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Development of Paper Using Coir Fibers as a Packaging Product

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ABSTRACT

This project was developed to investigate the potential of coir fibres to be used as secondary raw material in order to promote environmentally friendly packaging. In addition, old newspapers were embedded in the specimen to hold the coir fibres each other. The main objective was to determine mechanical properties of paper with different beating times and percentages of coir fibres. The responses of this research are tensile index and tear factor. Mechanical pulping process was chosen to produce the pulps in random orientation with cross-machine direction. Regression and Analysis of Variance (ANOVA) was employed to determine significant differences between percentages of fibres used and beating time for each response variables. The results show that as beating time increased, the mechanical properties of papers increased. Otherwise, the increment of fibres percentages has caused the mechanical paper properties decreased. The combination of 25% fibres and 75% newspaper with 20 min of beating time has produced the best mechanical properties. The conclusion suggests that coir fibres can be one of the alternative raw materials which can be applied for packaging product.

Key words: Coir fibers, tensile strength, tear factor, packaging, beating time

INTRODUCTION

Mechanical testing in determining several packaging properties such as tensile test and tear test was conducted to predict the mechanical behaviour of packaging raw material, such as coir fibre. There are few researchers have conducted study about the mechanical properties which were related to coir fibre. For instance, Monteiro *et al.* (2008) have investigated the mechanical performance of coir fibre/polyester composites by evaluating the structural characteristics and mechanical properties of coir fibre/polyester composites. The as-received coir fibre was characterized by Scanning Electron Microscopy coupled with X-ray dispersion analysis. The results of flexural strength have allowed comparison for technical performance of composites with other conventional materials (Monteiro *et al*., 2008). Other researchers, Gurav *et al.* (2003) has studied the mechanical properties of paper-pulp packaging by promoting the application of environmentally friendly packaging such as those materials made out of paper-pulp. In his publication, results which were consist of the determination of tensile and compressive strength for paper-pulp packaging with high variation in the earlier properties have been presented (Gurav *et al.*, 2003).

Fiber beating process was merely crucial in paper making process. When the fibre was beaten with the combination of different percentages of fibres and water, analysis need to be conducted so that it can be suitable to be used in paper manufacturing. In terms of fibre beating, Beg and

Pickering (2008) has discovered the influence of this process towards the mechanical properties of Kraft fibre reinforced polypropylene composites; meanwhile Beg and Pickering (2008) and Gabriel *et al.* (2007) characterized the performance of coir fibre as packing material by removing the ammonia in gas phase bio-filter.

In terms of fiber coir application in packaging, there are other researchers that managed to figure out several details about using coir fibers as sound absorption. Zulkifli *et al.* (2008) has started the investigation about the acoustic properties of multi-layer coir fibers sound absorption panel. Then, this research was extended by Nor *et al.* (2010). They have managed to define the effect of different factors on the acoustic absorption of coir fiber (Nor *et al.*, 2010). Zulkifli *et al.* (2010) then continued they previous study by performed a research about noise control using coconut coir fiber sound absorber with porous layer backing and perforated panel.

In this research, coconut fibres were used as the main raw material to discover the potential of being as an additive for pulp in paper making. Coir fibres are the biomass remaining after the fibres extracted from fruit coconut. This raw material is also more biodegradable, easier to recycle and has less impact on the environment. Therefore, this research was developed to consider the potential of coir fibres to be used as secondary raw material in order to promote environmentally friendly packaging. In addition, old newspapers were embedded in the specimen to hold the coir fibres each other. The objective of this project was to determine mechanical properties of paper with different beating times and percentages of coir fibres in lab scale experiments.

MATERIALS AND METHODS

In this research, there are two main raw materials that have been used, which were coconut fibres and old newspaper. The newspapers were used to hold the orientations of fibres because it contains recycled materials which automatically supplying the condition of fibres that need to be formed as sheets of paper. The mechanical pulping process was chosen to prepare the raw materials pulps this section, whereby the apparatus that were used are blender, a wooden deckle with draining net (21.2×28.7 cm), a large sponge, large plastic tub (35×30 cm), cotton cloth and scissors.

Procedure of paper making process and test specimen: The first stage of paper making process was the fibres been cut in range between 0.2 cm until 0.5 cm long. The newspaper also cut in small pieces. The total weight of raw materials for each compositions that be used was 24.4 g, respectively. The composition of raw materials was blended for 5 min to produce pulps. After that, the pulp transferred into a large plastic tub. The deckle deep in the tub, slowly raise the deckle and the screen was shacked. Take a few moments to make sure all the water was drained back into the tub. Next, the screen flipped on the cotton cloth and sponge was used to squeeze off the waters. Slowly the screen pulled off and the sheet of paper completely done.

For the drying process, the samples that completely ready be dried with the environment temperature for 8 h, after that the samples was pressed using padding machine (Airpad, 3486, China) with 3 kg cm^{-2} of pressure. The objective was to make sure that all the samples for each composition were approximately has the same thickness. After that, the samples thickness data was taken. The test specimen for tensile testing was 300 mm long and 15 mm width. This dimension based on TAPPI Standards (2011), sampling and accepting a single lot of paper,

paperboard, container board, or related product, Standard Practice T 400 sp-11 (TAPPI Standards, 2011). Meanwhile, the dimension for tear testing was 76 mm long and 63 mm width (TAPPI Standards, 2011).

Beating time process: Based on James (1981), in fibres preparation or treatment, cellulose fibres must be facing the mechanical treatment; such as bruising, rubbing, or crushing procedures on the fibres before they can be process become a piece of paper. The fibres separation and fibres cutting usually for refining, meanwhile beating is the most fundamentally important process in papermaking. This terms are the common used in paper industry to give a picture of pulp fibres mechanical treatment process been done. In general, by beaten the pulps fibres, it will give a strong, dense and in texture of paper. Other advantages in increasing beating within the commercial range increased bursting strength, tensile strength and folding endurance, but tends to decrease tearing resistance and secondly, it will also tends to increase smoothness, hardness and amount of fibres bonding of the fibres (James, 1981).

Basis weight or grammage: The different grammage will bring the different strength properties on paper. Grammage or basis weight is the mass of paper per unit area. Equation 1 has stated the grammage formula as stated in TAPPI Standards (2011):

$$\text{Grammage} = \frac{\text{Weight (g)}}{\text{Area (m}^2\text{)}} \tag{1}$$

Density: The density for paper is relating to the porosity, rigidity, hardness and strength. Paper density (in g cm^{-2}) expresses how compact the paper is. This is strongly supported by TAPPI standard method that density can be determined as shown in (2) and (3) as below (TAPPI Standards, 2011):

$$\text{Density (g m}^3\text{)} = \frac{\text{Grammage (g m}^{-2}\text{)} \times 0.0001001}{\text{Thickness (m)}} \tag{2}$$

$$\text{Specific volumes (mm}^3\ \text{g}^{-1}\text{)} = \frac{\text{Thickness (in microns)} \times 0.0001\ \text{mm}}{\text{Grammage (g mm}^{-2}\text{)}} \tag{3}$$

Tensile strength: The concept of the tensile strength for paper can be defined as how likely a paper is to break when a pulled force was applied at the opposite ends (pulp and paper dictionary). This is very important when running through high-speed web presses. Based on the TAPPI standard, formula that used to calculate the tensile strength is express in Eq. 4 (TAPPI Standards, 2011):

$$\text{Tensile strength (N m}^{-1}\text{)} = \frac{\text{Breaking load (N)}}{\text{Width (m)}} \tag{4}$$

From Eq. 5, the breaking length value will increase if the tensile strength increased. Based on the figure, it clearly proved that the relation of tensile strength and breaking length are positive proportional to each other. Furthermore, the Tensile Index was equal to the relationship between

tensile strength and basis weight. It can be expressed as shown in Eq. 5 as stated in (TAPPI Standards, 2011):

$$\text{Tensile index} = \frac{\text{Tensile strength (N m}^{-1})}{\text{Basis Weight (g mm}^{-2})} \quad (5)$$

Tear factor: According to pulp and paper dictionary, tear factor is a measure of how likely a paper will continue to tear once started. The tearing test is very sensitive to the physical properties of the fibres. As stated in TAPPI Standard (2011) the tear factor can be expressed as shown in Eq. 6 (TAPPI Standards, 2011):

$$\text{Tear factor} = \frac{10}{ER} \quad (6)$$

where, E is force in grams to tear a single sheet and R is the paper grammage. According to Goyal (2012), in general conclusion between tensile and tear relationship, this both strength will inversely proportional to each other. If the paper has maximum tensile strength, so the resulting sheet will be low in conversely. A sheet formed at maximum tear value will be low in tensile strength (Goyal, 2012).

Mechanical testing and measurement equipment: The test specimen weight was measured by using weight scale machine (GF-3000, Japan) and the thickness of the samples was measured by using Digimatic Mini Processor (Mitutoyo, DP-1VR, Japan). Others equipment that also be used are padding machine (Airpad, 3486, China) with pressure 3 kg cm^{-2}, punch strip was used to cut the papers, magnifying glass was used to observed the fibres orientation and stop watch. The U.T.M. machine, model Lloyd Instrument LR 30K, was used to measured tensile strength and tear strength. Firstly, the force and the speed of the machine must be set. Both mechanical properties that want to be measured have the same force and speed setting. The force was set at 10,000 N with its speed was 400 mm min^{-1}. Next, the specimen was placed between jigs and both ends be clamped. After the specimen was placed, the machine run and the test results appeared on computer screen.

Preliminary experiment: The main objective was done to get the best combination between minimum beating times for raw materials are beaten and maximum composition of raw materials especially coir fibres, for paper development. In addition, to decide either the combination of maximum percentage and minimum to be beaten in the process of paper development that be made from coir fibres can successfully be done or not. As a trial, the composition of raw materials used was 85% of fibres and 15% of newspaper be blend together and the minimum beating time was only 5 min.

The higher compositions of coir will also increased the compositions of lignin which that the main reason to make the structure of paper become weak. Nevertheless, this problem can be reduce by increased the percentages of newspaper, which helped to stabilized the coir structure. Therefore, only 85% of fibres and 15% of newspaper was decided to use as the maximum percentage of fibres that was used to run the preliminary experiment.

Meanwhile, the fibres be beaten only be beaten for 5 min because to make sure that the compositions of raw materials can be blended together as produced pulps. If the mechanical pulping process to produced pulps was succeeding by using only 5 min, so, it also is used in the actual

experiment as a minimum beating time. After the paper with the preliminary combination of raw materials was produce and be dried, the samples were tested based on the scope that had mention before. As a summary, the maximum percentage of fibres with the minimum beating time that be used in this preliminary paper development experiment, successfully can be done.

Experiment design: From the previous section, the preliminary experiment was be done by 85% of fibres and 15% of newspaper with 5 min of beating time. Therefore, based on that, in this section there are three categories that be experimented. First group was low percentage of fibres and newspaper used with 25%, second was medium percentage of fibres used with 45% and third was the maximum percentage of fibres used 65%. Meanwhile, the beating times were 5 minutes, 10 min, 15 and 20 min, respectively. All the experiment be repeated for three times (n = 3). There are two type of mechanical properties that be studied in this research. There are tensile strength and tear strength. Each mechanical properties total testing was 36 specimens, so that overall both specimens that be produced are 72.

RESULTS

Preliminary experiment results: The preliminary samples had tested by using Universal Testing Machine and all the results analyzed. Table 1 shows the preliminary experiment results by using 85% of fibres as the main raw material. From these data, the average thickness that this samples had is 1.186 mm, the extension at tensile and tear test are 1.957 and 1.87 mm. The maximum load that the sample can be manage by this fibres and newspaper compositions were at 163.47 N for tensile load and 26.957 N for maximum tear load. Generally, it can conclude that the composition of both raw materials in this preliminary experiment, with coir fibres as the main raw material, shows that the development of paper as a packaging material product successfully can made. Based on the results and preliminary success in paper development using coir fibres mixed with newspaper, the actual experiment also can made the paper using coir fibres as a main raw material. As a summary, the minimum beating time that be used was 5 min and the maximum of composition of fibres was below than 85%.

Based on Table 2, it shows the data for thickness, average samples weight, surface area produced, grammage and density of the papers produced in actual experiment. The average thickness that depends on time for pulps were beaten was 0.98 mm at 5 min, 0.91 mm at 10 min, 0.85 mm at 15 min and 0.92 mm at 20 min of beating. After that, the basis weight of paper calculated. Therefore, the grammage sheet of a paper was 178 g m^{-2}. The suggestion of usage is depends on its weight and the paperboard was in range of grammage between 120 g m^{-2} until 300 g m^{-2} with 5% of acceptable trade tolerance. In addition, according to ASTM standard, the basis weight for paper-fibres was 250 g m^{-2}. Therefore paper made from coir fibres was relevant and lies in the between of the range and also can be categorized as paper-fibres or paperboard.

Table 1: The preliminary experiment result

	Test No.			
Parameter	1	2	3	Average
Thickness (mm)	0.91	1.23	1.42	1.18
Maximum load at tensile test (N)	236.00	98.39	156	163.47
Extension at tensile test (mm)	2.94	1.39	1.58	1.95
Maximum load at tear test (N)	36.80	19.48	24.58	26.95
Extension at tear test (mm)	2.30	1.91	1.4	1.87

Table 2: The physical properties of samples

Properties	Values			
Grammage (g m^{-2})	10.840			
Weight (g)	0.0610			
Area (m^2)	178.00			
	Beating time (min)			
	5	10	15	20
Thickness (mm)	0.980	0.91	0.850	0.920
Density (g m^{-3})	0.018	0.02	0.021	0.019

Table 3: The preliminary experiment observation

Mixture (%)	Observation	Fibres direction
25% fibres and 65% news paper	Smooth surface	Cross machine direction
	Nearly same as a normal paper	
	Gray in colour	
	Easy to beat and blended	
	Run lightly and noise produced was normal	
45% fibres and 55% news paper	Gross surface. Physical colour was balance between gray and brown	Cross machine direction
	Hard to beat the raw materials and make noise	
65% fibres and 35% news paper	Rongh surface	Cross machine direction
	Brown in colour	
	Hard to blended	
	Run heavily and lot of noise	

Fig. 1(a-c): Samples according to the mixtures, (a) 25% of coir fibers and 65% news, (b) 45% of coir fibers and 55% news and (c) 65% of coir fibers and 35% news

Next, according to Table 3, it shows the general physical observation when the process of beating was done for all composition of fibres to develop the papers. It also concluded the type of fibres direction either machine direction or cross-machine direction. From the Table 3, it can be concluded that the more fibres used to developed the paper, the physical properties that mostly covered by fibres become more rough. Beating process also become heavy and a lot of noise produced. Lastly, for the type of direction, the fibres are randomly oriented and for each composition produced, the samples are all in the cross-machined direction. Figure 1 shows the orientation of fibres and colour each samples with different composition of fibres which were used supports all these explanations. The overall results of Tensile Index and Tear Factor was stated in Table 4.

Table 4: Tensile index and tear factor base on various settings

Setting	Tensile index	Tear factor
25% 5 min	0.860225	0.676541
25% 10 min	1.082191	0.523935
25% 15 min	0.850442	0.514519
25% 20 min	1.414026	0.419271
45% 5 min	0.650406	0.853562
45% 10 min	0.622030	0.804635
45% 15 min	1.311030	0.544543
45% 20 min	1.134663	0.481730
26% 5 min	0.426167	1.162006
65% 10 min	0.264004	1.333355
65% 15 min	0.525114	0.817418
65% 20 min	0.468354	0.792692

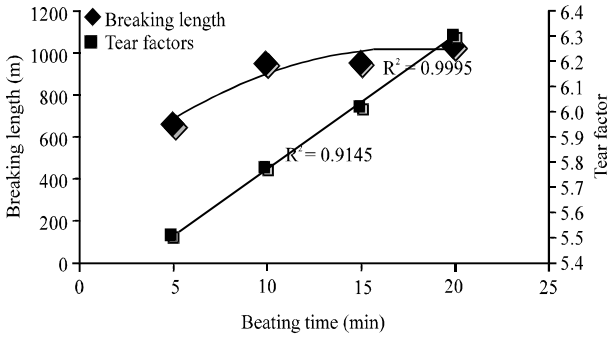

Fig. 2: Effect of beating time on physical properties of paper made from coir fibers

Tear strength factors and breaking length after beaten: As shown in Fig. 2, it illustrated the small amount of beating curve. The tear strength factors that produced by lots of beating amount is high as well as tensile strength factors. The highest values for both breaking and tear factor were at 20 min of beating. There was 1025.8 mm of breaking length and 6.3 of tear factor.

The values of R-Squared were 0.914 for breaking length and 0.999 for tear strength factors. It means that the correlation between the variables and the outcome was effective to each other. From the curves, it shows that both variables were inversely to each other. It supported by the previous researcher, James (1981) said that a small amount of beating would produce a absorbent sheet with high tear strength factors but low tensile strength factors.

Tensile loads and tear loads for each sample with different treatments: According to the Fig. 3 and 4, it is clearly shows that the mechanical properties; tensile and tear strength loads are inversely to each other when the factors were changed. The factors are the composition of fibers used and time to beat the pulps when the compositions of fibers are increase, the tensile strength loads and tear strength loads decreased. The maximum loads that can be supported by samples are at 25% of fibers and 75% of newspaper are used. Maximum load for tear strength was 110.7 N and tensile strength was 28.8 N. The highest composition of newspaper helped the samples stabilized the structures of fibers.

Otherwise, beating processes give opposite result that the tensile strength loads and tear strength loads are increase proportional with beating time. In the relationship between both

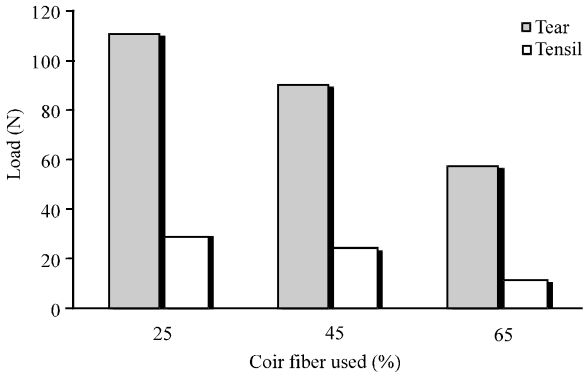

Fig. 3: Relationship between percentages of coir fibers used with mechanical properties

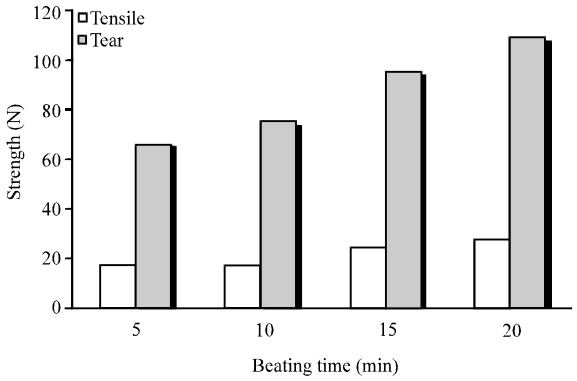

Fig. 4: Relationship between beating time with mechanical properties

mechanical properties of papers and times are peak at 20 min of beating. At this point, tear strength load was 109.2 N and tensile strength load was 28.1 N. Based on both results, it shows that the composition of 25% of fiber with 75% of newspaper and 20 min of beating will give the paper highest value of mechanical properties. It is supported the previous discussion, which that the stabilization of fiber structure and the beating time used to beat the pulp help to produce a paper that can hold the loads before it is failed.

DISCUSSION

In this study, fiber-paper was successfully done and the effect of different coir fiber percentages with different beating times was been compared based on its mechanical properties. All pulp was completely prepared by using mechanical pulping and the raw materials are coir fiber and newspaper. The percentage of fiber was set at three different ranges and the beating times were set at four different ranges.

One of the significant findings from this study is that the raw materials used to develop paper as a packaging material product has a capability to become the most economically composition. The best treatment between the compositions of raw materials and beating time that been chosen was 25% of coir mixed with 75% of newspaper and 20 min of beating. This combination of treatment was chosen not only because it was easy to be made, but also because it produced the optimum mechanical properties, especially tensile strength and tear strength.

Apart from that, the most important finding from this study is the ability to identify other mechanical properties (extension, breaking length, tensile index and tear factor) after paper been tested. The highest mechanical properties values were 37.73 N (tensile strength), 136.54 N (tear strength). For extension, the highest mean was 5.80 mm and the breaking length was 1442.31 m. All these values were obtained from (25%, 20 min) treatment. Otherwise, the highest tear factor was at (65 %, 10 minutes) treatment with 1.33.

For the further research, some recommendation that may be useful to make sure that this raw material always relevant to make a paper that can be use as packaging product in future. For instance, other techniques to analyse the findings also might lead to a better result. Fallstrom *et al.* (2000) have performed an experiment about the determination of paper stiffness and anisotropy from recorded bending waves in paper, subjected to tensile forces. The experiment has explored about bending wave propagation of paper sheets in tension by using all-electronic pulsed TV holography technique to record the bending wave field initiated by a laser pulse. It is found that the bending waves were influenced by mechanical properties such as density, thickness, bending stiffness, anisotropy and also by tensile forces in the paper (Fallstrom *et al.*, 2000).

CONCLUSION

This research has validated that as beating time increased, the mechanical properties of papers increased. Otherwise, the increment of fibres percentages has caused the mechanical paper properties decreased. The combination of 25% fibres and 75% newspaper with 20 min of beating time has produced the best mechanical properties. The conclusion suggests that coir fibres can be one of the alternative raw materials which can be applied for packaging product.

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