks* (CECS 201:2006), it is stipulated that the moisture content of agricultural straw in raw materials of blocks should not exceed 12%, and the fibers with a length of 10~20mm after crushing should account for 40%, which is conducive to the promotion and application of the blocks.
Li and Gao, (2011) of Shandong Institute of Building Materials conducted SEM analysis of plant fiber reinforced gypsum slag hollow blocks, their results showed that the inclusion of slag and cement and other substances made the matrix structure more compact, which improved the strength and water resistance of the matrix. The plant fiber treated with styrene-acrylic emulsion can effectively improve the interfacial bonding condition, effectively improve the strength and water resistance of the composite material, which proves that the fiber and the resin are firmly bonded and the interface bonding layer is firm and compact.
Wang et al., (2009) modified the straw fiber by alkali treatment and acrylic acid coating, and analyzed its microstructure by infrared spectrometer, SEM, and mercury injection apparatus. The results showed that the straw fibers were soaked in NaOH solution with a concentration of 7% for 10h, the strength respectively increased by 13.3% and 32.8% compared to the untreated plant fiber gypsum-based composite material samples. After the modification, the performance of the plant fiber is significantly improved, and the contact area with the matrix is increased, which is favorable for absorbing energy and increasing the strength of the material.
Yang and Yue, (2006) summarized the lightweight energy-saving features of plant fiber reinforced gypsum slag hollow block walls. Through multiple sampling tests on plant fiber gypsum slag hollow blocks, all of the indicators met or even exceeded the requirements of the national standards *Lightweight Aggregate Concrete Hollow Blocks*, the details are shown in Table 1.

*Table 1: Physical properties of plant fiber gypsum slag hollow blocks*

| Density (kg/m$^3$) | Strength (MPa) | Freezing Resistance (20 times freeze thawing) | Drying shrinkage value (mm/m) | Water absorption (%) | Softening coefficient | Radioactivity | Heat conductivity coefficient (W/(m·k)) | Sound insulation (dB) | Void ratio (%) |
|---|---|---|---|---|---|---|---|---|---|
| 450~1000 | 3.2~14.4 | Quality loss 0.48%, Loss of strength 4% | 0.19 | 10.2 | 0.84 | Internal/ external exposure index 0.1 | 0.12~0.135 | 45 | 26 |

Note: The inspection specification of the blocks is 500mm×250mm×190mm.

### 3.2 Plant fiber industry silica fume and slag concrete blocks

In 1970s, because of its low cost and wide source, plant fiber gradually attracted the attention of experts at home and abroad. Tests of sisal-reinforced mortars were carried out in the United Kingdom and Sweden, they soaked the sisal fibers into solutions in which glycerol formate and stearic acid are acted as separating agent and waterproofing agent respectively, after 60 and 120 cycles of CBI method, the bending strength retention of sisal-reinforced concrete was 70% and 41% of the value before aging, respectively. When about 45% of ground activated silica fume is incorporated into ordinary Portland cement, its pore water alkalinity is reduced. After 60 and 120 cycles of CBI method, the bending strength retention values are respectively 88% and 71% before aging. The sisal fiber-reinforced concrete without any treatment also had a flexural bending retention value of 2.7% and 1.2% before aging after 60 and 120 cycles of CBI method. It can be seen that modifying the surface of the plant fiber and reducing the alkalinity of the cementing material are effective methods for improving the durability of the plant fiber-reinforced cement-based composite materials.
In 1980, a Finnish Research Center developed a kind of wood fiber reinforced concrete with a density of 1200 to 1800 kg/m$^3$, which is predicted to have a service life of more than 50 years. In early 1990, Sarigaphuti et al., (1993) found that poplar and pine fiber played a role in retarding the expansion of concrete cracks, narrowing the crack width to 2/3 of that of ordinary concrete. In 1995, Egyptian scientists have found that palm leaf stalk fibers have structurally stable liquid delivery channels, demonstrating that the reinforcing effect of fibers that have been soaked in the cement solution is better.
In the 21st century, when studying the durability of alkali-sensitive fiber reinforced concrete, Brazil's Romildo D., Toledo Filho et al. found that, after the sisal fiber reinforced concrete is molded and put into the carbonization box ($CO_2$ 9.8%, 26.7°C, RH 64.3%) for 109 days, its embrittlement process was delayed

compared to the untreated concrete. Similarly, the sisal fiber that was soaked in the silica slurry for 10 min was combed neatly and mixed into the cement-based composite material and then dried in the air, its embrittlement process is also delayed compared to untreated concrete. In addition, the incorporation of mineral admixtures has also played a positive role in reducing the alkalinity of cementing materials, improving the compactness and pozzolanic activity of the composite materials, and improving the durability of concrete, replace the cement with 10% of silica fume and 40% of slag, the durability of concrete has been greatly improved.

China's Guangxi, Guangdong, and Fujian regions are also rich in plant fibers. Many scholars have explored plant fiber-reinforced cement-based composite materials. Zhang Xisheng and Zou Weiqian from Shandong Institute of Building Materials, and Ye Yingwei from Hong Kong Polytechnic University have all developed plant fiber cement composite panels with low price, leakage proof, and excellent performance, and have achieved good economic benefits.

### 3.3 Plant fiber reinforced alkali slag cementing material blocks

Use alkaline compounds or alkali industrial wastes (such as water glass, etc.) as activators to activate industrial waste residues (such as slag, phosphorus slag, etc.) to obtain alkali slag cementing materials that are environment-friendly and have excellent performance. The material has the advantages of room temperature curing, fast hardening, early strength, and high temperature resistance. Since in the raw materials of alkali slag cementing material, cement is not contained, it eliminates the cumbersome process of "grinding twice and burning once", and saves a lot of fuel, electricity and mineral resources (limestone, clay, etc.) consumed by the cement production, avoids the emission of large amounts of greenhouse gases ($CO_2$) and toxic gases ($SO_2$, $NO_x$) which pollutes the environment. Therefore, domestic and foreign scholars have actively explored the alkali slag cementing materials. In 1940, Purdon of Belgium studied NaOH-activated slag and alkaline salt materials, and proposed the "alkali activation" theory, which uses NaOH to dissolve the compounds ($Al_2O3$, $SiO_2$) in the cementing material to form sodium metaaluminate and sodium silicate; which then react with calcium hydroxide to form calcium aluminate and calcium silicate gels to force the cementing material to harden and to obtain sodium hydroxide again. It is known that sodium hydroxide plays a catalytic role in the hardening process of the cementing material.

In 1957, Prof. Glukhovsky of Kiev Institute of Engineering in Ukraine used sodium hydroxide or water glass as an activator to activate the mixture of crushed stone, boiler slag, ground granulated blast-furnace slag (GGBS) and quicklime, and then obtain cementing materials with good compressive strength up to 120MPa and good stability. Prof. Glukhovsky further demonstrated that the cementing material is like Portland cement, it can be hardened in water, under standard conditions or natural conditions, as well as hardened under steam curing or high-pressure treatment conditions. Dai and Cheng used an orthogonal design method to study the 45%~60% GGBS activated by 5%~11% alkaline activator and the 35%~50% fly ash, and concluded that water glass has better activation effect on slag or fly ash than sodium hydroxide.

Since 1976, French Davidovits applied for the first alkali slag cementing materials patent in United States, and achieved more than 30 patents in Britain, France, Europe and other countries, which involves coating, concrete, fireproofing; refractory matter, and other construction materials. It has been successfully used in prefabricates, blocks and the civil and industrial buildings on site, seaport buildings, road buildings and military projects. All of which have been proved to be effective in practice.

In the mid of 1980s, there was a high tide of research and application of alkali slag cementing materials at home and abroad. In China, Zhong Baiqian and Yang Nanru studied the depolymerization and repolymerization process of $[SO_4]^{2-}$ anion during slag activated by water glass. It revealed that the amount of high polymers increases with the decrease of $[SO_4]^{2-}$ monomers, and showed the double reaction of dimers and other low polymers to repolymerize from monomers.

Zheng Wenzhong of Harbin Institute of Technology research shows that alkali slag cementing materials can be cured at room temperature environment, and its compressive strength is not under C50 concrete. After 600℃ high temperature, its compressive strength does not reduce, and its price is basically equal with the concrete.

Since the advent of alkali slag cementing materials in the 1940s, it has been used to partially replace cement due to its advantages of high strength, low cost and good heat resistance. However, as this material is brittle material, its ductility is poor and its shrinkage is large, which seriously hinders its wide application in structural engineering.

Yan Xiaojie of Harbin University of Science and Technology etc. conducted experiments on alkali slag cementing materials reinforced by wheat straw, rice straw or corn straw, and perform experiment on wheat straw reinforced alkali slag cementing material blocks, it was found that, compared with rice straw and corn straw, wheat straw has more excellent toughness reinforcing effect. The strength of the plant fiber-reinforced alkali slag cementing material blocks was 16.75 MPa, and the compressive strength of the blocks after high temperature of 800°C was 18.6% of the room temperature, and the compressive strengths of the neat paste blocks at room temperature and 800°C was respectively 10.46 MPa and 1.78 MPa, it can be seen that the integrity of the straw reinforced alkali slag cementing material blocks is better than that of the neat paste blocks. The incorporation of wheat straw inhibits microcrack development and increases the ductility of the blocks. The thermal conductivity of plant fiber reinforced alkali slag cementing material blocks is 0.136W/(m·k), which is lower than the air thermal conductivity 0.84W/(m·k), and is smaller than the thermal conductivity of insulation materials 0.25W/(m·k), so it meets the requirements of insulation materials.

## 4. Engineering applications

The world-famous JamesHaidie Company has launched a plant fiber cement exterior wall cladding, which is durable, has high performance and excellent cost-effectiveness. A&A Co., Ltd. of Tokyo Japan mixed the bamboo produced in Thailand with cement and water and cast it to obtain high-strength products. A kind of water-absorbing cement has also been developed in China, which can absorb water up to 35% of its own weight, it can ease the greenhouse effect and contribute to greening.
China's plant fiber reinforced blocks are used in construction projects such as the Three-ring Printing Business, Baijia Park Plaza, Xiaogan, Wuhan Province, Shangdu Grand Hotel and Shushi Group Office Building etc. The new wall material has remarkable heat preservation and insulation effect, and it is well received by the residents.

## 5. Development prospects and existing problems of plant fiber reinforced blocks

### 5.1 Development prospects

The crack resistance of plant fiber and polypropylene fiber of the same admixture volume is comparable, but the price of plant fiber is only 1/10 of that of polypropylene fiber. If plant fiber can replace or partially replace polypropylene fiber to be applied into cement-based composite material products, it must be able to achieve good economic and social benefits. Since plant fiber reinforced blocks have the advantages of lightweight, high-strength, thermal insulation, low water absorption, and good resistance to freezing and thawing, they have huge demanding space in the wall material market. In Egypt, Brazil and other developing countries, their promotion and application increase rapidly, and they become the mainstream of the sustainable development of the wall material market. If we can vigorously promote plant fiber reinforced blocks, it will surely achieve good results.

### 5.2 Existing problems

At present, the raw materials of this type of blocks are different. Theoretical studies and actual conditions (environment, climate) are different, it is difficult to achieve unified mechanical properties and building performance standards, which hinders the promotion and application of this kind of blocks. The water absorption of various plant fibers, the corrosion of fibers in the alkaline environment of cement, the durability and tightness of the bond between composite materials and concrete, and the durability and fire resistance of such blocks have all become hot topics for domestic and foreign experts. If the above problems can be well solved, plant fibers that are abundant in nature will be widely used.

## 6. Conclusions and prospects

The crack resistance of plant fiber and polypropylene fiber of the same admixture volume is comparable, but the price of plant fiber is only 1/10 of that of polypropylene fiber. If plant fiber can replace or partially replace polypropylene fiber to be applied into cement-based composite material products, it must be able to achieve good economic and social benefits. For construction projects, the effect is significant, it’s a major breakthrough in energy-saving and environmental-friendly wall materials.

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