# A Review on Extraction of Bamboo Fibres and Its Properties

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**Abstract— Due to increasing environmental concerns and non-renewable resources dwindling at a higher rate, the researchers are working on replacement of traditional non-renewable materials with sustainable eco-friendly materials that can be recycled or biodegradable. Among the polymer composites reinforced with natural fibre, bamboo fibre is a strong contender for replacing synthetic fibres such as glass, carbon, etc. due to their comparable mechanical properties. Many parameters such as fibre extraction methods, moisture content, fibre size, temperature, fibre length, resin application and composite preparation techniques affect the properties of bamboo fibres and bamboo fibre reinforced polymer composites. In this review, various bamboo fibre extraction methods and its properties have been discussed. There are three main fibre extraction methods: mechanical extraction, chemical extraction, combined chemical and mechanical extraction. Among the three fibre extraction methods, mechanical extraction methods are more eco-friendly than other two methods.**

**Keywords— Bamboo fibre; Fibre extraction methods;Mechanical extraction; Chemical extraction; Combined chemical and mechanical extraction**

## I. INTRODUCTION

Due to their ease of production and high mechanical properties, carbon, graphite and glass fibre-reinforced polymer composites have been used in various industries. These polymer matrix composites have been widely investigated for their high performance. Due to their non-recyclable and non-degradable properties, their end of life disposal mode is unknown. Giving importance to the climate change and environment, researchers are interested in using natural fibres in the place of synthetic fibres. Natural fibres are classified as animal fibres containing protein such as silk, wool, hair, etc., and plant fibres – bamboo, sisal, hemp, flax, etc.[1]. There are four main ingredients in the plant fibres: lignin, pectin, cellulose and hemicellulose. Efficiency of the plant fibre reinforcement is defined by the type of cellulose and crystallinity[2] .There are seven categories of plant fibres namely – grass, stalk, wood, fruit, seed, bast, and leaf[3]. Bamboo belongs to a grass family called Bambusoideae and when compared with other plant fibres, bamboo has got several advantages such as low cost, low density, high growth rate, stiffness and high mechanical strength [4]-[8]. Difficulty in extracting straight and fine fibres, degradation with temperature during manufacturing and high moisture content are some of the disadvantages of bamboo for various applications [6],[9].

### A. Distribution of bamboo globally

In many continents of the world, bamboo is grown and its region can be classified accordingly: Asia-Pacific bamboo region, American bamboo region, African bamboo region and European bamboo region. Asia-Pacific bamboo region countries include India, China, Burma, Bangladesh, Thailand, Cambodia, Japan, Vietnam, Indonesia, Philippines, Sri Lanka, Korea and Malaysia. American bamboo region countries include Guatemala, Mexico, Costa Rica, Honduras, Nicaragua, Columbia, Brazil and Venezuela. African bamboo region countries include Eastern Sudan and Mozambique. European bamboo region countries include France, England, Germany, Belgium, Italy and Holland. About 65% of the world's bamboo is in the Asian continent and the rest are in the other continents. Hence, Asian continent is the region with largest bamboo population in the world [10].

### B. Structure of bamboo

Bamboo grass consists of culm, which is a hollow cylinder with its inside having several diaphragms, while outside of the culm appear as rings. The space or gap between the two rings is known as 'internode'. The distance between each node is different for each species [11]. There are several vascular bundles in the culm wall of bamboo, which provides strength to the culm [12]. Consequently, the bamboo species is characterized by its number of vascular bundles, density and average size. Their physical properties and usability are reflected by the anatomy of bamboo culm [12]. With the decreasing upper diameter of the bamboo culm, the fibre density increases. So the top section of the bamboo culm has higher strength than the base section [13].

### C. Chemical composition of bamboo

Lignin, cellulose and hemicellulose are the important components in bamboo and these components constitute 90% of the total weight of bamboo. Other important constituents of bamboo are pectin, fat, protein, tannin, ash and pigments. Physiological activity of the bamboo is determined by these components [14]. The chemical composition of bamboo keeps changing with age. With increase in age, the cellulose content keeps on decreasing and the chemical composition of bamboo is affected directly. Bamboo gets its stiffness and yellow colour from the lignin content. Since lignin is quite resistant to various alkalis, all lignin content cannot be removed by different treatments. Non cellulosic components of the bamboo contribute to properties such as density, moisture, flexibility and strength [15].

## II. METHODS

### A. Mechanical Extraction Methods

There are many forms of mechanical extraction methods such as steam explosion method, crushing, grinding, rolling in a mill and retting. These methods are used for the extraction of bamboo fibre for application in various industries for making bamboo fibre reinforced composites.

1) Steam Explosion Method: This method is a low energy consumption method and to produce pulp, the cell walls of a plant has to be separated. Steam explosion method is an appropriate method for separating the lignin content from the plant surface, but the resulting fibres produced are rigid and dark [16]. In one research study, it is found that single fibres are not effectively separated from the fibre bundles. With sifter machine and mesh filter, fibre bundles with 125-210μm diameter were produced. The fibres were then dried at 120°C for 2 hours. This is a notable method to remove lignin content from the fibres completely, as the function of this technique is to remove lignin content from the woody materials. Thus by removing the lignin from the fibres, bamboo fibre cotton is produced [17]. The same steam explosion process was performed for a raw bamboo by cutting and overheating it in an autoclave at 175°C for 60 minutes at 0.7-0.8MPa. Then the steam was immediately released for 5 minutes and for nine more times. The same process was repeated to ensure that the cell walls were fractured. Subsequently, the ash content from the fibre was removed by washing it in hot water at 90-95°C and then dried in an oven at 105°C for 24 hours. As most of the lignin content was condensed on the fibre surface, it reduced the adhesion between the resin and extracted fibres[18]. In the steam explosion process, fibre cell walls are cracked and bamboo fibres became soft, thus enabling extraction. The crushed cell walls, struck onto the surfaces of the bamboo fibre had low shear resistance. The researchers ultrasonically washed the fibres with partly decomposed lignin and then treated the fibres with isocyanate silane to remove the unexpended cells. From the results, it is found that steam exploded bamboo fibres had higher tensile strength than silane treated fibres[19]. The interfaces are weak beween the fibres and soft cells and these weak interfaces reduce the tensile strength of these fibre reinforced thermoplastics. Proper surface treatment is needed to achieve strong adhesion between fibre and the matrix [20].

2) Crushing: In this procedure, raw bamboo is first cut into small pieces by a roller crusher. Then the coarse fibres were extracted from small pieces of bamboo by a pin-roller. Then the fibres were boiled at 90°C for 10 hours to remove the fat and later dried in the rotary dryer and put in a dehydrator [18]. The main problem with this process is that it yields only short fibres, and with mechanical over-processing, it becomes powdered [20].

3) Grinding: In this procedure, bamboo culm without any nodes was cut into strips and then soaked in water for 24 hours. Then those drenched strips were cut into smaller pieces with a knife. Wider strips were passed through an extruder and long bamboo strips were cut into small bamboo chips. These small bamboo chips were ground in a high speed blender for 30 minutes to acquire short bamboo fibres. Using several sieves with various apertures, the fibres were separated by size. The extracted fibres were finally dried in an oven at 105°C for 72 hours [21]. Long fibres are able to carry high tensile load due to the increase in transverse length and thus tensile modulus of the composite is increased. Some researchers used the same method for extracting bamboo fibres and the rheological and morphological behavior of the bamboofibre composite were studied [22]. This method has also been used in studies, where particles from dry bamboo strands are used with nanoclay[23].

4) Rolling Mill: In this procedure, bamboo culm was cut into small pieces from the nodes and these pieces were cut into strips with 1mm thickness. To facilitate the separation of fibres from the strips, the strips were soaked in water for 1 hour. They were then passed through the rolling mill under slight pressure and at low speed. The rolled strips were soaked for 30 minutes in water and then using a razor blade, the fibres were separated. The obtained fibres were dried in the sun for 2 weeks and their length ranged from 220 to 270mm [4]. In another study, bamboo strips were cut from the bamboo culm and pressed between two pairs of steel cylinders and without soaking in water, fibres were extracted [24]. In another study, sliced bamboo strips are steamed and soaked in water to soften the lignin content and the fibres are then passed through the roller. The length of fibres extracted ranged from 30 to 60 cm [25].

TABLE 1 Comparison of mechanical and physical properties of bamboo fibre based on the extraction procedures with glass fibre [6], [18], [17], [26], [32], [37], [38 ]

| Fibre | Extraction procedure | Tensile strength (MPa) | Young's modulus (GPa) | Fibre diameter (µm) | Fibre length (mm) | Density (g/cm3) |
|---|---|---|---|---|---|---|
| **Bamboo** | **Mechanical methods** | | | | | |
| | Steam explosion | 441 ± 220 | 36 ± 13 | 15–210 | – | – |
| | Crushing | 420 ± 170 | 38.2 ± 16 | 262 ± 160 | – | – |
| | Grinding | 450–800 | 18–30 | – | – | 1.4 |
| | Rolling mill | 270 | – | 100–600 | 220–270 | – |
| | Retting | 503 | 35.91 | – | – | 0.91 |
| | **Chemical methods** | | | | | |
| | Chemical | 450 | 18 | 270 | 10 | 1.3 |
| | Alkaline | 395 ± 155 | 26.1 ± 14.5 | 230 ± 180 | – | – |
| | **Combined chemical and mechanical methods:** | | | | | |
| | • Chemical + Compression | 645 Max: 1000 | – | 50–400 HC:150–250 | >10 | 0.8–0.9 |
| | • Chemical + Roller mill | 370 Max: 480 | – | HC: 50–100 | 120–170 | – |
| E-Glass | – | 1200–1500 | 70 | 9–15 | – | 2.5 |

5) Retting: In this procedure, cylindrical part of the bamboo culm was peeled to obtain the strips. The bundles of strips were kept in water for three days. The wetted strips were beaten, then scraped with a sharp edged knife and combed [26]. In this method, the process of scraping had strong effect on the fibre quality and the fibres broke less. In another study, no scraping or combing is involved, but raw bamboo is simply cut into several longitudinal parts without the removal of bamboo node and epidermis. The bamboo strips were then cleaned with flowing water and were fermented in water at room temperature for 2 months. Two different retting types namely aerobic and anaerobic retting were used to separate the fibre bundles from the culm. The authors found that from every fibre bundle, single fibre can be extracted and the fibre length can be acquired in any length [27].

B. Chemical Extraction Methods

The chemical extraction methods such as chemical retting and alkali or acid retting are used to remove or reduce the lignin content from the fibres. These chemical extraction methods also have effects on other fibre components such as pectin and hemicelluloses [28], [29], [30].

1) Chemical Retting: Chemical Assisted Natural (CAN) retting procedure was used by researchers to reduce lignin and water content in the fibres. Bamboo culm was cut in longitudinal direction with a slicer into thin slabs. The fibres separated manually were immersed in $Zn(NO_3)_2$ solution with 1%, 2% and 3% (owf) concentrations at 1:20 material to liquor ratio. These fibres were immersed at 40°C for 116 hours in neutral pH and kept in BOD incubator and then for 1hr they are boiled in water. This procedure was able to remove more lignin than alkali and acid retting, but the treated fibres had high moisture content [29]. In another study, bamboo culm is slit into 2cm chips and the chips are roasted at 150°C for 30 minutes. The chips were then immersed in water for 24 hours at 60°C and air dried prior to removing further impurity. Further, the fibre bundles were cooked with 2% sodium silicate, 2% sodium sulphite, 2% sodium polyphosphate and 0.5% NaOH (w/v) solutions at 100°C for 60 minutes at 20:1 liquor to bamboo ratio. The fibres were then washed with hot water and treated with 0.04% xylanase and 0.5% diethylene triamine pentacetic acid at 70°C with pH 6.5 for 60 minutes. The fibres obtained were again cooked at 100°C for 60 minutes with the same procedure, but with 0.7% NaOH. The fibres were then put in a polyethylene bag and bleached with 0.5% sodium silicate, 4% $H_2O_2$ and 0.2% sodium hydroxide for 50 minutes. The liquor ratio was maintained at 20 and the pH was kept at 10.5. Finally the fibres are treated with 0.5% sulphuric acid for 10 minutes and after emulsification for 5 days, refined bamboo fibres were obtained. The study found that bamboo fibres had smaller orientation angle for exterior macro fibrils, and in comparison with flax, ramie and cotton fibres, bamboo fibre is suitable for fibre reinforcement in composites [31].

2) Alkali or Acid Retting: In the alkali retting procedure, bamboo strips were heated with 1.5N NaOH solution in a stainless steel container at 70°C for 5 hours. Then the

alkali treated bamboo strips were pressed using a press machine and by using steel nail, fibres were separated. Finally, water was used to wash these extracted fibres and the extracted fibres were dried in an oven. Fibre damage caused in this extraction method is less [32]. In another study, to influence the cellulosic and non-cellulosic parts of bamboo fibres, bamboo strips in size of chips were soaked in NaOH with 4% mass per volume for 2 hours. To extract the fibre in pulp form, this procedure was repeated several times at a certain pressure. Problem with this extraction procedure is that it produced large fibre bundles [33]. In another research, small bamboo strips were soaked in 1N sodium hydroxide solution for 72 hours to facilitate extraction of fibres[28]. Trifluoroacetic acid (TFA) and alkaline solutions were used to extract the fibres as lignin content is soluble in acidic and alkaline conditions. Amount of lignin in the middle lamellae was also considered by the researchers. Results showed that lignin remained in the middle lamellae, in the alkali procedure, but a large portion was removed in the TFA process [34]. The interfacial bonding and surface adhesion of composites with alkali treatment is improved as compared to other methods [35],[36].

C. Combined Chemical and Mechanical Extraction

Usually after alkali treatment and chemical treatment, compression moulding technique (CMT) and roller mill technique (RMT) are used to extract fibres. In a research study, a bed of alkaline treated bamboo strips between two flat platens were pressurized under a load of 10 tons using CMT. To separate high quality fibres, starting bed thickness and compression time are important factors to be considered. In the RMT, two rollers with one fixed and other rotated were used and the treated bamboo strips were forced between two rollers. In both compression moulding technique and roller mill technique, bamboo strips are flattened and the combination of alkaline and mechanical extraction enabled the easy separation of fibres from bamboo strips [28].

The mechanical and physical properties of bamboo fibres, influenced by mechanical methods, chemical methods, combined chemical and mechanical methods of fibre extraction are shown in Table 1.

## III. CONCLUSION

Due to its high growth rate and high strength, bamboo fibre has got many advantages over otherplant fibres. Compared to glass fibres, bamboo fibre has got many advantages and this has generated great interest among researchers for using bamboo fibre as reinforcement in polymer composite materials. Based on their application in different fields of study and in different industries, various extraction methods have been used to extract bamboo fibres. In this study, many extraction methods have been reviewed and some of them have benefit over the others.

- Lignin content from the bamboo is removed using chemical methods and steam explosion method, thus influencing the microstructure of bamboo. Only short fibres can be extracted using these methods.
- Retting process and rolling mill method are able to produce long fibres, when compared with chemical methods and steam explosion method. Fibre length could be controlled in the retting process while extracting fibres.
- The fibres extracted using grinding method and crushing method could be used in the particle form for matrix crystallization.
- In the chemical extraction methods, alkali treatment removes lignin content from the fibres and interfacial adhesion between fibre and matrix is enhanced.
- The chemical retting method removed more lignin content than other chemical methods.

To aid researchers to use bamboo fibre effectively for various industrial applications, various fibre extraction methods and its properties are classified. A methodical research is required for using bamboo fibre as reinforced composite for replacing synthetic fibre composites with bamboo fibre reinforced composites.

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