Effect of Pineapple Leaf Nanofibers on Physical and Mechanical Properties of Bagasse Sheets

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Abstract. Agro-waste pineapple leaves (PA) were extracted into cellulose nanofibers by pretreated with soda pulping process and then disintegrated by microfluidizer. The resulting PA nanofibers with an average length of 1.7±0.5 µm and diameter of 15.5±3.6 nm was then used to improve properties of bagasse (BG) pulp sheets at different contents (0.5, 1, and 5 wt%). The results showed that integration of PA nanofibers increased the density of the sheets but decreased their porosity. With addition of 5 wt% PA nanofibers, BG sheets showed the increases in all tensile properties, especially tensile strength (64%) and elongation (140%). SEM images revealed the smoother surface of the sheets and indicated the reduction of the pores by PA nanofibers filling and bridging between BG fibers network. This increased fibers bonding area in the sheet structures and hence improving their mechanical properties.

1. Introduction
There has been an intensive study of paper reinforcement by adding additives and cellulose nanofibers. Since cellulose nanofibers have high aspect ratio, surface area, and crystallinity etc. [1], it can improve fibers bonding and reduce pores between fibers leading to an enhancement in the air resistance and mechanical properties of papers [2]. Cellulose nanofibers can be extracted from both wood and non-wood resources such as eucalyptus, coconut husk, oil palm, rice straw, bamboo, bagasse, and pineapple leaf [3]. Agro-waste pineapple leaf is abundant in South East Asian region [4], relatively inexpensive and has high specific strength, stiffness and crystallinity (70 – 82%) [5]. Therefore, it is considered as an outstanding alternative raw material to produce cellulose nanofibers. However, no research in using the pineapple leaf nanofibers as reinforcement in paper has been reported so far. This research aims to study the effect of adding PA nanofibers on physical and mechanical properties of paper made from bagasse pulp.

2. Experimental
2.1. Materials
Bleached bagasse pulp in dry sheet form supplied by Biodegradable Packaging for Environmental Co., Ltd (BPE), Thailand was used as the raw material. Nanglae pineapple leaves used in this study were obtained from the cultivation area in Chiang Rai, Thailand. Sodium hydroxide (NaOH) AR grade pellet was supplied by QRëC™.
2.2. Preparation of cellulose nanofibers from pineapple leaf

Pineapple leaves (PA) were cut into 10 cm and dried until constant weight. The dried PA were then ground into small pieces. After that, they were cooked in 18%(w/w) NaOH at a controlled temperature of 98 ± 2°C for 30 minutes. The PA pulp was washed to remove the unreacted chemical reagent and then blended by the shear mixer at speed 15,000 rpm for 1 minute. Mesh no.18 (1 mm) and no.200 (0.074 mm) were used to screen the pulp. To produce the nanofibrils, the pulp suspension was diluted to 0.5% consistency and refined in the microfluidizer (M-110P, Microfluidics). The pulp was passed through the microfluidizer with an 87 µm chamber under pressure of 25,000 psi for 20 cycles.

2.3. Paper sheet preparation

Bleached bagasse (BG) sheet form was torn into small pieces and soaked in water overnight. Then, it was disintegrated by shear mixing 15,000 rpm in a household blender for 10 minutes. The BG pulp that passed through mesh no.18 but contained in mesh no.200 was collected. The screened BG pulp was diluted to 2% consistency. The certain amount (0.5, 1 and 5 wt%) of nanofibers was added to BG pulp. The paper sheets were prepared by using hot press compression molding technique. They were pressed under pressure of 159 kPa and heated at 105°C for 5 minutes.

2.4. Morphological studies

The surface morphology of BG and different amount of nanofibrils reinforced sheets was observed by scanning electron microscope (SEM) LEO/1450 VP operating at an accelerating voltage of 10 kV. The carbon was coated onto samples surface before observation. The PA nanofibrils were investigated by transmission electron microscope (TEM, Hitachi model HT7700). The fibers were diluted to 0.001% concentration and drop on a copper grid with the formvar film. The sample was dyed with 2% uranyl acetate for 5 minutes and performed at an accelerating voltage of 80 kV.

2.5. Physical properties

The grammage of the sheet expressed in terms of grams per square meter (g/m²) according to TAPPI T410. The density of the sheets was calculated from the ratio of the mass to the area by measuring the dimension and weight.

2.6. Mechanical properties

Before testing, each sheet was conditioned at 25°C and 50% RH at least overnight. Mechanical properties of the sheets including tensile index, Young’s modulus, elongation and breaking length were calculated from the results of tensile test. Tensile testing was performed by the universal testing machine (Instron Machine model 5566) with 1 kN cell load (according to TAPPI T494). The gauge length of the sample was set at 30 mm with the width 10 mm.

3. Results and Discussion

The SEM and TEM were used to examine the morphology of the BG fibers and PA nanofibers. The SEM micrograph of BG shows in Figure 1a. The dimension of BG fiber was reported in average value from 50 fibers. The length and diameter of BG fibers is 275 ± 11 µm and 12 ± 5 µm, respectively. The TEM image of PA nanofibers shows in Figure 1b. The dimension of PA nanofibers was reported in average value from 10 fibers. The length and diameter of PA nanofibers is 1.7 ± 0.5 µm and 15.5 ± 3.6 nm, respectively.

The physical properties including grammage, density, and porosity of the pure BG sheet and BG sheet reinforced by the PA nanofibers were summarized in Table 1. The grammage of both the BG sheets and BG sheets reinforced by PA nanofibers were not significantly different. The density of the sheets increases as the amount of PA nanofibers increases but in contrast to the porosity. It is because PA nanofibers can fill up the gap between fibers [2] and nano-network was created between fibers [6]. Nano-network created higher bonding and packing between fibers [7] as shown in figure 2.
Figure 1. Morphology of a) the bagasse pulp fibers and b) pineapple leaves nanofibers.

Table 1. Physical properties of the BG sheets at different content of adding PA nanofibers.

| Sample         | Grammage (g/m²) | Density (g/cm³) | Porosity (%) |
|----------------|-----------------|-----------------|--------------|
| BG             | 288.30          | 0.87            | 43.10        |
| BG-PA 0.5%     | 254.95          | 0.94            | 38.64        |
| BG-PA 1%       | 294.17          | 1.03            | 32.80        |
| BG-PA 5%       | 275.45          | 1.06            | 30.96        |

Figure 2. SEM images taken under 1,000× magnification of bagasse (BG) sheets reinforced by different contents of pineapple leaves nanofibrils (PA). a) 0wt%; b) 0.5wt%; c) 1wt%; d) 5wt%.

Figure 2 shows the surface of the BG sheet and BG reinforced by PA nanofibers sheets. Figure 2a displays the voids between BG fibers and no network between fibers when compared to the sheets added with 0.5, 1 and 5 wt% content of PA nanofibers. The addition of PA created the connection or bridging of this nanofiber and reduced the gaps between BG fibers (Figure 2b-d). Moreover, it was
observed that the sheets tended to be smoother when added more nanofibers. The 5wt% PA nanofiber reinforced sheet showed the smoothest surface. Furthermore, it was found that the mechanical properties of the sheets were also considerably enhanced by adding the PA cellulose nanofibrils as presented in Table 2.

Table 2. Mechanical properties of the BG sheets at different contents of adding PA nanofibers.

| Sample         | Tensile strength (MPa) | Elongation (%) | Young’s modulus (MPa) | Breaking length (m) |
|----------------|------------------------|----------------|-----------------------|---------------------|
| BG             | 24.42 ± 4.26           | 1.55 ± 0.39    | 3060.20 ± 592.04      | 2914.01 ± 535.10    |
| BG-PA 0.5%     | 28.48 ± 2.41           | 2.53 ± 0.42    | 2838.20 ± 130.37      | 3226.30 ± 602.01    |
| BG-PA 1%       | 30.66 ± 3.64           | 2.00 ± 0.29    | 3348.90 ± 288.59      | 3361.36 ± 803.04    |
| BG-PA 5%       | 40.05 ± 4.63           | 3.72 ± 0.49    | 3450.58 ± 262.34      | 3794.04 ± 563.75    |

The average tensile strength, elongation, Young’s modulus, and breaking length of all sheets were summarized in Table 2. The results indicated that the mechanical properties highly depend on the amount of cellulose nanofibrils content. The BG sheet with adding PA nanofibers 5wt% shows the maximum all of the mechanical properties followed by 1, 0.5, and 0 wt% of PA nanofibers content. The results show the tensile strength, elongation, Young’s modulus and breaking length increase to 64%, 140%, 13%, and 30% respectively when compared to the sheet with 0wt% PA nanofibers addition. The highest elongation from adding PA nanofibers 5wt% to BG sheet indicates to high inter-fiber bonding area in the sheets [8]. Elongation is measured by the strain at breaking point as can be seen in stress-strain curves of the sheets from the tensile testing (see Figure 3).

Figure 3. Stress-strain curves of BG sheets with different amounts of cellulose nanofibers.

The superior mechanical properties of this current sheets were contributed from reinforcing effect of cellulose nanofibers which fulfill the pore between fibers and better internal bonding of the sheet [1, 9, 10]. Similarly, Ding et al. [11] investigated that the fluorescent cellulose nanofibrils (FCNF) had high fiber-bond degree with the pulp fibers and highly enhanced the mechanical properties of papers. But its elongation increased only 81% with adding 10wt% of FCNF to the paper.

4. Conclusion

The effect of different PA nanofibers content on physical and mechanical properties of bagasse sheet was investigated. The higher content of PA nanofibers to BG sheets resulted in increased density, reduced porosity and enhanced tensile properties of the BG sheets. Addition of PA nanofibers at 5wt%
on BG sheet showed the increases in tensile strength, elongation, Young’s modulus and breaking length to 64%, 140%, 13% and 30% respectively. The notable positive effect on mechanical properties of BG sheets involved the reduction of the gap between fibers due to the filling of PA nanofibers which also increased bonding area within the sheets structure.

5. References

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