Development of Paper Packaging from Bagasse Fiber Modified with Natural Rubber Latex

Thitima Boontha, Sukunya Ross, Gareth M. Ross, Sararat Mahasaranon*

Biopolymer Group, Department of Chemistry, Faculty of Science, Naresuan University, Phitsanulok 65000, Thailand

*E-mail: sararatm@nu.ac.th

Abstract:

This work was interested in the improvement to the physical and mechanical properties of bagasse paper packaging (BPP) using natural rubber latex (NRL). These BPP materials can be processed from the bagasse fiber in paper pulp form. NRL was coated on BPP utilizing a dipping technique. NRL can protect against water, moisture and also improves the mechanical properties (tensile and tear strength). Greater concentrations of NRL in BPP produce a smooth surface and a barrier against water which was confirmed via a contact angle test. Increasing vulcanization time under ultraviolet light (UVA) conditions, decreased % swelling of BPP, gave higher tensile strength and % elongation at break of BPP. Finally, BPP dipped with 30% (w/w) NRL at a vulcanization time of 9 hr, showed lower % water absorption and a hydrophobic contact angle. Moreover, this sample has the highest tensile strength and % elongation at break. Additionally, this research was focused on the use of renewable resources (bagasse fiber and NRL) and produced environmentally friendly products with high added value.

1. Introduction

Nowadays, packaging is vital for the protection of products, with paper being the most widely used type of packaging. However, paper has less strength than a majority of other packaging materials. Also, paper has can attract water and moisture causing a decrease in the overall strength of the packaging. During the common use of packaging is difficult to avoid these problems. Therefore, instead of using paper other packaging materials are used with increase strength. However, there are several techniques that can improve the properties of paper, such as coating natural or synthetic polymers as presented by Adisai et al.,1 work. They took cotton yarn and coated with natural rubber in order to replace canvas in swimming pool applications. The results showed that the natural rubber coated on cotton yarn could protect water and moisture permeability. Paper that is used for packaging can made from many natural fibers such as hemp fiber, sisal fiber, kenaf fiber, coir fibers, ramie fiber and jute fiber.2

This research is interested to fabricate paper as a packaging material from bagasse fibers that protect against water and moisture adsorption and also with a increase in strength. Development of paper from bagasse fiber that was dipped in natural rubber for moisture and water resistant and vulcanizes under UVA conditions, for a reduction in chemicals used. Manshaie et al.,3 studied mechanical properties of NR/SBR blends cured by electron beam irradiation and sulfur, the results show that the NR/SBR blends cured by irradiation had better mechanical properties than sulfur curing. Similarly of Youssef, et al.,4 blends of NR/SBR vulcanization by irradiation of gamma rays with varying dose, the results present that the addition of NR improved the mechanical properties and decrease the swelling ratio. Moreover, the paper packaging obtains in this research was not toxic to the environment.
2. Materials and Methods

2.1 Materials

Bagasse fiber from Phitsanulok Sugar Co., Ltd. Rubber latex with 60% total solid content was obtained from Thai rubber latex Co., Ltd. Sodium hydroxide 99% (NaOH, Commercial grade) from AGC Chemical Thailand Co., Ltd.

2.2 Experiment

2.2.1 Preparation of bagasse paper

This research studied the preparation processes of bagasse paper pulp (BP). For this bagasse fibers (BF) were taken from sugarcane residue in a sugar factory. The BF was then washed and cleaned by water to remove grit, dust and dried in an oven at 90-100 °C for 5 h. Modification of the fiber surface was the next step, 10.00 g of bagasse fiber was used with 15% Sodium hydroxide (NaOH), at a temperature of 70 °C for 2 h. After that, the pulp was neutralized by washed with pure water. Then the size of bagasse fibers was reduced using a blender (600 watt) for 20 mins. Finally, it was poured into a mold and passed through a sieve to remove excess water to form a paper sheet.

2.2.2 Modified surface bagasse paper by natural rubber

The bagasse paper pulp (BP) was dipped into natural rubber latex (NRL) with different concentration (15% and 30% of NRL) and BP was vulcanized under UVA condition for 3, 6 and 9 h. The thermal energy of UVA lamp used was 60 J/sec. The symbols “BPP153 (Bagasse + 15% natural rubber + 3h)” and “BPP303 (Bagasse + 30% natural rubber + 3h)” etc., were used. BP was cut into a square shape with size of 18.0 x 18.0 cm. Next, it was dipped in NRL for 30s before being placed under UVA light.

2.3 Characterizations of bagasse paper

2.3.1 Scanning electron microscope (SEM)

The morphology of BP and BPP samples were studied; samples were cut and put on stubs. Next, all samples were coated with gold and store in a desiccator to prevent moisture before testing.

2.3.2 Color parameter

Color parameter of BP and BPP used Color reader (CR-20). The sample was cut into 10.0 x 10.0 cm and test color parameters follow by standard ASTM E 313-96. Different colors of samples were analyzed by the following formula. Moreover, the results are shown in $L^*$, $a^*$ and $b^*$ term. $L^*$ represents lightness, $-L^*$ and $+L^*$mean white and black, $-a^*$ and $+a^*$mean green and red, $-b^*$ and $+b^*$mean blue and yellow.

$$
\Delta E = \sqrt{(L_1^* - L_2^*)^2 + (a_1^* - a_2^*)^2 + (b_1^* - b_2^*)^2}
$$

Where: $\Delta E$ is the difference in color

2.3.3 Contact angle analysis (CAA)

Characterize surface properties and hydrophobic behavior of BP and BPP, using Contact angle (CA), Dataphysics Model OCA20. Generally, if the material water contact angle is smaller than 90° then the material is hydrophilic and larger than 90° is hydrophobic.

2.3.4 Water absorption test

The BP and BPP, were cut into 2.0 x 2.0 cm and put in 10.00 mL water. Water absorption equation was show below, where; $w_1$= initial weight and $w_2$= final weight.

$$
\text{Water absorption} \equiv \frac{(w_2 - w_1)}{w_1} \times 100
$$

2.3.5 Swelling test

The samples were cut into 2.0 x 2.0 cm, weighed before soaking in toluene solution at room temperature. The sample was weighed again. The percentage degree of crosslink equation was showed below, where $w_d$= weight of dry sample, $w_s$= swollen samples and $M_w$= molar mass of toluene (92.14 g.mol$^{-1}$)
2.3.6 Tensile testing

The tensile properties of the BP and BPP were determined following standard TAPPI T494. The sample was cut to 25.00 x 180.00 mm for at least 7 specimens. The test load cell 1 kN and speed at 25 mm/min was used.

2.3.7 Tear testing

The tear properties of the BP and BPP samples were determined by standard ASTM D2261. The sample was cut into 76.00 x 203.00 mm for at least 7 specimens. The testing load cell 1 kN and speed at 50 mm/min is used.

3. Results & Discussion

3.1 Physical properties

3.1.1 Morphology, color parameter and ratio dipping

Table 1 shows the bagasse paper (BP) and modified surface bagasse paper (BPP) dipping ratio of BP and NRL by weight (B:R ratio) and the color-parameter test. The results found that, the BPP samples using 15% NRL (BPP153, BPP156 and BPP159) with different vulcanized time showed B: R ratio = 1:1 and the B:R ratio of BPP samples of 30% NRL (BPP303, BPP306 and BPP309) was 2:1. The 30%NRL coated on paper weighs more than 15% of NRL.

The BP and BPP gave brown and yellow-brown colors, respectively (table 1). BPP had lower lightness parameters than BP. The BPP with higher NRL concentration has lowest lightness levels due to the NRL coated on the paper having a more cross-linked structure that reduces transmittance. For the UVA vulcanization time at 3, 6 and 9 h, increasing of the vulcanization time caused to the lightness and color parameter to increase due to an increase in the cross-linked structure. For ∆E value, BP shows a slight difference when compared with BP 15% NRL but shows larger difference when compared with BP 30% NRL because of the increasing amount of NRL.

3.1.2 Scanning electron microscope (SEM)

The SEM images of BP and BPP from the surface (100x magnification) and cross section (200x magnification) are shown in figure 1. The surface of BP (figure 1(a)) shows the fibers have gaps between fibers and mechanical entanglement on fibers but the fibers are not crosslinked.

When considering the BPP with 15% NRL and 30% NRL, it was found that these samples show that NRL has infiltrated the gaps between fibers. The BPP309 sample shows that the NRL infiltrated into the bagasse paper and caused more adhesion than in other samples. As the time of vulcanization was increased there was greater crosslinking of NRL and BP.

The SEM images of BPP cross section (samples from tensile testing) found that BPP with 30% NRL (figure 1 (l, m and n)) shows a higher content of NRL than the BPP with 15% NRL (figure 1 (i, j and k)). This relates to the results of tensile testing which were described in the part of tensile testing.

3.1.3 Contact angle

The wettability of BP and BPP were measure by contact angle. The BP had an angle of 87.73° meaning BF can be referred to as a hydrophilic fiber. BPP has an angle of greater than 90° due to NRL was coated on BP which has a 1,4-polyisoprene as main component. Therefore, BPP presents a hydrophobic surface. When consider BPP at 30% NRL it was found the angle was lower than 15% NRL, because NRL contains proteins and fatty acids that increase the contact angle due to more hydrophobic .

When the time of vulcanization was increased the results showed the hydrophobicity increases due to more crosslinked of natural rubber molecules. The
slope has minus value it shown wettability of samples, which from start initial angle to finished angle. The BP has a slope of -14.61 giving a faster increase in wettability than BPP because BP has gaps between fibers and NRL adsorbed into the gaps, which slow the wettability. This can be seen in the pictures in table 2.

3.1.4 Water absorption test
The water absorption of BP and BPP (shown in figure 2 (a)) were measured by soaking in water for 24 h. BP has the highest water absorption due to the hydrophilic nature of BF. The BPP with 15% NRL absorbs more water than 30% NRL. For vulcanization time with UVA, the ability of absorption decreases when longer vulcanization time was used due increase in hydrocarbon content, which is a non-polar molecule. However, increasing the vulcanization time showed a very strong material and good resistant to water.

3.1.5 Swelling test
The swelling test of BP and BPP samples were measured by soaking in toluene for 1 h. BP has the lowest swelling, at 0.16% ± 0.006 due to cellulose fibers having polar structures that mean the samples cannot swell and dissolve in non-polar solvent. After the sample was coated with rubber it showed high swelling due to hydrocarbon is a non-polar molecule that it can swell in non-polar solvents such as benzene, hexane and toluene. BPP with 30% NRL has higher swelling than 15% NRL because BPP with 30% NRL has a high amount of NRL that affects the swelling more. From the Figure 2 (b), the % swelling of the BPP with 30% NRL at 3 and 6 h have lower values than BPP at 9 h due to BPP at 3 and 6 h having less crosslinking. However, the BPP with 15% NRL, using different vulcanization times found that values of % swelling showed a slight increase due to the similar amounts of crosslinking.

Table 1. The results of color-parameter test and picture of samples for different ratios of BF: NRL (w/w)

<table>
<thead>
<tr>
<th>Sample</th>
<th>Ratio (B:R)</th>
<th>Picture</th>
<th>Color parameters</th>
</tr>
</thead>
<tbody>
<tr>
<td>BP</td>
<td>1:0</td>
<td><img src="image1.png" alt="Image" /></td>
<td>L*</td>
</tr>
<tr>
<td>BPP</td>
<td>1:1</td>
<td><img src="image2.png" alt="Image" /></td>
<td>73.32</td>
</tr>
<tr>
<td>BPP</td>
<td>1:1</td>
<td><img src="image3.png" alt="Image" /></td>
<td>64.54</td>
</tr>
<tr>
<td>BPP</td>
<td>1:1</td>
<td><img src="image4.png" alt="Image" /></td>
<td>61.10</td>
</tr>
<tr>
<td>BPP</td>
<td>1:1</td>
<td><img src="image5.png" alt="Image" /></td>
<td>62.96</td>
</tr>
<tr>
<td>BPP</td>
<td>1:2</td>
<td><img src="image6.png" alt="Image" /></td>
<td>55.92</td>
</tr>
<tr>
<td>BPP</td>
<td>1:2</td>
<td><img src="image7.png" alt="Image" /></td>
<td>53.83</td>
</tr>
<tr>
<td>BPP</td>
<td>1:2</td>
<td><img src="image8.png" alt="Image" /></td>
<td>53.43</td>
</tr>
</tbody>
</table>
Table 2. The result of contact angle test at initial angle and finished angle of BP and BPP

<table>
<thead>
<tr>
<th>Sample</th>
<th>Contact angle (°)</th>
<th>slope</th>
<th>Picture</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Initial angle</td>
<td>Finishe</td>
<td></td>
</tr>
<tr>
<td></td>
<td>angle</td>
<td>d angle</td>
<td></td>
</tr>
<tr>
<td>BP</td>
<td>87.73</td>
<td>0</td>
<td>-14.614</td>
</tr>
<tr>
<td>BPP 153</td>
<td>120.25</td>
<td>112.07</td>
<td>-0.0452</td>
</tr>
<tr>
<td>BPP 156</td>
<td>120.53</td>
<td>115.33</td>
<td>-0.0348</td>
</tr>
<tr>
<td>BPP 159</td>
<td>127.10</td>
<td>120.82</td>
<td>-0.1122</td>
</tr>
<tr>
<td>BPP 303</td>
<td>97.64</td>
<td>84.03</td>
<td>-0.1122</td>
</tr>
<tr>
<td>BPP 306</td>
<td>108.08</td>
<td>84.10</td>
<td>-0.2736</td>
</tr>
<tr>
<td>BPP 309</td>
<td>117.04</td>
<td>102.31</td>
<td>-0.1172</td>
</tr>
</tbody>
</table>

Figure 2. a) Percentage of water absorption and b) Percentage of swelling in toluene

3.2 Mechanical properties

3.2.1 Tensile testing

Tensile strength at break and %elongation at break of BP gave lower values than BPP vulcanization with UVA. BP is mechanical entanglement of fiber-fiber that has poor tensile strength. On the other hand, BPP showed higher tensile strength than BP because NRL is able to coat on the BP with adhesion between pulp-pulp and pulp-natural rubber. BPP with 30% NRL showed higher tensile strength than 15% NRL, because it has a high amount of NRL and structure of NRL is changed from amorphous to crystalline when stretched during the tensile test.

The tensile strength of BPP at 30% NRL is related to the SEM results. It shows 30% NRL has highest strength because the amount of NRL affects to adhesiveness and mechanical entanglement.

The results of tensile strength at break and %elongation at break increased with increasing NRL content and vulcanization time (3, 6 and 9 h).

Modulus at break of BP had the highest value. In contrast, BPP samples decreased with increasing amounts of NRL and also higher vulcanization time. Natural rubber has a movable polymer chains which can affect the flexibility of the samples. The tensile testing of BP and BPP are shown in figure 3.

3.2.2 Tear testing

Tear strength of BP was higher than BPP and the results are shown in figure 3 (d). BP has highest to tear strength, and BPP has lower tear strength than BP because NRL inserts into gap between fiber-fiber giving low shear and low resistance tear when compared to BP. The BPP at 30% NRL found higher resistance tear than 15% NRL because amount of NRL affects to adhesiveness and mechanical entanglement. When considering vulcanization time there was a slight increase with increasing time.

4. Conclusion

In this research, the BPP was studied in different concentration of NRL (15% and 30%), and vulcanized under UVA conditions at 3, 6 and 9 h. Moreover, these BPP were tested for properties regarding water protection, moisture and strength. The results showed that BPP with 30% NRL and vulcanization time of 9 h had excellent properties. It possessed hydrophobic properties, low water absorption and good mechanical properties. Finally, this BPP can
be used to produce good packaging materials that are environmentally friendly.

Figure 3. The mechanical properties of BP and BPP a) Tensile strength at yield, b) %Elongation at break, c) Modulus at break and d) Tear strength.

References
1. Prince of songkla university and Research and Development Office.
Coating technology for pool with natural latex. Natural rubber 2. 2014.