Effect of Chemical Solution on Tensile Strength of Bamboo Fiber

Jerachard Kaima¹, Itthichai Preechawuttipong¹*, Pawarut Jongchansitto¹ and Nattaphat Charoenloe²
¹Department of Mechanical Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand
²Department of Civil Engineering, Faculty of Engineering, Chiang Mai University, Chiang Mai, Thailand

* Corresponding Author: itthichai.p@cmu.ac.th

Abstract
This study aims to investigate the effect of a chemical solution on the tensile strength of the bamboo fiber. The bamboo woods were cut into the size of small pieces 60 mm x 5 mm x 1 mm. Seven solutions were used in this work which is distilled water (control conditions), ASH and NaOH solution with concentrations of 20%, 10%, and 5% by weight. The bamboo pieces were soaked in the solution with 11 different soaking times except soaking in distilled water for 5 different soaking times. After that processed bamboo pieces were washed and dried at room temperature for 1 week. They were separated by hand to get processed bamboo fiber with cross-section size between 0.06-0.27 mm². For all specimen, more than 5 pieces of processed bamboo fibre were tested following to ASTM D3039. The results show that the cross-section area in rang 0.06-0.27 mm² from raw materials have similar tensile strength with 290 MPa [1]. The higher concentration of NaOH, the lower value of the tensile strength which decreases and reach below 100 MPa for 20% NaOH solution. For ASH solution, the values of the tensile strength as the function of soaking time are the same inclination with the different concentration. The tensile strength of processed bamboo fibres is pretty splattered between 200-400 MPa for the soaking time less than 48 hours. While tensile strengths have the range between 275-300 MPa for the soaking time more than 48 hours. Because some fungus grew on bamboo fibre surface soaked in distilled water, the tensile strength of processed bamboo fibres soaked in 20% ash solution is greater 100 MPa than the tensile strength of bamboo fiber soaked in distilled water for the soaking time more than 120 hours.

Keywords: Tensile Strength; Bamboo Fiber; Chemical Solution

1. Introduction
Thailand is one of the countries having the most distribute bamboo species in the world [2], i.e. more than 31 species of bamboo can be found in Thailand. In Thailand, the bamboo has been applied in many areas for a long time. Its applications can be found from kitchenware at home like chopsticks to the structure of buildings. This is because the bamboo is easy to find, rapid growth rate, and better...
mechanical properties. It must be noted that the bamboo is ready to use within 3 years after planting, while other woods are available after planting more than 20 years [3]. Nowadays, bamboo becomes a popular raw material. However, a lifetime of bamboo applications must be concerned, because the lifetime can be reduced by major enemies: insects and funguses. In this case, a degradation of the lignin in bamboo by such enemies causes a reduction of the bamboo’s strength [4, 5].

To obtain pure cellulose of the bamboo fiber consisting of xylem and phloem, the lignin inside the bamboo must be removed by mechanical or chemical treatments. This pure cellulose is also called an avascular bundle, which is an important structure related to the strength of the bamboo fiber [6, 7]. The widely-used chemical treatment to remove the lignin from the bamboo is the use of Sodium Hydroxide (NaOH) solution. Nevertheless, its base strength is very strong that can rapidly destroy the strength of the bamboo fiber [6]. In addition, this procedure is non-environmentally friendly. In the northern region of Thailand, an ash solution, which is local knowledge, was employed by Hmong peoples to wash dishes, clean clothes, and fabricate clothes. The authors expect that it would be useful for the removing of the lignin from the bamboo fiber. It is important to note that no previous studies have focused on the effect of concentration of ash solution on the tensile strength of the bamboo fiber. Therefore, the present study aims at experimentally investigating the influence of the concentration of ash and NaOH solutions on the tensile strength of the bamboo fiber.

2. Material and Method

2.1. Material Preparation

A bamboo tree can be generally separated into 3 parts: a base part (0-0.5 m from a ground), a middle part (0.5-2 m from) and a top part (more than 2 m). The middle part of the bamboo for the age of more than 3 years was used in this study [8], because this part consists of fewer bamboo joints and more wood compared with the other parts. The middle part of the bamboo was then dried out at the temperature of about 35-37°C for 7 days. After that, it was cut into a small piece with dimensions of 60 x 5 x 1 mm (length x width x thickness). The selected specimens are shown in Fig. 1. Then specimens were washed by distilled water for clean grime on bamboo skin and dried in control room temperature (25°C) for 7 days.

Figure 1. The selected part of the bamboo used as a specimen

Chemical solutions in this study were ash solution, NaOH solution. distilled water was used to mix the solution and be control condition. Ash solution was made by Longan wood ash that popular to use in local northern Thai kitchen. After Longan tree woods were burned in the burner, all the ash was cooled for 3 hours and collect ash powder in plastic bags to avoid moisture added. Ash powder was mixed with different concentration following equation (1) and measured by digital scales.

Then distilled water and ash powder were mixed by shaking the bottle. After that, the mixture was let to sit for 1 day. From the ash mixing process, water will get ash containing sediment lying on the bottom of the bottle. The ash solution used in this study will use the only solution with clear color above.
For the preparation of the NaOH solution, a commercial NaOH quartz 98% was used in this study. They were measured by digital scales. Then NaOH was separated in quite small 5 groups to avoid the heave chemical reaction. After that distilled water was added in each group and mixed them following equation (1).

\[
\%Sol = \left( \frac{M_{Sub} \times \%Pure}{M_{Sub} \times \%Pure + M_{WATER}} \right) \times 100
\]

where \( \%Sol \) is a concentration of a solution, \( M_{Sub} \) is a mass of a substance (g) and \( M_{WATER} \) is a mass of a distilled water (g), \( \%Pure \) is a purity of a substance.

Chemical solution mixture and number of soaking times in each specimen are shown in the Table 1. Dried bamboo strips were soaked in ash solution and NaOH solution in the cylinder bottles size 4 cm diameter 8 cm in height. Both chemical solutions have 3 concentrations which are 5%, 10%, 20%. The bottles were closed and leave it in control room temperature (25°C) for the 11 different soaking times which are 1, 3, 6, 9, 12, 18, 24, 48, 72, 120, 168 hours. The same method was applied with distilled water for the control group, but the soaking time change to be 5 different times which are 24, 48, 72, 120, 168 hours. After leaving the specimen from the solution with the different soaking time, the specimens were washed and dried in control room temperature for 7 days. After that specimens were packed in the plastic bag for more than 1 month. Each bamboo fiber was then separated by hand pullingout. All of the bamboo fiber was measured cross-section size in rang 0.06-0.27 mm².

### Table 1. Chemical solution mixture in 1000 g and the number of soaking times in each specimen are show in table

| Substance | Purity of substance (%) | Concentration (% | Substance (g) | Distilled water (g) | Number of Soaking Times |
|-----------|-------------------------|----------------|--------------|---------------------|------------------------|
| Ash       | 100%                    | 5              | 50.00        | 950.00              | 11                     |
|           |                         | 10             | 100.00       | 900.00              |                        |
|           |                         | 20             | 200.00       | 800.00              |                        |
| NaOH      | 98%                     | 5              | 51.02        | 948.98              | 11                     |
|           |                         | 10             | 102.04       | 897.96              |                        |
|           |                         | 20             | 204.08       | 795.92              |                        |
| Distilled Water | 100%       | 0              | 0            | 1000                | 5                      |

2.2. Tensile strength test

Fibers destroy by the clamping is the problem in this part. So, paper grips and rubber glue were used to solve machine clamping destroy [9]. The paper grips method for the tensile test are shown in Fig. 2. Fibers were stuck in the centre line of paper grips by rubber glue. Top and bottom of paper grips were flipped to the centre. The paper grip with specimens was let in control room temperature more than 2 hours for dried glue. Following ASTM D3039 [10], a tensile loading was then applied to the specimen by using INSTRON 5566 testing machine. The loading was displacement-controlled of 1 mm/s. It must be noted that guideline areas beside the paper grips were cut before the machine start pulling out.
3. Result

3.1. Effect of the cross-sectional area of the fiber on tensile strength

Separating processed bamboo fibers by hand pull out cause fibers have varieties size of the cross-section area. The varieties size of cross section is effect to tensile test that are destroy by the clamping point while fibers are too thin and fibers are slip from clamping point when fibers are too big [11,12]. So raw bamboo fibers were separated by the same way to find the rang of fibers able to use in this method.

Fibers were classified in 5 groups by cross-section area size which is A, B, C, D, E. all of them were tested on tensile strength test. The result of this test is shown in Table 2.

| Group | Range of cross-section (mm²) | Tensile stress (MPa) |
|-------|-----------------------------|----------------------|
| A     | Less than 0.06              | Destroy by clamping  |
| B     | 0.06-0.08                   | 265.74               |
| C     | 0.13-0.19                   | 290.40               |
| D     | 0.20-0.27                   | 275.36               |
| E     | More than 0.27              | Slip                 |
|       | N/A                         | 290.00               |

The result showed that the cross-sectional area of the fiber in group A is too thin. Fibers were destroyed by the clamping point when pulling out. Moreover, the cross-sectional area of the fiber in group E is too big for paper grip. The fiber is not torn apart. So only the cross-section in group B, C, D can use in this test. The values of tensile strength are the same as Wang and Chen’s study [1,13].

3.2. Effect of chemical solutions on tensile strength

The results of the concentration of ash and NaOH solutions on tensile strength at the soaking time of 168 hours are shown in Table 3. For the NaOH solution, the tensile strength decreases with an increment of the solution concentration. This can be explained by the fact that both the lignin and the bamboo fiber are destroyed by the NaOH solution [14]. In the case of the ash solution, the tensile strength decreases with the concentration. The tensile strength of the processed bamboo fiber in 20% ash solution is higher
than raw material. Because process bamboo fibers are soft and smooth than raw material. In the case of the distilled water, the tensile strength is lower than the raw bamboo fiber, because of the growth of fungus on processed bamboo fibers [15]. For bamboo fiber that soaked in a chemical solution, there is no fungus growth.

**Table 3.** Effect of a chemical solution on tensile strength at 168 hours.

| Solution | Tensile strength (MPa) | Fungus growth |
|----------|------------------------|---------------|
| ASH 5%   | 244.21                 | No            |
| ASH 10%  | 274.91                 | No            |
| ASH 20%  | 368.24                 | No            |
| NaOH 5%  | 199.628                | No            |
| NaOH 10% | 165.82                 | No            |
| NaOH 20% | 25.27                  | No            |
| Distilled water | 264.90          | Yes           |

### 3.3. Effect of soaking time on tensile strength

The result of soaking time on tensile strength is shown in figure 3. It is observed that the soaking time less than 48 hours causes a fluctuation of the tensile strength of the bamboo fiber. Tensile strength of processed bamboo fibers soaked in NaOH is decreased by the time. As same as ash solution at concentration 5%, 10% and distilled water tensile strength are decreased by the time. On the other hand, the tensile strength of process bamboo fibers soaked in 20% ash solution have a different tendency. The values are increased above distilled water after 120 hours. Our study recommends 20% ash solution as the best chemical solution to enhance the tensile strength of the bamboo fiber.

![Figure 3. Effect of soaking time on tensile strength](image-url)
4. Conclusion
This research has studied the effect of ash and NaOH solution on the tensile strength of bamboo fiber that extracts by hand pull out. For ash solution, the tensile strengths are decreased by the concentration. The best concentration recommended by this study is 20% ash solution. For NaOH not only lignin but also bamboo fibers were strongly destroyed so this chemical is not suggested by this study.

The effects of soaking time on tensile strength of bamboo fiber after 48 hours-soaked bamboos in chemical solution the tensile strength values change little. So, 48 hours is enough time for soaked bamboo in a chemical solution.

Acknowledgments
The authors would like to acknowledge Research and Researchers for Industries Scholarship (Grant No. PHD 60I0039) and Charoen Triphop Limited Partnership for the financial support during this research. The authors also would like to acknowledge Faculty of Engineering, Chiang Mai University for equipment support and scholarship for the conference at the 10th TSME International Conference on Mechanical Engineering.

References
[1] Wang G Chen F 2017 Advanced High Strength Natural Fiber Composites in Construction chapter 10 (Woodhead Publishing:United Kingdom) 235–253
[2] Dransfield S Widjaja, E.A. 1995 Bamboos 7 189
[3] Chawla K K 2016 Fibrous Materials (Cambridge university press)
[4] Horrocks A R Price D 2001 Fire retardant materials (Woodhead Publishing:England)
[5] Liese W 1992 Proc. 5th Int Conf on Forest Product 2 (Nancy Publisher) 742–51
[6] Khan Z Yousif B F Islam M 2014 Composites Part B 116 186–199
[7] Amada S Ichikawa Y Munekata T Nagase Y Shimizu H 1997 Composites Part B: Engineering 28 13–20
[8] Zakikhani P Zahari R Sultan M T H Majid D L 2014 Materials and Design 63 820–828
[9] Haameem J A M Majid M S A Afendi M Marzuki H F A Fahmi I Gibson A G 2016 Composite Structures 136 1–10
[10] ASTM International 2017 Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials (West Conshohocken)
[11] Pickering K L 2008 Properties and performance of natural-fibre composites (Cambridge:England)
[12] Chawla K K 2016 Fibrous Materials (Cambridge:England)
[13] Takaki H Ichihara Y 2004 JSME International Journal 47 332–339
[14] Yong C Yi-Qiang W U 2008 J. Cent. South Univ. Technol. 15 564–567
[15] Garcia C M Giron M Y Mabilangan L C 2000 Proc. the BAMBOO 2000 International Symposium (Chiang Mai:Thailand)