TECHNIQUE FOR PRODCUTION OF PAPERBOARD BRIQUETTE FROM WASTEPAPER

Sanan Tangsathit[1*] and Sompop Sanongraj[2,3]

Received: Apr 9, 2012; Revised: May 16, 2012; Accepted: Jun 1, 2012

Abstract

The goal of this research was to study techniques for producing paperboard briquette from A4-wastepaper using no binder with 50-kN of mechanical compression. The steps of this process were classified into 3 stages: (1) a shredding process using A4-wastepaper as raw material, (2) a paper pulp produced from shredded wastepaper by mixing the shredded wastepaper with tap water, and (3) a molding process for producing the wet paperboard briquette from the paper pulp. The proximate composition and selected physical properties of the wastepaper, paper pulp, and paperboard briquette products were measured according to ASTM Standard Methods. These properties included density and tensile stress of the paperboard briquette products according to ASTM Standard Methods. Various soaking times (1, 3, 6, 12, and 24 h) and molding periods (1, 3, and 6 h) were studied to find the optimal conditions for production of the paperboard briquette. The study investigated paperboard briquette production from A4-wastepaper with 2.2 MPa hydraulic compression using no binder in the raw material. It was found that the optimal conditions for producing the paperboard briquette were 3 h of soaking time in the paper pulp process followed by a molding period of 1 h. The resulting products had 7.42% (wt/wt) moisture content on a wet basis, 15.77% (wt/wt) dry matter, 443.95 g/L density, and 1.93 MPa tensile stress at the point of failure.

Keywords: Wastepaper, paperboard briquette, paper pulp, hydraulic compression

Introduction

Currently, pulp and paper production is one of the world's highest demands in the industrial sectors. Advances in pulp and paper technology have mitigated many environmental problems. The use of alternate raw materials reduces greenhouse gas effects since the cutting of rain forests and original growth forests is rarely practiced today.

Raw materials for the pulp production are obtained from wood fibrous raw materials

[1] *Environmental Engineering Program, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani 34190 Thailand, Email: sanan@sut.ac.th*

[2] *Department of Chemical Engineering, Faculty of Engineering, Ubon Ratchathani University, Ubon Ratchathani 34190 Thailand, Email: sompopsanongraj@yahoo.com*

[3] *National Center of Excellence for Environmental and Hazardous Waste Management, Ubon Ratchathani University, Ubon Ratchathani 34190 Thailand, E-mail: sompopsanongraj@yahoo.com*

* *Corresponding author*

and non-wood fibrous raw materials. Some of these are shown in Figure 1. For example, raw materials for pulp production in Thailand were bagasse, kenaf, bamboo, rice straw, Burma grass, eucalyptus and waste paper or waste paper pulp (Abad *et al.*, 2000).

Recently, environmental problems have necessitated cleaner technology in paper making. New non-fibrous wood and residual materials have been substituted for traditional fibrous wood raw materials. Less polluting cooking and pulp bleaching processes have been developed (Akkarakultron, 1996). Procedures employing cleaner technology have been applied to achieve increased production with minimal effects on the environment. They more efficiently utilize and recycle expensive and scarce chemicals and raw materials. This technology is often referred to as low and non-waste technology (Müller, 2000).

Waste management principals can be referred to as the 3R's: reduction, reuse, and recycling. Responsible disposal of wastepaper employs the 3 R's. Paper usage may be reduced through maximization. In this practice, paper is more efficiently used before being recycled. Additionally, waste paper can be transformed into value-added products. These could include fiber-cement composites (Thaemngoen *et al.*, 2003), granular and sheet activated carbon (Littrell *et al.*, 2002; Uradei *et al.*, 2000; Khezami *et al.*, 2007; Masahiro *et al.*, 2004; Malikov *et al.*, 2007; Yorgun *et al.*, 2009), and activated carbon monoliths (Kercher and Nagle, 2003; Nakagawa *et al.*, 2007). However, some important techniques and details concerning the production of these products are proprietary in nature and therefore not available in the scientific literature.

A case study of the recycling of solid waste in the Suranaree University of Technology, Nakhon Rachasima, Thailand found that the average amount of solid waste each day was 21333 km (Srisawang, 2002). Moreover, a related study found that the quantity of discarded office wastepaper was approximately 60% of all waste each day (Umnoi, 1997).

The molding process of paperboard from pulp is divided into 2 types : the cold process and the hot process. These processes may involve heat usage or may be done without application of heat (Usaborisut and Mahayosanun, 2005). Furthermore, a general cold process can be classified into 2 types. These include the hydraulic pressing and screw pressing systems as shown in Figure 2 (Loloon *et al.*, 2008; Usaborisut and Mahayosanun, 2005).

The main objective of the present work was to study the techniques for production of paperboard briquette from A4-wastepaper. It was our goal to do so using no binder in a cold process. A 50 kN hydraulic system capable of producing a pressure of 2.2 MPa was used to elucidate the best conditions for production of the briquette products. Experimental conditions varied, including the soaking time and molding periods. Experimental results are reflected in the

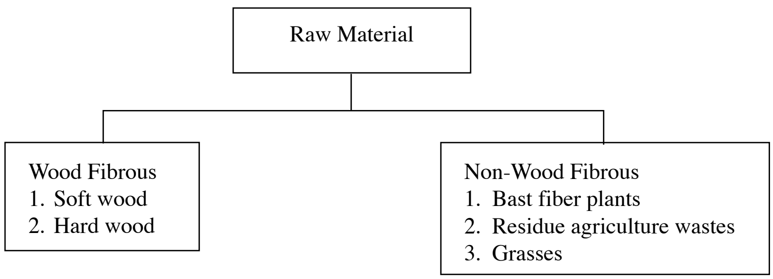
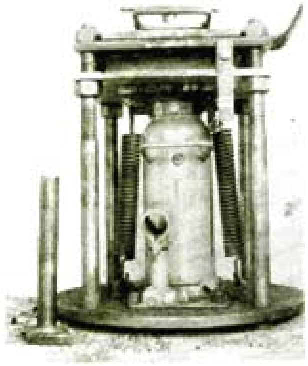


Figure 1. Raw materials for production of paper pulp in Thailand (Akkharakultron, 1996)

proximate properties of the paperboard briquette products and the tensile stress of the dried paperboard briquette products. These properties were measured according to ASTM standards methods as shown in Table 1 (ASTM, 1997; 1998; 2010).

(a)



(b)

Figure 2. General instruments for casting specimens by cold processes (a) Hydraulic compression system, (b) Screw system (Usaborisut and Mahayosanun, 2005; Loloon *et al.*, 2008)

Table 1. ASTM standards methods

Items	Wastepaper	Paper pulp	Briquette products	Standard methods
Tensile Stress	-	-	√	ASTM D828-93 (ASTM, 1998)
Moisture Content	√	√	√	ASTM D644-94 (ASTM, 1998)
Ash	√	√	√	ASTM D586-96 (ASTM, 1998)
Volatile Matter	√	√	√	ASTM D3175-8 (a)-97 (ASTM, 1998)
Fixed Carbon	√	√	√	ASTM D3172-89 (ASTM, 1997)
Length, width	√	√	√	-
Thickness	√	√	√	ASTM D645M-96 (ASTM, 1998)
Bulk Density	-	-	√	ASTM C559-90 (ASTM, 2010)

√ = Check these properties of sample.

Materials and Methods

Materials

Wastepaper as a raw material in this study was obtained from numerous collection points within the Institute of Engineering, Suranaree University of Technology, Nakhon Rachasima, Thailand.

Figure 3. A sample of A4-wastepaper after passing through an electric shredder

Material Preparation

Material preparations in the study are divided into 2 stages. They were shredding of the A4-wastepaper and paper pulp preparation from the shredded paper.

Shredding Preparation

In the first step, A4-wastepaper was shredded (4 mm width × 10 cm length) using an electric shredder. A sample of this shredded wastepaper is shown in Figure 3. The specifications of the electric shredder are shown in Table 2. Samples of the shredded wastepaper were used to determine the proximate properties of the raw material used in this study. The moisture content, ash content, volatile matter, and fixed carbon were determined according to ASTM standards methods (Table 1). The results are shown in Table 3.

Paper Pulp Preparation

Approximately 140 g of A4-wastepaper was weighed and put in a plastic tank

Table 2. Specifications of the electric shredder used in this study

Items	Details
Trade Name	Paper Shredder
Model	Olympia PS-15
Cutting Style	High Security Cross Cut
Cutting Size	4 mm Width × 10 cm Length
Throat	140 mm
Feed Capacity	8 Sheets (A4)
Safety Feature	Automatic Reverse in case of over load
Dimension (W x D x H)	160 × 250 × 300 mm
Weight	2.5 kg Approx

Table 3. Properties of wastepaper and paper pulp

Sample	Proximate properties (%)			
	Moisture content	Ash	Volatile matter	Fixed carbon
Wastepaper	2.7-4.9	10.3-13.0	51.3-55.0	29.3-31.6
Paper pulp	20.4-25.5	13.2-16.0	40.7-44.4	18.3-23.2

(diameter 16 cm × depth 16 cm). Then 2 L of tap water were added to the shredded wastepaper. Treatments included the following soaking times: 1, 3, 6, 12, and 24 h. After soaking, the resulting mixtures were poured into the vessel of an electric blender. The blender was operated at high speed for 3-5 min. This was done 1-2 times until sample textures were homogeneous as shown in Figure 4. The homogeneous paper pulp samples were poured back into their original raw material tanks. Samples of the homogenate having masses of approximately 5 g were removed to determine their proximate properties. The methods used for the proximate analyses are shown in Table 1. The results of the proximate analyses are shown in Table 3.

Paperboard Briquette Production Process.

Homogenous paper pulp was poured from the plastic tank into specimen setting

Figure 4. An example of homogenous paper pulp sample to be used as raw material for production of paperboard briquette products

Figure 5. A specimen setting mold in this study for production of paper-board briquette products

Table 4. Specifications of hydraulic press used in this study

Items	Details
Trade Name	Press (Minchen Machinery CO., Ltd., Thailand)
Model	HP 60
Over Height	1930 mm
Working Width	800 mm
Frame Width	1080 mm
Overall Width	1295 mm
Working Width of Side	305 mm
Frame Wide of Side	390 mm
Over Wide of Side	915 mm
Frame Hole	40 mm
Distance between Frame Hole	133 mm
Piston Rod Diameter	89 mm
Ram Stoke	185 mm
Working Height Ram to Table	830 mm
Net Weight	665 kg

molds having dimensions of 15 cm (width) × 15 cm (length) × 5 mm (depth) as shown in Figure 5. The slurry was cast into the shape of a wetted paperboard briquette having dimensions of 15 cm (width) × 15 cm (length) × 5 mm (depth). A hydraulic press capable of 50-kN pressure (Model: HP 60, Minchen Machinery Co. Ltd., Thailand) was used to apply 2.2 MPa pressure to the samples. The proximate analyses of the resulting briquettes are shown in Figure 6. The specifications of the hydraulic press are given in Table 4.

The samples were allowed to cure at the ambient temperature following the molding periods of 1, 3, and 6 h. At the conclusion of the curing periods, samples were removed from their molds. The textures of the resulting samples were examined for uniformity and cracking. Uniform samples were selected and weighed with a 4 digit-balance (Model XT 6200, Precisa Gravimetrics, Dietikon, Switzerland).

Finally, samples of selected products were dried in a hot air oven at 105-110°C overnight according to ASTM standards methods (Table 1). Upon removal from the

Figure 6. The 50-kN hydraulic press (Model: HP 60, Minchen Machinery CO., Ltd., Thailand)

Table 5. Proximate properties of briquette products

Products	Moisture Content			Ash			Volatile matter			Fixed carbon		
	Range	Avg*	SD**	Range	Avg*	SD**	Range	Avg*	SD**	Range	Avg*	SD**
S1M1	9-12.6	10.33	1.97	16.6-18.1	17.59	0.84	59.5-63.4	61.98	2.12	9.5-11.0	10.10	0.83
S1M3	9.8-11.7	10.42	1.10	15.2-17.2	16.15	1.01	63.4-65.9	64.52	1.20	7.2-10.8	8.91	1.79
S1M6	9.5-10.8	10.29	0.70	14.7-16.0	15.49	0.73	63.0-68.9	65.39	2.38	7.9-10.5	8.83	1.47
S3M1	6.5-9.0	7.42	1.33	16.1-16.4	16.27	0.13	59.1-61.3	60.53	1.22	15.7-16.0	15.77	0.17
S3M3	7.1-9.4	8.02	1.25	16.1-18.6	17.30	1.25	61-61.2	60.93	0.25	13.3-14.5	13.74	0.64
S3M6	8.3-10.7	9.42	1.21	15.3-16.4	16.00	0.60	60.5-65.4	62.34	2.66	9-14.8	12.23	2.97
S6M1	7.2-10.3	8.56	1.57	15.9-19.5	17.27	1.97	63.6-66.1	64.79	1.22	11.3-12.9	9.38	4.61
S6M3	7.2-11.7	8.77	1.77	13.5-16.6	15.13	1.54	65.3-66.3	65.87	0.50	9.5-11.0	10.23	0.74
S6M6	9.3-10.5	9.70	0.66	8.5-12.4	10.51	1.96	38-72.5	70.13	2.26	8.9-10.3	9.66	0.70
S12M1	11.7-12.4	11.97	0.37	14.6-20	17.23	2.70	60.9-64.1	62.53	1.65	5.1-12.9	8.27	4.08
S12M3	11.5-13.7	12.58	1.10	14.8-16.1	15.28	0.74	60.8-62.4	61.80	0.88	5-12.9	10.35	2.15
S12M6	10.4-11.3	11.00	0.55	14.5-16.9	15.81	1.23	63.1-66.7	64.47	1.91	5.1-12.1	8.71	3.48
S24M1	10.2-11.9	11.48	0.64	15.2-23.8	18.53	4.61	54.1-58.6	57.02	2.53	10.4-14.3	12.97	2.27
S24M3	10.8-14.3	12.63	1.77	13.5-16.5	14.71	1.58	60.8-65.6	63.95	2.74	6.7-12.0	8.71	2.83
S24M6	14.4-15.9	15.11	0.73	10.7-11.5	11.17	0.45	62.7-67	65.16	2.23	7.3-10.0	8.56	1.33

** Avg = Average value and **SD = Standard deviation value, S = The soaking time, M = The molding period*

The first numerical set placed after the abbreviated S instant for the duration time of soaked shredded paper with tap water.

The second numerical set placed after the abbreviated M instant for the molding period of casting of the paper pulp into products.

oven, the samples were placed in a desiccator and allowed to cool to room temperature for about 3 h. The masses of the dried products were measured. One sample from each treatment was selected for measurement of the proximate properties. The methods to determine the proximate properties, including tensile stress, according to ASTM standards methods are shown in Table 1. Figure 7 shows a sample of the dried paperboard briquette product.

Determination of Properties of Wastepaper, Paper Pulp, and Paperboard Briquettes.

Shredded A4-wastepaper was used as raw material for making paper pulp. The resulting samples were used to measure the proximate properties (moisture content, ash, volatile solid, and fixed solid) according to ASTM standards methods, as shown in Table 1. Additionally proximate analyses of the paper pulp used for producing the briquettes were conducted. Proximate analyses were also done for the briquettes produced in this study. These results are shown in Table 5. The densities and tensile stresses of the briquettes, determined according to ASTM standards methods, are presented in Table 6.

Figure 7. A digital image of dried paper-board briquette product sample

Table 6. Bulk Density and Tensile stress of briquette products

Products	Bulk Density (g/L)			Tensile Stress (MPa)		
	Range	Avg*	SD**	Range	Avg*	SD**
S1M1	435.51-437.45	436.34	1.00	0.67-1.01	1.13	0.43
S1M3	431.73-443.21	436.22	6.13	1.02-2.02	1.36	0.57
S1M6	435.87-439.39	438.11	1.95	1.10-1.96	1.50	0.43
S3M1	443.11-445.46	443.95	1.31	1.64-2.30	1.93	0.34
S3M3	440.05-443.98	442.21	1.99	1.02-1.99	1.51	0.49
S3M6	438.47-442.25	442.52	0.91	1.07-2.01	1.40	0.53
S6M1	440-442.19	440.92	1.14	0.98-1.71	1.27	0.39
S6M3	440.05-441.74	440.99	0.86	0.95-1.56	1.24	0.31
S6M6	439.39-442.91	440.71	1.91	0.96-1.42	1.23	0.24
S12M1	429.49-445.16	436.51	7.96	0.94-1.82	1.28	0.47
S12M3	435.-77-439.39	437.99	1.95	1.02-1.99	1.35	0.55
S12M6	441.07-443.98	442.14	0.81	1.01-1.97	1.57	0.50
S24M1	439.13-440.41	439.90	0.67	1.01-1.07	1.14	0.18
S24M3	437.3-440.87	439.03	1.79	1.02-1.15	1.11	0.08
S24M6	438.47-440.87	439.57	1.21	1.07-1.52	1.23	0.25

** Avg = Average value and **SD = Standard deviation value, S = The soaking time, M = The molding period*

The first numerical set placed after the abbreviated S instant for the duration time of soaked shredded paper with tap water.

The second numerical set placed after the abbreviated M instant for the molding period of casting of the paper pulp into products.

Moisture Content

The masses of the test pieces (m_1) were determined and then dried in a hot air oven at 103±2°C over night according to ASTM standards methods (Table 1). The test pieces were cooled to room temperature, and then the mass of each dried test piece (m_0) was determined. The moisture content of the test pieces was calculated using Equation 1.

$$\text{Moisture content: } \% = \left[\frac{m_1 - m_o}{m_1}\right] * 100 \quad (1)$$

where, m_0 = mass (g) of the test piece after being heated

m_1 = mass (g) of the original test piece

Ash

Crucibles with their covers were placed in a muffle furnace and heated to 525±25°C for 30-60 min according to ASTM standards methods (Table 1). After heating, they were allowed to cool slightly and then placed in a desiccator. All crucibles were cooled to room temperature in the desiccator. The mass of each crucible was determined (B). The weighed crucibles were filled with a paper pulp sample of about 1 g. Then the mass of each crucible plus the original specimen sample (C) was measured. The weighed crucibles were placed with their covers in the muffle furnace at 525±25°C for 30-60 min. After heating, the crucibles were removed from the muffle furnace and allowed to cool slightly and then placed in a desiccator. After all the crucibles were cooled to room temperature, the mass of each crucible plus the specimen sample (D) was determined. The ash content of each specimen was calculated according to Equation 2:

$$\text{Ash } (\%) = \left[\frac{D-B}{C-B}\right] * 100 \quad (2)$$

where, B = mass (g) of each ignited crucible

C = mass (g) of each ignited crucible plus the original specimen sample

D = mass (g) of each ignited crucible plus the ashes of the specimen sample

Volatile Matter

The crucibles with their covers were placed in a muffle furnace and heated to 950±25°C for 7 min ±10 sec according to ASTM standards methods (Table 1). After heating, the crucibles were allowed to cool slightly. Following this, they were placed in a desiccator. All crucibles were cooled to room temperature, and then the mass of each crucible was determined (B). The crucibles were filled with 1 g of sample and then weighed to arrive at a mass for each crucible plus the original sample (C). The crucibles with their covers were heated at 950±25°C for 7 min ±10 sec. After heating, the crucibles were allowed to cool slightly and then placed in a desiccator where they cooled to room temperature. The mass of each crucible plus the de-volatized matter of the sample (D) was measured. The volatile matter of each sample was calculated according to the following Equation 3:

$$\text{Volatile matter } (\%) = \left[\frac{C-D}{C-B}\right] * 100 \quad (3)$$

where, B = mass (g) of each ignited crucible

C = mass (g) of each ignited crucible plus the original specimen sample

D = mass (g) of each ignited crucible plus the de-volatilized specimen sample

Fixed Carbon

The fixed carbon of the specimen sample was calculated by difference according to ASTM standards methods (Table 1) as follows in Equation 4:

$$\text{Fixed Carbon } (\%) = 100 - \text{Ash} - \text{Volatile Matter} \quad (4)$$

where, Ash = ash content (%) in each specimen sample

Volatile matter = volatile matter (%) in each specimen sample

Bulk Density

The lengths, widths, and thicknesses of each test piece were measured at 3 points according to ASTM standards methods (Table 1) as shown in Figure 8. The mean values of the length, width, and also thickness of each test piece was determined. The mass of each dried test piece was determined. The bulk density of the test pieces was calculated according to ASTM standards methods (Table 1) as the following Equation 5:

$$\text{Bulk density (g/cubic mm)} = \left[\frac{m_1}{l * w * t}\right] \quad (5)$$

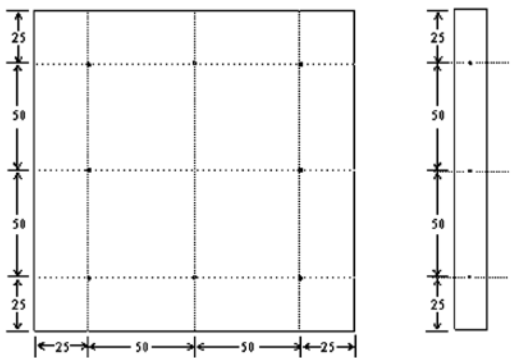
where, m_1 = mass (g) of the specimen sample after being heated
l = mean value of length (mm) of the specimen sample after being heated
w = mean value of width (mm) of the specimen sample after being heated
t = mean value of thickness (mm) of the specimen sample after being heated

Tensile Stress

Test pieces were cut into 9 sections as shown in Figures 8 and 9. The lengths and widths of sections #1, #3, #5, #7, and #9 were measured. Selected samples were place into position to test the tensile stress according to ASTM standards methods (Table 1) with an Instron Universal Testing Machine as shown in Figure 10. The instrument was set to determine the tensile stress at a sample's failure. When the test piece was broken, the maximum tensile stress used was recorded. The tensile stress of each section was calculated according to Equation 6. The average values of the tensile stresses were also determined and are shown in Table 6.

$$\text{Tensile Stress (MPa)} = \left[\frac{P_{max}}{b * l}\right] \quad (6)$$

where, Pmax = maximum tensile force (N)
b = width (mm) of test section of the test pieces
l = thickness (mm) of test section of the test pieces



(a) (b)

Figure 8. Points at which lengths, widths and thicknesses (mm) of test pieces were measured (a) Planview (b) Side view

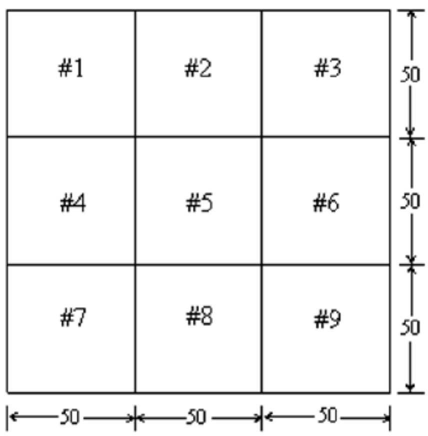


Figure 9. Selected sections for deter-mination of testing tensile stress of specimen sample. Dimensions are in mm

Results and Discussion

Characterisation of Wastepaper and Paper Pulp

Wastepaper in this study had proximate properties in the ranges of 2.7-4.9%, 10.3-13.0%, 51.3-55.0%, and 29.3-31.6% for moisture content, ash content, volatile matter, and fixed carbon, respectively. Paper pulp produced in this study had proximate properties ranging from 20.4-25.5%, 13.2-16.0%, 40.7-44.4%, and 18.3-23.2% for moisture content, ash content, volatile matter, and fixed carbon, respectively. These results are shown in Table 3.

The results showed that the moisture contents of the paper pulp produced for all molding times increased due to water absorption into the shredded material. However, both the volatile matter and fixed carbon of those materials decreased, as shown in Table 3.

Characterisation of Paperboard Briquette Products at Constant Molding Periods (1, 3, and 6 h) and Varyied Soaking Times (1, 3, 6, 12, and 24 h)

The proximate properties of the paperboard briquette products are shown in Table 5. The densities and tensile stresses of these products are shown in Table 6.

All samples of the paperboard briquette had moisture contents much less than those of the paper pulps (20.4-25.5%) from which they were produced. This is a result of the pressure loading of the samples with a 50-kN hydraulic press. Thus, water was pressed from the paper pulp samples.

The molding times of 1, 3, and 6 h were each examined for each of the 1, 3, 6, 12, and 24 h soaking times. For all molding times, it was found that the briquette products exhibited the highest densities, tensile stresses at failure, fixed solids content, and lowest moisture contents with the soaking time of 3 h. These results are shown graphically in Figures 11-13 and in tabular form in Tables 5 and 6. Also these results are consistent with those reported earlier (Sophon, 2003).

Effects of Both the Soaking Times and Molding Periods on the Properties of Paperboard Briquette Products

Figure 14 compares the properties of S3M1, S3M3, and S3M6 products. It was

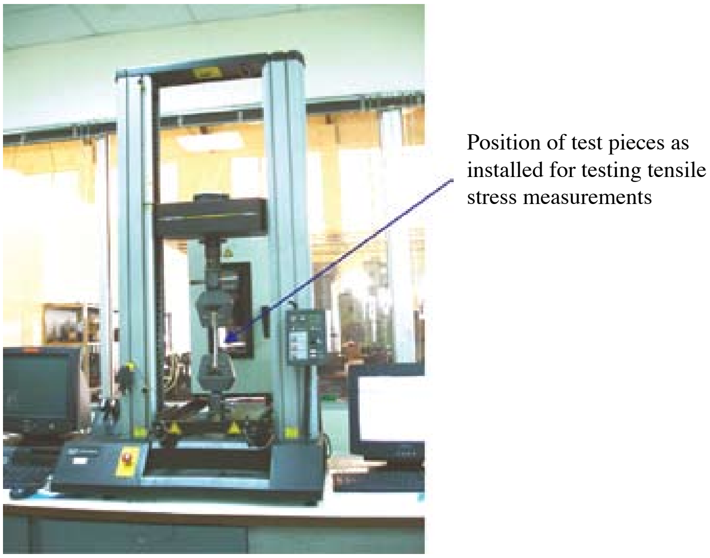
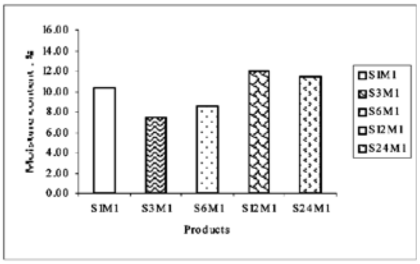
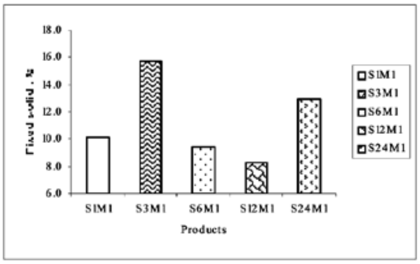


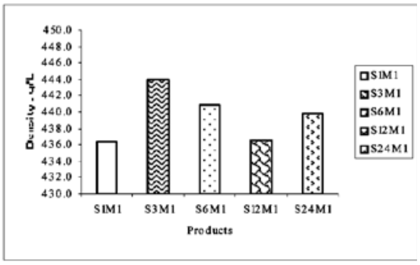
Figure 10. An Instron Universal Testing Machine for determination of tensile stress of test pieces



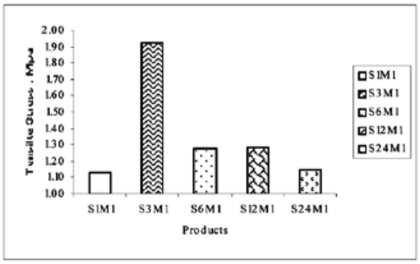
(a)



(b)

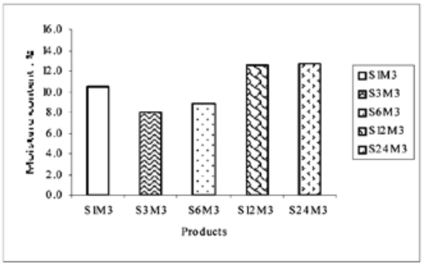


(c)

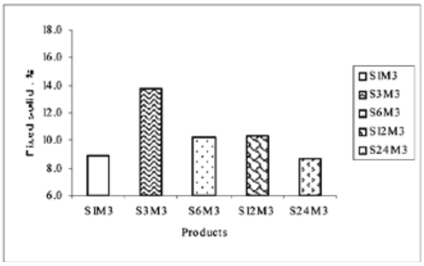


(d)

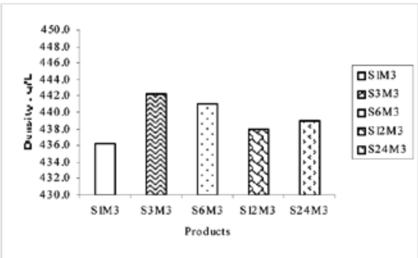
Figure 11. Characterisation of paperboard briquette products at a constant molding period 1 h and varied soaking time (1, 3, 6, 12, and 24 h). (a) Moisture Content (b) Fixed Carbon (c) Bulk Density (d) Tensile Stress



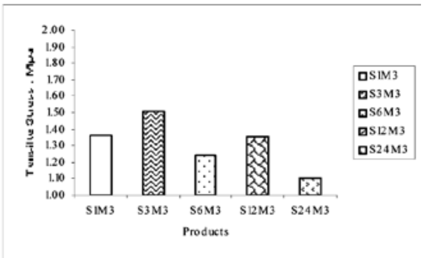
(a)



(b)



(c)



(d)

Figure 12. Characterisation of paperboard briquette products at a constant molding period 3 h and varied soaking time (1, 3, 6, 12, and 24 h). (a) Moisture Content (b) Fixed Carbon (c) Bulk Density (d) Tensile Stress

found that the moisture content of the products was gradually increased from 7.42% to 9.42% with increasing the molding time. This is shown in Figure 14(a). The fixed carbon levels of the products decreased from 15.77% to12.23% as the molding times were increased from 1 to 6 h. This is shown in Figure 14(b). The density of the products decreased slightly from 443.95 g/L to 442.52 g/L with increasing the molding time, as shown in Figure 14(c). Lastly, the tensile stresses of the products decreased from 1.93 MPa to 1.40 MPa, as shown in Figure 14(d). The product S3M1 had the lowest moisture content (7.42%), as shown in Figure 14(a). However, it had the highest fixed carbon (15.77%), the highest density (443.95 g/L), and the highest tensile stress at failure (1.93 MPa) of the samples with 3 h soaking times. So we can conclude that products made from paper pulp with 3 h of soaking time followed by 1 h of molding time had the best properties for the production of paperboard briquettes. In other words, they exhibited the lowest moisture contents, and the highest values for fixed carbon, density, and tensile stress.

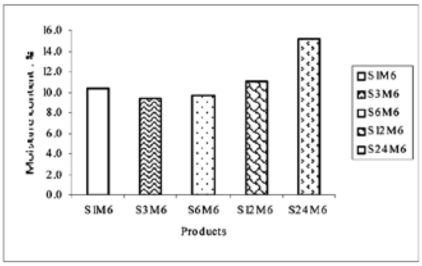
Conclusions

The findings of the study provide substantial support for the production of paperboard briquette products from A4-wastepaper using no binder and using a hydraulic compression machine with a pressure of 2.2 MPa.

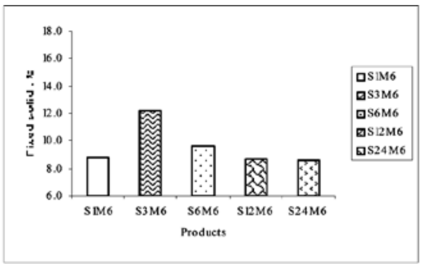
Results indicated that the S3M1 products, i.e. those made with 3 h of soaking time and 1 h of molding time exhibited the most favorable properties. They showed the lowest moisture content (7.42%), and the highest values for fixed carbon (15.77%), density (443.95 g/L), and tensile stress (1.93 MPa).

Acknowledgements

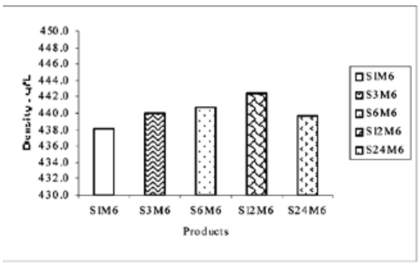
We would like to gratefully acknowledge support of this work by the Institute of Research and Development of Suranaree University of Technology, Nakhon Rachasima,



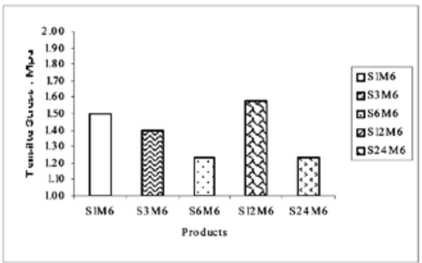
(a)



(b)

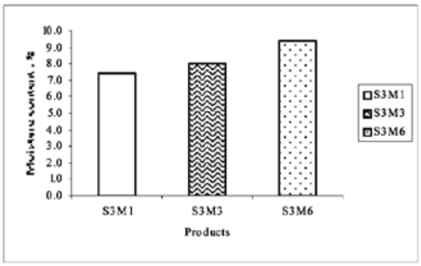


(c)

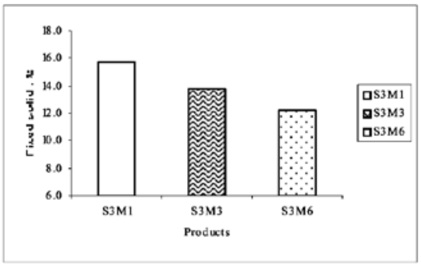


(d)

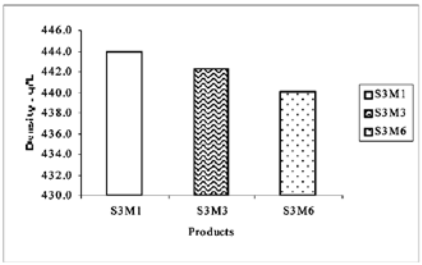
Figure 13. Characterisation of paperboard briquette products at a constant molding period 6 h and varied soaking time (1, 3, 6, 12, and 24 h).
(a) Moisture Content (b) Fixed Carbon (c) Bulk Density (d) Tensile Stress



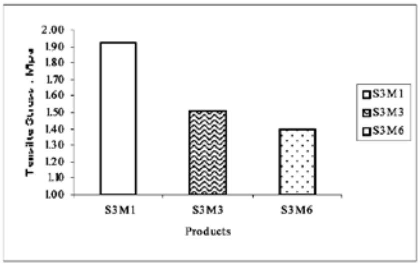
(a)



(b)



(c)



(d)

Figure 14. Comparison properties of paperboard briquette products (S3M1, S3M3, and S3M6). (a) Moisture Content (b) Fixed Carbon (c) Bulk Density (d) Tensile Stress

Thailand. The University generously provided financial support, use of equipment, and a valuable scholarship from the National Science and Technology Development Agency (NSTDA). Finally, the corresponding author would like to express his great appreciation to Assistant Professor Dr. Sompop Sanongraj, his advisor at the Ubon Rachathani University, Ubon Rachathani, Thailand, for giving his valuable guidance in this research.

References

Abad, S., Santo, V., and Parajó, J.C. (2000). Formic acid-peroxyformic acid pulping of aspen wood: an optimization study. Holzforschung., 54(5): 544-552.

Akkarakultron, P. (1996). The status of usage of waste paper in Thailand and its evaluation in the future [Msc. Thesis]. Department of Environmental Technology, School of Energy and Materials, King Mongkut's Institute of Technology of Thonburi, Bangkok, Thailand, 102p.

ASTM. (1997). Annual Book of ASTM Standards. Standard Practice for Proximate Analysis of Coal and Coke D3172-89. ASTM International, West Conshohocken, PA, USA, p. 300-302.

ASTM. (1998). Annual Book of ASTM Standards. Standard Test Method for Tensile Properties of Paper and Paperboard Using Constant-Rate-Elongation Apparatus D828-93. ASTM International, West Conshohocken, PA, USA, p. 102-108.

ASTM. (1998). Annual Book of ASTM Standards. Standard Test Method for Moisture Content of Paper and Paperboard by Oven-Drying D644-94. ASTM International, West Conshohocken, PA, USA, p. 32-33.

ASTM. (1998). Annual Book of ASTM Standards. Standard Test Method for Ash in Pulp, Paper and Paperboard D586-96. ASTM International, West Conshohocken, PA, USA, p. 11-13.

ASTM. (1998). Annual Book of ASTM Standards. Standard Test Method for Volatile Matter in the Analysis Sample of Coal and Coke D3175-89a-97. ASTM International, West Conshohocken, PA, USA, p. 306-308.

ASTM. (1998). Annual Book of ASTM Standards. Standard Test Method for Thickness of Paper and Paperboard D645/D645M-96. ASTM International, West Conshohocken, PA, USA, p. 34-36.

ASTM. (2010). Annual Book of ASTM Standards. Standard Test Method for Bulk Density by

Physical Measurement of Manufactured Carbon and Graphite Articles C559-90. ASTM International, West Conshohocken, PA, USA, p. 1-2.

Kercher, A.A. and Nagle, D.C. (2003). Monolithic activated carbon sheets from carbonized medium-density fiberboard. Carbon., 41:3-13.

Khezami, L., Ould-Dris, A., and Capart, R. (2007). Activated carbon from thermo-compressed wood and other lignocellulosic precursors. Bioresources., 2(2):193-209.

Littrell, K.C., Khalili, N.R., Campbell, M. Sandi, G., and Thiyagarajan, P. (2000). Structure characterization of activated carbon adsorbents prepared from paper mill sludge. Chem. Mater., 14(1):327-333.

Loloon, K., Sudajan, S., and Chusil, S. (2008). An efficiency improvement on bio-coal in household industry, Agricultural Sci. J., 39(3):461-464.

Malikov, I.N., Noskova, Y.A., Karaseva, M.S., and Perederii, M.A. (2007). Granulated sorbents from wood waste. Solid Fuel Chem., 41(2):100-106.

Masahiro, S., Iida, T., Kawarada, K., Chiba, Y., Mamoto, T., and Okayama, T. (2004). Pore structure and adsorption properties of activated carbon prepared from granular molded waste paper. J. Mater Cycles Waste, 6:111-118.

Müller, K. (2000). Reports and reviews: report: low-and-non-waste technology: theory and practice. Waste Manage. Res., 4(1):226-228.

Nakagawa, Y., Molina-Sabio, M., and Rodríguez-Reinoso, F. (2007). Modification of the porous structure along the preparation of activated carbon monoliths with H_3PO_4 and $ZnCl_2$. Micropor. Mesopor. Mat., 103:29-34.

Sophon, V., (2003). Sound absorption properties of particle board from recycled papers, [ME. Thesis], Department of Civil Engineering, Faculty of Engineering, Mahanakorn University of Technology, Bangkok, Thailand, 71p.

Sriswang, K. (2002). A study for recycling of solid waste in Suranaree University of Technology [ME. Thesis]. School of Environmental Engineering, Institute of Engineering, Suranaree University of Technology, Nakhon Rachasima, Thailand, 128p.

Thaemngoen, C., Sungwornpatansakul, W., and Asavapisit, S. (2003). The potential for utilization of bagasse and eucalyptus pulp sludges from wastewater treatment plants of the pulp industries to produce fiber-cement composites. Suranaree J. Sci. Technol., 11:125-131.

Umnoi, N. (1997). Feasibility of recycling papers: a case study at Salaya Sanitation Area, Phutamonthon District, Nakhon Pathom Province, Thailand, [MSc. Thesis]. Department of Appropriate Technolgy for Resources and Environment Development, Faculty of Environment and Resource Studies, Mahidol University, Nakhon Pathom, Thailand, 110p.

Uradei, Y., Taniwatashi, R., and Kubo, S. (2000). Activated carbon sheet prepared from softwood acetic acid lignin. J. Wood Sci., 46:52-58.

Usaborisut, P. and Mahayosanun, T. (2005). Study on briquetting cassava stump coal using manual hydraulic pressing machine. Engineering Journal Kasetsart, 19(56):32-40.

Yorgun, S., Vural, N., and Demiral, H. (2009). Preparation of high-surface-area activated carbons from paulownia wood by ZnCl2 Activation. Micropor. Mesopor. Mat., 122:189-194.