

## Bamboo Fiber-based Insulating Paper: A Potential Choice towards Greener Power and Paper Industries

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Insulating paper is the key material utilized in ultra-high voltage (UHV) projects, and it affects the safe and stable operation of the whole power system. Cellulose fiber-based insulating paper, having the advantages of low price and environmental friendliness, has been widely used as the preferred insulating material for certain transformers. Bamboo, as a fast-growing raw material, has a favorable fiber length and its carbon sequestration is better than that of wood. Bamboo can be potentially used as a new raw material for insulating paper, thus promoting the green development of the power and paper industry. This article mainly discusses the challenges and potentials of bamboo fiber-based insulating paper and the opportunities of bamboo fiber-based paper materials.

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### The Importance of Insulating Paper

The electric-power industry is an important support for the development of national economies, especially in the fight against COVID-19 pandemic. To promote economic development, China is constructing the 1000 kV extra-high voltage (EHV) projects to sustain the requirements of electrical energy transmission across long distances and to optimize energy resources distribution. Insulating paper as one of the key materials in transformer technologies. It has an essential impact on the whole working conditions of the electrical system, including the service life and a safe environment.

Electrical insulating paper can be divided into synthetic fiber insulating paper, cellulosic fiber insulating paper, inorganic fiber insulating paper, and composite insulating paper. Cellulosic fiber insulating paper has been widely used in power transformers because of its low cost, environmentally friendly attributes, and high strength performance. Unbleached sulfate softwood pulp with a long fiber length and high cellulose content is typically used in transformer insulating paper because it can reduce the dielectric loss and improve the strength of insulating paper. However, the shortage of wood fiber resources in China may bring some uncertainty in price and quality to the insulating paper industry and market. Therefore, exploring new fiber raw materials for high-performance cellulose fiber-based electrical insulating paper as supplement may be of importance to increase the localization rate of electrical system materials in China.

## Advantages of Bamboo Fiber

Bamboo resources in China rank first in the world, and the existing bamboo forest area is as high as 7.02 million hectares, accounting for about 1/3 of the world's bamboo forest area. Unlike wood, bamboo has a shorter growth cycle, which is approximately 3 to 5 years. Bamboo can be managed reasonably without reforestation for decades. Importantly, from the perspective of environmental protection, bamboo has good carbon sequestration capacity (Zhang *et al.* 2022). The average annual carbon sequestration of bamboo per hectare is 5.06 tons, which is 1.46 and 1.33 times more than fir and tropical rainforest, respectively. This excellent carbon sequestration capability can facilitate the goal of carbon neutrality. In terms of fiber morphology, bamboo fiber is slender, and the fiber length is between those of softwood and hardwood fiber, such that it can deliver paper with good strength.

Besides the advantages in fiber characteristics, bamboo pulp production is growing in China (Chen *et al.* 2019). Bamboo pulp production in China was 2.42 million tons in 2021, and the year-on-year growth was up to 10.5%. There are twelve pulp lines with an annual capacity of more than 100,000 tons. Therefore, the use of bamboo fiber partly instead of wood fiber in insulation paper is significant to alleviate the shortage of wood resources and promote environmental performance of paper production.

## Challenges of Bamboo Fiber in Insulation Paper

Despite many advantages of bamboo fibers, there are still many challenges with respect to using it in electrical insulation paper. Insulating paper is subjected to various mechanical forces during the operation of electrical equipment, so it requires high strength. Bamboo fiber has a thicker cell wall compared to wood fiber, leading to a higher bulk and lower strength properties of paper. However, the high bulk of bamboo paper may provide better absorption in electric insulating oil or resin. In addition, the secondary walls of bamboo fibers are multi-layered. The microfibrils in S1 layer are intertwined on the S2 layer perpendicular to the fiber axis, which makes it difficult to be fibrillated during refining. Besides, the presence of a high content parenchyma cells not only retards the drainage of pulp and paper furnish but it also affects dielectric properties. Therefore, papermakers should pay more attention in the treatment of parenchyma cells and refining of bamboo fiber (Song *et al.* 2011). The high ash content of bamboo fiber is also a non-negligible issue. Considering the favorable electrical properties, cellulose fiber-based insulation paper has a strict requirement on the ash content based on the paper grade. The ash content of unbleached bamboo pulp can be up to 0.55%-1.0%, and it contains more than ten different metal ions. Therefore, purification should be a key process. During the process, it is also important to enhance ash removal by acidifying the pulp while maintaining the degree of polymerization of the fiber.

## Opportunity of Bamboo Fiber-based Paper Materials

Although there are many challenges facing the development of bamboo fiber based insulating paper, especially in the screening, purification, and refining processes, its good fiber properties, fast growth, and carbon sequestration capacity can make it possible to deliver paper with more sustainability and environmentally-friendliness, thus giving more opportunities in bamboo pulp industry, especially in the background of carbon neutral around the world. Besides, the innovations in bamboo fiber-based specialty pulp or cellulose products (such as bamboo fiber based nanocellulose, micro-fibrillated cellulose)

will also bring many possibilities in enhance the strength properties of specialty pulps or replacing petroleum-based products. Therefore, many potential opportunities in bamboo fiber-based pulp and paper still need to be explored by industry and academia in the future.

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