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MATERIAL PROPERTIES CHARACTERIZATION OF COIR CARDBOARD

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ABSTRACT

Material property is an important element to be considered during the design and engineering application of cardboard to avoid any failure. This study involves the development method for producing the cardboard by using natural waste which is a combination of coir fiber and recycled box. Experimental procedures have been conducted to analyze the mechanical properties and chemical properties of the cardboard. The two parameters in producing cardboard are time soaking coir fiber in sodium hydroxide and the ratio mixing between two materials. For mechanical property, the impulsive excitation test has been performed by tapping a specimen elastically by using an impactor. This experiment is to obtain dynamic Young's modulus property of the cardboard based on its fundamental longitudinal resonant frequency of vibration. In chemical analyzation property, it was performed by using the Fourier transform infrared spectroscopy (FTIR), a technique to obtain an infrared spectrum of absorption, emission, photoconductivity or Raman scattering of a solid specimen. The experimental results show that a higher ratio of coir fiber and longer time treated with sodium hydroxide produces higher dynamic Young' modulus property of cardboard.

Keywords: natural waste, coir, soaking time, mechanical properties, chemical properties.

INTRODUCTION

Coir is a natural fiber extracted from the husk of the coconut and used in products such as floor mats, door mats, brushes and mattresses. Technically, coir is the fibrous material found between the hard, internal shell and the outer coat of a coconut. To date, relatively little attention has been given to the use of this coconut waste which can create environmental problem if not disposed properly. The utilization of coir can create economic and environmental advantages because the fibers are renewable, non-abrasive, cheaper, and available in abundance and show less health and safety concern during handling and processing. These advantages can be of great potential in converting the coir fibers into pulp and paper products.

Natural waste such as coconut coir fiber can be easily found in Indonesia and Malaysia. These fibers are considered as environment friendly materials owing to their biodegradability and renewable characteristics. This fiber can be found in almost all of the country in Asia. The coconut plantation in Malaysia is in a declining trend compared to other coconut plantation such as in Philippine and Indonesia. In many island economies, it is a major source of revenue and is an integral part of the livelihood of the population. In searching for such new material, a study has been made where coconut fiber (also known as coir fiber) is compounded with composite material. Coir is extracted from the tissues surrounding the seed of the coconut palm (Cocos nucifera). Coir is the natural fiber of the coconut husk where it is a thick and coarse but durable fiber. The husk contains 20% to 30% fiber of varying length.

Elastic properties are fundamental for the complete characterization of materials [1] and important for design applications. A well-known technique is an impulsive excitation test by analyzing their dynamic response which consists of setting a sample by impact [2] into mechanical vibration in vibrational modes at one or more frequency at which the vibration displacements are at a maximum (resonance). This method results the time domain and frequency domain of the impulse signal. The decay time of the vibration response due to impact excitation is characterized by its mass, width, thickness and length of the sample [3]. Dynamic Young's modulus [4] can be calculated by using Equation. (1):

$$\mathbf{E = 0.9465 \ \frac{mf_f^2}{b} \ \frac{L^3}{t^3} \ T} \tag{1}$$

where E is dynamic Young's modulus, m is mass, f_f is natural frequency in flexure dimension, b is width, L is length and t is the thickness of the cardboard.

The purpose of this research is to produce cardboard which is contained coir fiber and reused boxes and determine the material properties characterization of the coir cardboard. The impulse excitation test will be performed on the sample to measure dynamic Young's modulus while Fourier transform infrared spectroscopy (FTIR) test to determine chemical properties.

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MATERIALS AND METHODS

Materials

Coir fiber is one of the natural wastes used for making the cardboard and as a raw material besides the recycled box. Coconut belts can be easily found around with a low cost price. The brown husk fiber from matured coconut was collected to obtain the fiber which present at the outer shell of coconut [5]. Coir fiber was grinded by using a grinder machine to produce smaller size. Sodium hydroxide (NaOH), coir fiber, recycled boxes and distilled water were used in this experiment.

Preparation for sodium hydroxide

For chemical treatment of the natural waste, 1L of 1M sodium hydroxide was prepared. About 40 grams of sodium hydroxide in forms of solid (pellets) were weighted by using a weighing scale. The amount of sodium hydroxide required (40W/g) is weighed out as quickly as possible from a fresh bottle of sodium hydroxide pellets to minimize the exposure to the environmental air. Then, distilled water was added into 1L beaker together with the sodium hydroxide pellets until the quantity of 1L. The solution was stirred until it dissolved completely.

Soaking process

The concentration of sodium hydroxide and soaking time were the key factor affecting the treatment. The scope of concentration is 1M. The reasons for the improved mechanical properties were the removal of impurities on the fibers during alkali treatment. In general, high concentration of alkali solution and shorter soaking time provides better impact strength whereas low and medium concentration of the alkali solution for longer shorter time provides improved flexural and tensile properties respectively [6]. Immediately after the sodium hydroxide is prepared, the pulverized coconut belt has been inserted in the beaker. A soaking process takes place in a closed beaker to avoid being exposed to the outside environmental air, causing an inaccurate immersion effect by parameter soaking days.

Washing fiber

After completion of soaking, the material is washed with distilled water to remove any dirt or chemicals stuck on the fiber. A filter was used during the washing process. Fiber is washed with distilled water flows to ensure all fiber cleaned properly. Then the fiber was put into the 'loyang aluminium' for the drying process in the oven. This process was carried out to ensure all dirt or water that is still attached to the fiber to be removed. This process does so easily to a belt weighing sessions during mixing between the fiber and the box by a predetermined ratio. This is to ensure the formation process is done effectively.

Preparation of pulp

The next step is to prepare the pulp by mixing the coir fiber and recycled box. The desired weight of the recycled box and fiber was prepared. The total mixture of a combination of both raw materials is 60 grams. For the coir fiber to be soaked in 1 day sodium hydroxide, the ratio taken (fiber to box) were 1:3, 1:1 and 3:1. The ratio taken is still same for the fiber that was to be soaked for 3 days and 5 days.

Forming cardboard

The mixing was put into the mold to shape of the cardboard. The method used was manually, which need to press the mixing hardly to ensure the products in tight condition. Next, the cardboard was transferred to the fabric for drying process. The drying process was performed under natural sun about 5 hours to make sure the remaining water is removed. The approximates temperature of the direct heat sun is about 28-35 ˚C.

Impulsive excitation test

The experimental set-up consists of rectangular bars of sample 8cm x 2cm (length x width), an impactor, a microphone and a signal pickup system to measure the acoustic signal. The experiment was conducted in a low-noise level room and the procedure is in accordance with [4]. The microphone was located over an antinode point and closes enough to the test specimen to measure the acoustic waveform. The specimen was impacted by using an impactor at the center of the sample and the acoustic reading was recorded simultaneously. The procedure has been repeated for five times to obtain the average acoustic signal. Fast Fourier Transform (FFT) signal analysis was performed to obtain fundamental longitudinal resonant frequency. This frequency was then used to calculate the dynamic Young's modulus of the sample from the mentioned equation.

FTIR analysis

The sample of each cardboard was cut into small size of 2cm x 2cm (length x width). The background spectra were collected to subtract from the test spectra to ensure the actual sample is analyzed. Then, the sample was analyzed by fully-computerized FTIR system which generates the absorbance spectra showing the unique chemical bonds and the molecular structure of the sample material. This profile is in the form of an absorption spectrum which shows peaks representing components in higher concentration. Absorbance peaks on the spectrum indicate functional groups (e.g. alcohols, ketones, acid chlorides). Different types of bonds, and thus different functional groups, absorb infrared radiation of different wavelengths. Although the analysis was performed in absorbance, it can be converted to transmittance, since they are simply the inversions of each other. The analytical spectrum was then compared with a reference

ARPN Journal of Engineering and Applied Sciences

library program with cataloged spectra to identify the components or to find a "best match" for unknown material by using the cataloged spectra of known materials.

RESULTS AND DISCUSSIONS

The sample of dry coir fiber cardboards is shown in Figure-1. The sample of coir fiber cardboards is based on the time soaking days for coir fiber in 1 mol of NaO); and the ratio between the coir fiber and recycled box. The size of the sample is 16cm x 4cm.

Figure-1. Sample of cardboard (specimen).

Impulse excitation

The impulse excitation method has been applied to determine the dynamic Young's modulus of the samples on its non-destructive characteristic [7]. The experimental procedures have been performed in the low noise level location to avoid any interference to the impulsive acoustic signal. Impactor used for carrying out the impulsive force to the specimen is made from steel. Figure-2 shows an impulsive acoustic signal of the sample which has been measured by using a microphone.

The time domain shows transient decaying characteristics. This waveform is high oscillation as a result of the dynamic response of the impulsive testing interaction between the impactor tip and the sample's surface [8]. The amplitude of the acoustic signal increase and the vibration response of the sample decreasing as a function of time with an exponential characteristic during the interval of 0.04 seconds. The time domain decays to lower amplitude when the maximum amplitude reached.

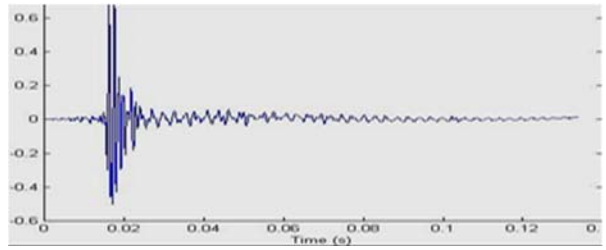

Figure-2. Time domain waveform of the recorded signal.

The specimen vibrates freely based on its natural frequencies which depends on the stiffness and mass of the sample. The time domain waveform has been converted to the frequency domain by using the FFT algorithm. FFT signal analysis has been performed by using Matlab®. Figure-3 shows the spectrum of the corresponding transient decaying acoustic signal waveform.

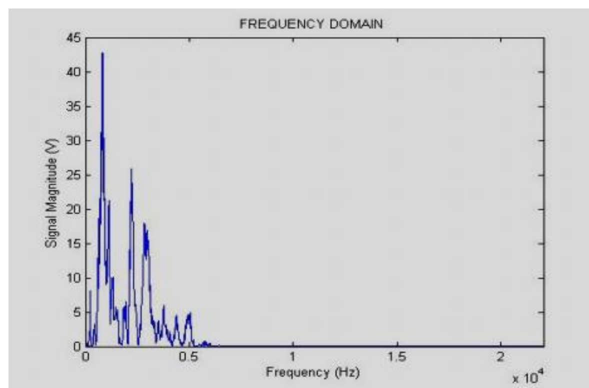

Figure-3. Frequency content of the measured signal.

Information in the plot of acoustic signal magnitude versus frequency content obtained after the FFT process shows several modes of acoustic signal that was generated during the impact-excited process [9]. The spectrum of frequency components is the frequency domain representation of the signal. Determination of the dynamic Young's modulus of the sample is based on the value of fundamental longitudinal resonant frequency [10]. Table-1 shows the average value of the fundamental longitudinal resonant frequency. The resonant frequency range is between 667 to 764Hz.

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Table-1. Calculated dynamic's Young modulus.

Soaking day (Day)	**Ratio (Box: coir fiber)**	**Average fundamental longitudinal resonant frequency** (Hz)	**Dynamic Young's modulus** (GPa)
1	3:1	667.47	1.94
	1:1	704.80	1.39
	1:3	682.06	0.91
3	3:1	673.60	0.78
	1:1	742.07	0.61
	1:3	639.00	0.14
5	3:1	671.10	0.69
	1:1	653.30	0.44
	1:3	764.13	2.25

The average range between the values of dynamic Young's modulus obtained from the data above is between 0.14 to 2.25GPa. The higher value of the dynamic Young's modulus refers to the higher elastic property of the produced cardboard. For this research, the highest elastic property of dynamic Young's modulus is cardboard from 5 days soaking in sodium hydroxide with ratio between fiber and box is 1:3.

FTIR results

Fourier transform spectroscopy is a measurement system whereby spectra are gathered in view of the coherence of the lucidness of a radiative source, utilizing time-domain or space-domain estimations of the electromagnetic radiation or other kind of radiation. FTIR spectrometers are widely used in organic synthesis, polymer science, petrochemical engineering, pharmaceutical industry and food analysis.

Referring to Figure-4 to Figure-6, the result for cardboard soak for 1 day with 1 fiber: 3 box has the wavelength of 3337.86cm^{-1} and 2916.18cm^{-1} respectively. For cardboard that is soaked for 3 days with the ratio of a 1 fiber: 3 box, the wavelength are 3335.72cm^{-1} and 2899.46cm^{-1}. Meanwhile, for cardboard with a soaking period of 5 days and a ratio of 1 fiber: 3 box has the wavelength of 3333.85cm^{-1} and 2916.15cm^{-1}.

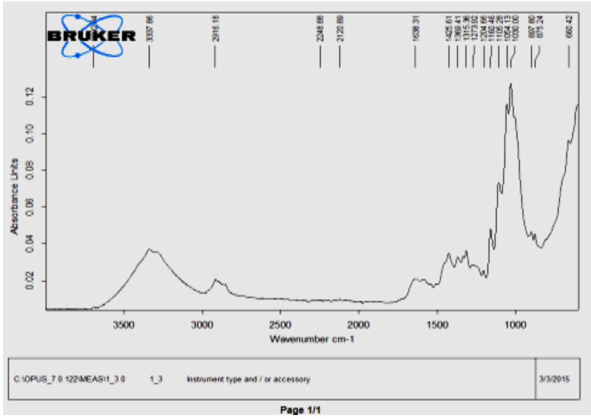

Figure-4. FTIR result of treated coir fiber in 1M NaOH for 1 day for ratio 1 fiber: 3 box.

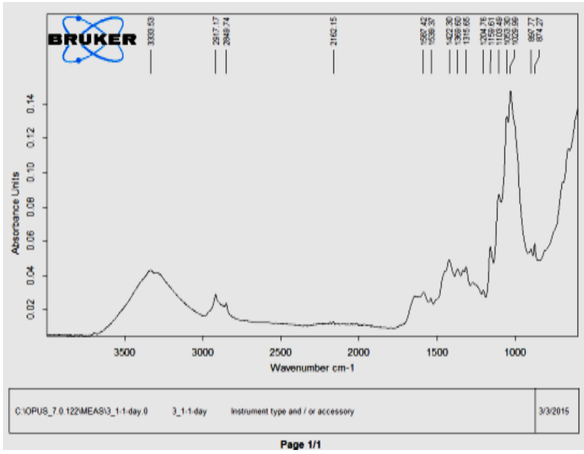

Figure-5. FTIR result of treated coir fiber in 1M NaOH for 3 day for ratio 1 fiber: 3 box.

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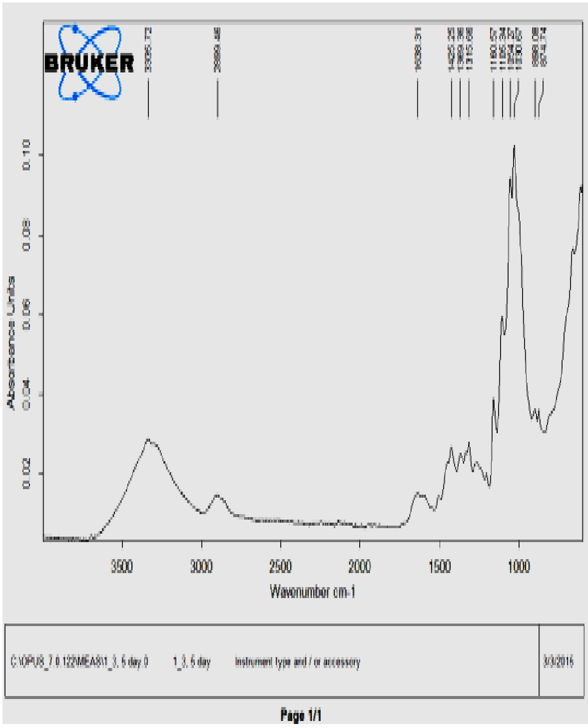

Figure-6. FTIR result of treated coir fiber in 1M NaOH for 5 days for ratio 1 fiber: 3 box.

From Figure-7, the wavelength for in range of 3200cm^{-1} to 3500cm^{-1} is referring to the functional group that is identified as phenols and alcohol. The functional group that is identified as phenols and alcohol is shown in Figure-8. For the wavelength in the range of 2800cm^{-1} to 3000cm^{-1}, the functional group is alkanes as shown in Figure-9.

bond		type of compound	frequency
-C-H	(stretch)	alkanes	2800-3000
=C-H	(stretch)	alkenes, aromatics	3000-3100
≡C-H	(stretch)	alkynes	3300
-O-H	(stretch)	alcohols, phenols	3600-3650 (free) 3200-3500 (H-bonded) (broad)
-O-H	(stretch)	carboxylic acids	2500-3300
-N-H	(stretch)	amines	3300-3500 (doublet for NH_2)
O=C-H	(stretch)	aldehydes	2720 and 2820
-C=C-	(stretch)	alkenes	1600-1680
-C=C-	(stretch)	aromatics	1500-1600
-C≡C-H	(stretch)	alkynes	2100-2270
O=C-	(stretch)	aldehyde, ketones, carboxylic acids	1680-1740
-C≡N	(stretch)	nitriles	2220-2260
C-N	(stretch)	amines	1180-1360
-C-H	(bending)	alkanes	1375 (methyl)
-C-H	(bending)	alkanes	1460 (methyl and methylene)
-C-H	(bending)	alkanes	1370 and 1385 (isopropyl split)

Figure-7. FTIR characteristic of IR absorptions.

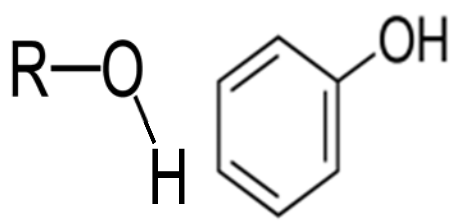

Figure-8. Phenols and alcohols group.

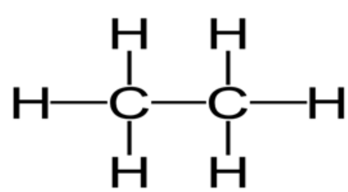

Figure-9. Alkanes group.

Based on the obtained functional group from the plot, alcohol with the OH-stretching vibration shows good results about the hydrogen bond formation. It also made the cardboard good with absorption. For the alkanes group, the C-H stretching vibration brings the medium absorption.

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CONCLUSIONS

The cardboard preparation by using a combination of coir fiber and recycled box has been achieved. The mechanical property of dynamic Young's modulus of coir fiber cardboard has been measured by using an impulsive excitation technique. The chemical properties characterization has been achieved by using FTIR. As the composition inside the coir fibers contain high of cellulose that can increase the bonding between coir cardboard and recycled box. It is found that the cardboard preparation is optimal in terms of dynamic Young's modulus and chemical property at 5 days of soaking with NaOH solvent in a ratio of 75% of coir fiber and 25% of a recycled box.

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