The effect of chemical extraction with heat on the bamboo fibre strength

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Abstract: Bamboo is a renewable material widely used as a reinforced composite. One of the steps in making bamboo composites is soaking or heating using NaOH. The process is intended to eliminate small animals that may live in the bamboo. The attainment of strength and toughness is the most crucial requirement in structural material. This study compared the Apus, Atter, and Black bamboo fiber's strength by administering several methods and applying three different extraction times. The methods are the 5% NaOH chemical extraction method at a temperature of 70°C (heated), the 5% NaOH chemical extraction method (permeated) at room temperature, and the extraction method without treatment nor administering heat. The highest tensile strength among the three methods for each Apus, Atter, and Black bamboo is 194.25 N/mm\(^2\), 142.67 N/mm\(^2\), and 178.46 N/mm\(^2\), respectively. Among the methods used in this research, heating the bamboo in 5% NaOH solution with a 70°C temperature is more effective than soaking it at room temperature. The strength was increased up to 112%, 98%, and 190% for Apus, Atter, and Black bamboo. Black bamboo shows a significant improvement by using a chemical extraction process.

1. Introduction
Bamboo is an environmentally friendly material and, comparable to several other materials, is sustainable renewable materials [1]. Bamboo is also interesting to study because it is one of the energy-saving materials [2],[3]. Bamboo can reduce greenhouse gas emissions in cities due to around 40% of concrete building materials [4]. The use of bamboo reduces forest damage as bamboo can be the best alternative wood material applied in various ways[5]. Bamboo has approximately 1600 species [6],[7], which has similar mechanical characteristics to wood and is a fast-growing plant [8],[9],[10] up to 100 cm/day[11]. Bamboo is also a perennial plant that can be harvested multiple times and has a high-quality cellulose fiber [12]. As mentioned earlier, the bamboo consists of a cellulose content of 40-55%, a hemicellulose content of 18-20.8%, and lignin content of 15-32.2% [13].

Bamboo has been widely used since the 21\(^{st}\) century as it is utilized from the emergence of several predicaments, namely from the environmental pollution to energy shortages[14]. Bamboo utilization or modeling has been widely implemented in various applications, both traditionally and conventionally, such as mat boards, laminated bamboo, bamboo scriber, and bamboo application fiber-reinforced composites[15][16][17].

Research on the bamboo application is expanding, such as in the manufacturing of ceramics[18], magnetic reconstituted bamboo boards[19], and ultrasonication method to improve the flexibility of bamboo fibers[20].
To develop bamboo composite material, several processes must be performed. Start from harvesting, extracting, drying, and preliminary processes to increase the bamboo resistance on pets, rotten, and weathering. Soaking the bamboo in NaOH is the standard way to improve the bamboo resistance. However, there is still a lack of information about the effect of NaOH on bamboo strength. This research aims to compare bamboo fibers’ strength by subjugating them with several methods and implementing various set times when the extraction is carried out.

2. Materials and Methods
In this research, three bamboo types of bamboo were tested, Apus/String (Gigantochloa apus), Atter/Sweet (Gigantochloa Atter), and Black bamboo (Phyllostachys nigra Munro). Each type of bamboo implemented two distinctive treatment process, which is:

1. Fiber treatment process through the medium of 5% NaOH chemical extraction method (permeated) with no heat added for 60, 90, and 120 minutes.
2. Fiber treatment process through the medium of 5% NaOH chemical extraction method at a set temperature of 70°C (heated) for 60, 90, and 120 minutes.

Before applying these methods, the bamboo nodes, outer and inner sheaths, were eliminated from the bamboo stem. The bamboo culm was cut into bamboo pieces with a length of 30 cm and an average thickness of 5 mm, as shown in Figure 1 (a) and (b). The bamboo pieces were then washed in clean water for approximately an hour and drained at room temperature for half an hour. Figure 1 (e) shows the mechanical extraction process performed with a rolling machine. The bamboo rolled several times to remove the water from the previous process and dried in the sun for a half-day, as shown in Figure 1 (f). Before chemical extraction, the bamboo pieces were sliced into the bamboo fiber with 1 mm of thickness.

The chemical extraction was performed in a 5% NaOH solution. The ratio between the bamboo fiber and the sodium hydroxide solution was 1:10, which means 10 mL of 5% NaOH solution applied for every 1 gram of bamboo fiber in 5 L of water. Then, the extraction begins for each method, which is heating at 70°C and soaking. Figure 1 (g) shows the heating process for bamboo fiber treatment,
where the bamboo was put inside a pan fill with NaOH solution, and the temperature was kept at 70°C. Figure 1 (h) shows the bamboo soaking process, so the NaOH solution permeated the bamboo. Other researchers had performed a chemical extraction method of 5% NaOH solution at the temperature of 70°C [18, 19]. However, there is a lack of information about the processing time on bamboo fiber strength. In this research, the extraction time is determined at 60, 90, and 120 minutes.

After the chemical extraction, the bamboo fiber was then washed with clean water, drained, and dried in the sun until the water content ranged 17%-20%, as shown in Figure 1(k). Figure 2 shows the stack of each type of bamboo ready to test. The tensile tests were performed according to the ASTM D3379-75 standard. There were 30 specimens tested for each treatment and extraction duration. In total, there are 300 specimens tested, including the specimens without treatment.

Figure 2. Stack of bamboo fiber: (a) Apus, (b) Atter, and (c) Black bamboo

3. Results and Discussions

In this research, fiber with no treatment was used to compare both chemical extraction treatments. Figure 3 shows the strength of each untreated type of bamboo fiber. It shows that Apus bamboo has the highest strength compare to Atter and Black Bamboo, up to 91.56 N/mm². Apus bamboo is 27.3% and 48.7% stronger than Atter and Black bamboo, respectively. This result consistent with the research performed by Rochim et al. [21], which found that the tensile strength of Apus bamboo is higher than Atter bamboo (Jawa bamboo) when performing the test in pieces of the bamboo specimen (not fiber). However, Abdullah et al.[22] found that the order of bamboos from the strongest among five different bamboo is Atter (Tameng), Apus, Kuning (Bambusa vulgaris schard var. Vitata), Gombong (Gigantochloa pseudoarundinacea), and Black bamboo. The research confirm that Black bamboo has a lower tensile strength.

Figure 3. The strength of bamboo without any treatment
Figure 4 shows that each bamboo type is the tensile test result for both treatments, soaking and heating the bamboo in 60, 90, and 120 minutes. Compare to the un-treated bamboo, the tensile strength for all the treated specimen is improving. However, the duration of treatment shows an ununiform pattern of the effect on the tensile strength. Figure 4 shows that the highest tensile strength was obtained by Apus bamboo with the 5% NaOH extraction method at the temperature of 70°C for 90 minutes, with a value of 194.25 N/mm². Meanwhile, the optimum tensile strength by soaking bamboo in 5% NaOH solution at room temperature achieved by Black bamboo up to 139.94 N/mm², with soaking duration for 60 minutes.

Table 1 shows the optimum and minimum improvement for each bamboo type. Soaking Apus bamboo at a room temperature of 5% NaOH solution for 120 minutes increases the strength up to 51%. The Apus bamboo strength increases more than 112% when the bamboo is heated in 5% NaOH solution with a temperature of 70°C for 90 minutes. However, soaking Apus bamboo for 90 minutes only improves 15% of its strength. For Atter bamboo, the optimum result was achieved 98% by a heating process for 90 min. Soaking Atter bamboo at room temperature for 60 min only increase 41% of the strength.

Table 1. The optimum and minimum result for each treatment

| Optimum Result | Tensile Strength (N/mm²) | Soaking Time Duration | Improvement | Heating Tensile Strength (N/mm²) | Time Duration | Improvement |
|----------------|--------------------------|-----------------------|-------------|----------------------------------|---------------|-------------|
| Apus           | 138.25                   | 120 min               | 51%         | 194.25                           | 90 min        | 112%        |
| Atter          | 132.39                   | 90 min                | 84%         | 142.67                           | 90 min        | 98%         |
| Black          | 139.94                   | 60 min                | 127%        | 178.46                           | 60 min        | 190%        |

| Minimum Result | Tensile Strength (N/mm²) | Soaking Time Duration | Improvement | Heating Tensile Strength (N/mm²) | Time Duration | Improvement |
|----------------|--------------------------|-----------------------|-------------|----------------------------------|---------------|-------------|
| Apus           | 105.73                   | 90 min                | 15%         | 136.74                           | 120 min       | 49%         |
| Atter          | 101.29                   | 60 min                | 41%         | 118.46                           | 60 min        | 65%         |
| Black          | 113.4                    | 90 min                | 84%         | 170.33                           | 60 min        | 177%        |
Black bamboo shows a significant improvement by 5% NaOH chemical extraction. Although the strength of untreated Atter bamboo is higher than Black bamboo, with chemical extraction, the strength of Atter bamboo is surpassed by Black bamboo, as shown in Figure 2. The strength of Black bamboo is improved by up to 190% with chemical extraction with heat for 60 minutes. The minimum result was obtained by 90 minutes soaking process.

Thus, from these results, it can be concluded that the use of 5% NaOH as an extractive substance remover provides evidence that the use of sodium hydroxide (NaOH) can increase the strength of bamboo fibers exceptionally. By making a visual comparison, the treated bamboo fibers are smoother and softer than the untreated ones. A 5% NaOH solution provides evidence that the resulting fiber has a non-coarse fiber characteristic.

4. Conclusion
Based on the experiment result, it can be concluded that the mechanical extraction method of 5% NaOH at the temperature of 70°C improved the fiber strength. The fiber tensile test results proved that the set time given to the bamboo extraction did not provide a consistent graph or value from the set of time given. Administering a high temperature at the time of extraction has a well-desired effect on the bamboo fibers. It might be because this process of elimination can draw out extractive substances thoroughly.

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