The Role of Recycled Waste Polystyrene Foam on Physical and Mechanical Properties of Novel Ceiling Boards

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Abstract

Novel Ceiling boards were prepared from bagasses (BG) and expanded polystyrene foam (EPS) waste. Urea-formaldehyde and Phenol-formaldehyde at 15% were used as binders, with curing time at 15 minutes. Ratios of BG/EPS, EPS sizes, board densities and effect of EPS in board were investigated. The results indicated that properties of ceiling boards mixed with Phenol formaldehyde (PF) were better than Urea-formaldehyde (UF) for water absorption resistance, thickness swelling resistance and bending strength. Water absorption and thickness swelling decreased with decreasing the amount of Bagasse and size of EPS. On the other hand, bending strength increasing depending on the amount of EPS and board density.

Keywords: Ceiling boards, Expanded polystyrene foam, Binder

1. Introduction

Man-made materials from agricultural lignocellulosic fiber residues such as particleboard, plywood, medium density fiber board (MDF), etc. [1-6] were used as construction materials. Raw materials including bagasses (BG), rice straw, etc. can be easily crushed to chips or particles. Expanded polystyrene foams (EPS) have stimulated high demands in many applications e.g. packaging, cushioning and insulation, due to their low cost, light weight, ease of application and fabrication. Low thermal conductivity, consumer appeal, and mechanical properties such as compressive properties are also factors attracting such high demands. Total worldwide EPS consumption during year 2000 was estimated at around 2,570,000 tons. [7] However, it is difficult to degrade such material, resulting in a small amount being recycled. This will consequently lead to environmental pollution.

The role of recycled expanded polystyrene foam on physical and mechanical properties of ceiling boards made from bagasses is the aim of this study. Such boards can be used as a substitute for gypsum boards. The advantages of these ceiling boards are to reduce agricultural wastes and polystyrene foam waste left in the environment.

2. Methodology of Experiment

2.1 Raw Materials

2.1.1 Raw bagasses (BG) of *The Cholburi Sugar Corporation Ltd.* were ground and screened into size of 20-35 mesh by a grinding machine and sieve apparatus. (mesh = number of small holes between the threads in one square inch)

2.1.2 Expanded polystyrene foam (EPS) from packaging and cushioning was collected, ground and screened into 3 groups.

- EPS diameter of 2-3 mm
- EPS mixed size : Mixture of 25% of diameter of less than 2 mm, 35% diameter of 2-3 mm, 39% of diameter of 3-6 mm and 1% diameter of more than 6 mm.
- EPS diameter of 3-6 mm

2.1.3 Urea-formaldehyde resin (UF)

Appearance	Light brownish powder
Trade name	Weldwood®
Product of	DAP INCORPORATION ; USA

2.1.4 Phenol-formaldehyde resin (PF)

Appearance	Reddish liquid
%Solid content (105 °C x 3 hrs.)	45.23
Specific gravity (25 °C)	1.204
pH	13.81
Viscosity (25 °C ; Brookfield, cps)	97
Product of	TOA-DOVECHEM INDUSTRIES CO.,LTD.

2.1.5. Distilled water

2.2 Apparatus

For Ceiling board Process

2.2.1 Grinding machine : Hammer mill type of Bosco Engineering Co.,Ltd.

2.2.2. Sieve machine : Vibration type of RETSCH ®

2.2.3 Paddle-type blender : Heavy duty drill press, model SE-330B of REXON ®

2.2.4 Compression machine : Model 20 x 20 x 7, No. 27-1-92 of Chaijaroern Karnchang Factory, Bangkok

2.2.5 Blending container

2.2.6 Mat forming apparatus : Composted of steel caul sheets (46 cm x 46 cm x 0.3 cm), forming frame (30 cm x 30 cm x 0.9 cm) and forming box (30 cm x 30 cm x 30 cm)

2.2.7 Oven : Model UM 400 of MEMERT®

For Specimen Testing

2.2.8 Universal testing machine : LR 5K of LLOYD Instruments ®

2.2.9 Balance : Model TP-6101 of Denver Instrument Company

2.2.10 Micrometer

2.2.11 Plastic container

Process of Preparation Ceiling Board

Screened BG were dried at 103 °C for 24 hrs or until their moisture content remained in the range of 3-6%. EPS were milled one time by grinding machine. Both BG and EPS were blended by *Paddle-type blender*. Then, adhesive was gradually added into the particles. Adhesive urea-formaldehyde was prepared in liquid form by dissolving with distilled water, UF/water 60/40 by weight. Phenol- formaldehyde was used as received.

Mixture of Bagasses and EPS was poured in the forming box placed over the forming frame (mold). Next, the forming box was removed. Finally, the formed mat was covered by an upper steel sheet and transferred to prepressing. The formed mat was consolidated into a rigid cake with cold press three times by the compression machine in order to reduce their thickness.

Finally, the mat was pressed at 100 °C by the compression machine for 10 minutes. The boards were conditioned in a conditioning room for 1 week at room temperature in order to be completely cured. Boards were sawed and trimmed into specific dimension for further testing.

2.3 Study of Interesting Parameters

2.3.1 Study of Ratios of BG to EPS

Table 1 Summary of samples based on various ratios of BG/EPS.

Items	**Samples**					
	1	**2**	**3**	**4**	**5**	**6**
<u>**BG/EPS ratios**</u> <u>(wt/wt)</u>						
BG (20-35 mesh)/EPS	95/5	90/10	85/15	95/5	90/10	85/15
<u>**Adhesives**</u>						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target density (g/cm^3)	0.6	0.6	0.6	0.6	0.6	0.6

2.3.2 Study of EPS Sizes

Based on the results of previous steps, the ratios of BG/EPS at 85/15 by weight (wt/wt) were chosen for studying EPS sizes. Other conditions are shown in Table 2.

Table 2 Summary of samples based on selected EPS sizes.

Items	Samples					
	3	7	8	6	9	10
BG/EPS ratio (wt/wt)						
BG (20-35 mesh)/EPS (2-3 mm)	85/15	-	-	85/15	-	-
BG (20-35 mesh)/EPS (mixed size)	-	85/15	-	-	85/15	-
BG (20-35 mesh)/EPS (3-6 mm)	-	-	85/15	-	-	85/15
Adhesives						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target density (g/cm^3)	0.6	0.6	0.6	0.6	0.6	0.6

2.3.3 Study of Board Density

Boards which had densities of 0.1, 0.3 and 0.6 g/cm^3 were studied by using the same condition as previous step. Other conditions are shown in Table 3.

Table 3 Summary of samples at different densities.

Items	Samples					
	11	12	7	13	14	9
BG/EPS ratio (wt/wt)						
BG (20-35 mesh)/EPS (mixed size)	85/15	85/15	85/15	85/15	85/15	85/15
Adhesives						
%UF (of dry particle weight)	15	15	15	-	-	-
%PF (of dry particle weight)	-	-	-	15	15	15
Target densities (g/cm^3)	0.1	0.3	0.6	0.1	0.3	0.6

2.4 Test Methods

2.4.1 Bulk Density (JIS A 5908-1994)

The test pieces were measured, including the lengths, widths and thicknesses, at the points as shown in Figure 1. After that their respective mean values were calculated. The volume (V) was calculated from the above mean values. Then the mass (m) was weighed. The bulk density was calculated as the equation (1). In this case, the thickness, length, width and mass was measured to the nearest of 0.05 mm, 0.1 mm, 0.1 mm and 0.1 g respectively. The bulk density was calculated to the nearest 0.01 g/cm^3. The number of test pieces were at least five.

$$\text{Bulk Density (g/cm}^3\text{)} = \frac{m}{V} \qquad (1)$$

Where m : mass (g)
V : volume (cm^3)

2.4.2 Water Absorption (TIS 876-2532)

The water soak test determined the water absorption behavior of the particleboards. The mass (m_1) of the test pieces were preliminarily weighed. After 24 hours of submersion in water at 20 ± 1 °C, horizontally about 3 cm below the water surface, the test pieces were weighed after the excess water was drained off (m_2). The number of test pieces was at least ten. The following calculation can then be made:

Water absorption (%)

$$= \frac{(m_2 - m_1)x100}{m_1} \qquad (2)$$

where m_1 : mass (g) before water absorption

m_2 : mass (g) after water absorption

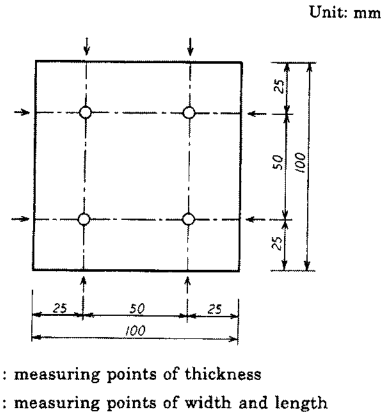

Figure 1 Points to be measured of lengths, widths and thicknesses

2.4.3 Thickness Swelling (JIS A 5908-1994)

The water soak test determined not only the water absorption behavior of the particleboards but also the effects of the absorbed water on particleboards dimensions. The thickness (t_1) of the test pieces were preliminarily measured at four points midway along each side at 25 mm. After 24 hours of submersion in water at 20 ± 1 °C, horizontally about 3 cm below the water surface, the thickness of test pieces were measured at the same four points and the average was obtained. Thickness swelling was calculated from the equation below. The number of test pieces were at least ten.

Thickness swelling (%)

$$= \left(\frac{t_2 - t_1}{t_1} \right) x100 \qquad (3)$$

where

t_1 : thickness (mm) before water absorption

t_2 : thickness (mm) after water absorption

2.4.4 Bending Strength (Modulus of Rupture, MOR and Modulus of Elasticity, MOE) (JIS A 5908-1994)

Bending strength was measured by using the apparatus as shown in Figure 2. The loading bar was moved with a crosshead speed of 10 mm/min at a mean deformation speed on the surface of the test pieces. Modulus of Rupture (MOR) was calculated from the maximum load (P) as equation 4 below. The number of test pieces were at least seven.

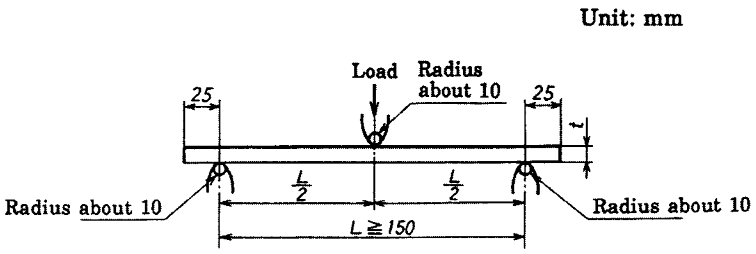

Figure 2 Test apparatus for bending strength

$$\text{MOR (MPa)} = \frac{3PL}{2Bt^2} \qquad (4)$$

where

P : maximum load (N)

L : span (mm)

B : width of test piece (mm)

t : thickness of test piece (mm)

Modulus of Elasticity (MOE) was calculated from the graph, which plotted between maximum load (P) and deformation distance of test pieces. The obtained value of such maximum load (P) and deformation distance were measured. MOE was calculated from equation 5 as below:

$$\text{MOE (MPa)} = \frac{L^3 \Delta W}{4bt^3 \Delta S} \qquad (5)$$

where

L : span (mm)

ΔW : increasing load in the range of linear line of graph (N)

ΔS : increasing bending distance in the range of linear line of graph (mm)

b : width of test piece (mm)

t : thickness of test piece (mm)

3. Experimental Results

3.1 Effect of Ratios of BG to EPS

Mechanical and physical properties of samples 1-6 are given in Table 4.

Table 4 Properties of boards with various ratios of BG/EPS

Properties		Samples 1	2	3	4	5	6
		95/5, UF	**90/10, UF**	**85/15, UF**	**95/5, PF**	**90/10, PF**	**85/15, PF**
Board density (g/cm^3)		0.62	0.63	0.63	0.62	0.60	0.61
Bending	**MOR** (MPa)	5.13	5.60	6.71	7.08	8.38	9.22
	MOE (MPa)	455.94	483.93	520.05	540.11	587.56	640.04
Water absorption 24 hrs (%)		105.80	92.50	70.20	74.30	68.10	50.50
Thickness swelling 24 hrs (%)		14.60	13.90	11.50	7.90	6.80	5.80

3.1.1 Water Absorption

The effect of BG/EPS ratios on water absorption is shown in Figure 3. The highest water absorption was found at a BG/EPS ratio of 95/5 wt/wt. Whereas a BG/EPS ratio of 85/15 wt/wt, showed the lowest the water absorption. This means that water absorption varied with the amount of BG, which is a cellulose composed of hydroxyl groups. Normally, hydroxyl groups can easily absorb the water and thus, when the amount of BG increased, the water absorption also increased as well. In contrast, EPS is a hydrocarbon polymer which could not absorb water; consequently, water absorption was inversely affected by the amount of EPS.

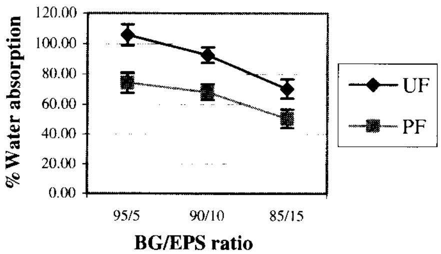

Figure 3 %Water absorption vs BG/EPS ratios

With regard to water absorption, UF boards were higher than PF boards. The adhesion of UF resins to cellulose is sensitive to water. Not only the nitrogen of amide groups[-NH-C(O)-] can be split rather easily by water attack in UF resin but, also theoretical calculations have shown that the average adhesion of water to cellulose is stronger. The inverse effect is valid for PF resin which shows complete resistance to hydrolysis of the C-C bonds between the aromatic nucleus and the methylene bridges [8]. For those reasons, water absorption of UF boards was higher than that of PF boards.

3.1.2 Thickness Swelling

Figure 4 shows the relationship between thickness swelling and BG/EPS ratio after soaking boards in water at room temperature at various BG/EPS ratios. In this graph, a BG/EPS ratio of 95/5 wt/wt gave the highest thickness swelling. On the other hand, a BG/EPS ratio of 85/15 wt/wt gave the lowest. The results suggested that thickness swelling varied with the amount of BG as well as water absorption. It was found that thickness swelling of UF boards was higher than that of PF boards. As previously described, thickness swelling depends on bond qualities and adhesive properties [4]. Thus, the weaker bond of UF boards resulted in the higher thickness swelling.

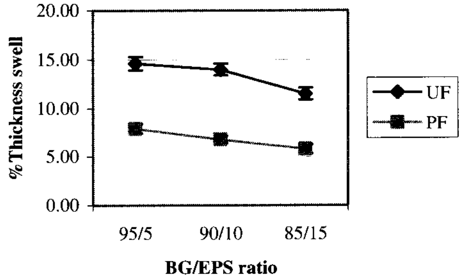

Figure 4 % Thickness swelling vs BG/EPS ratios

3.1.3 MOR and MOE

The relationship between MOR and various BG/EPS ratios is shown in Figure 5. The results showed that a BG/EPS ratio of 85/15 wt/wt yielded the highest MOR, while a BG/EPS ratio of 95/5 wt/wt yielded the lowest MOR. This is probably because the dispersion of adhesives is shown well by substituting of EPS, as shown in Figure 7. In contrast, this incident did not exist in 100% BG (in the absence of EPS) as shown in Figure 6. Since EPS is a nonpolar polymer, it contributed electrostatically during the blending process. Moreover, the agglomeration of BG with adhesives in BG/EPS ratio of 85/15 wt/wt was less than that of BG/EPS ratio of 95/5 wt/wt. So the higher the amount of EPS, the better the dispersion of the mixture. Consequently, MOR of the higher amount of EPS showed higher dispersion than that of the lower amount of EPS. In comparing MOR of PF boards and UF boards, the results showed that the first type of boards expressed higher MOR

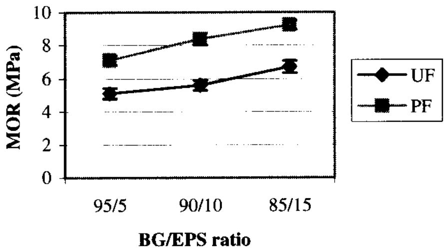

Figure 5 MOR (Modulus of Rupture) vs BG/EPS ratios

than the second type of boards. Because the bond strength of PF boards was higher than that of UF boards, they could absorb and well dissipate applied force.

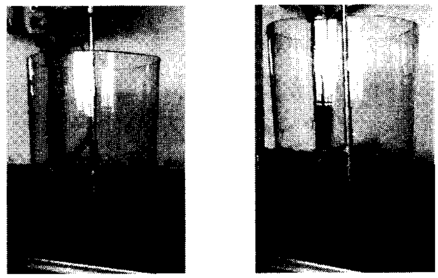

Figure 6 Illustrates BG in blending container (a) before stirring and adding adhesive, (b) after stirring and adding adhesive

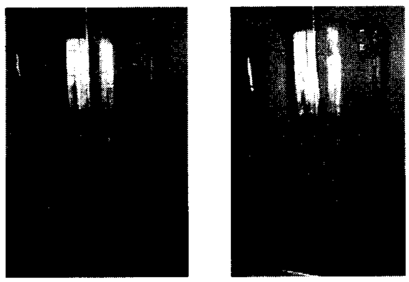

Figure 7 Illustrates the mixture of BG and EPS in blending container. (a) before stirring and adding adhesive, (b) after stirring and adding adhesive

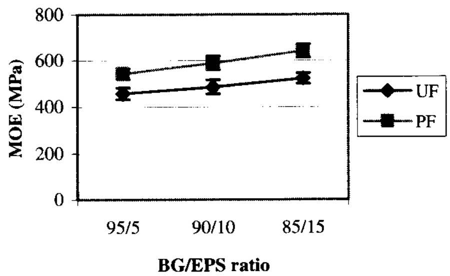

Figure 8 MOE (Modulus of Elasticity) vs BG/EPS ratios

Figure 8 shows MOE against various BG/EPS ratios. MOE showed a similar trend as MOR, that is, MOE increased by increasing the amount of EPS. Besides, this MOE of PF boards was higher than that of UF boards.

3.2 Effect of EPS Sizes on MOR and MOE

The results of different sizes of EPS are given in Table 5.

Table 5 Properties of particleboards with various sizes of EPS

Properties		Samples					
		3	7	8	6	9	10
		2-3 mm, UF	Mixed size, UF	3-6 mm, UF	2-3 mm, PF	Mixed size, PF	3-6 mm, PF
Board density (g/cm^3)		0.63	0.62	0.60	0.61	0.61	0.62
Bending	MOR(MPa)	6.71	7.05	6.27	9.22	9.70	9.83
	MOE(MPa)	520.05	531.11	498.43	640.04	633.05	601.56
Water absorption 24 hrs (%)		70.20	73.30	74.50	50.50	48.00	55.20
Thickness swelling 24 hrs (%)		11.50	11.10	10.10	5.80	5.60	6.1

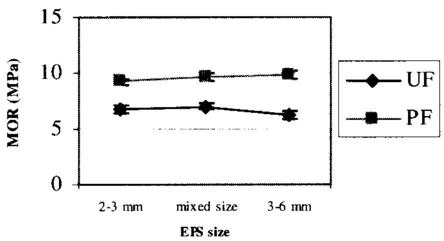

Figure 9 MOR (Modulus of Rupture) vs EPS sizes

MOR and MOE of different sizes of EPS were slightly different as shown in Figure 9 and Figure 10, respectively. Probably, this is because the amount of used EPS was the same and the sizes of EPS were not obviously different. Therefore, the ability of water absorption and applied loading force dissipation was almost the same. The results showed that MOE of PF boards was higher than that of UF boards.

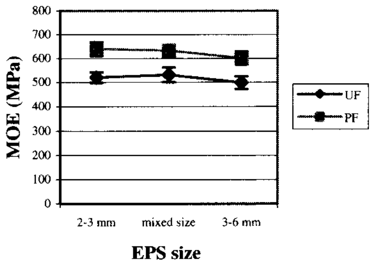

Figure 10 MOE (Modulus of Elasticity) vs EPS sizes

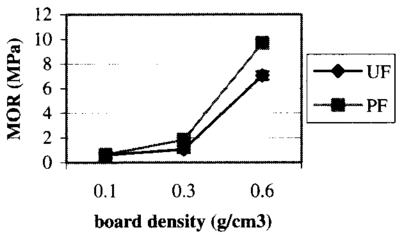

Figure 11 MOR (Modulus of Rupture) vs board densities

Table 6 Properties of boards with various boards densities

Properties		Samples					
		11	12	7	13	14	9
		0.1 g/cm^3, UF	0.3 g/cm^3, UF	0.6 g/cm^3, UF	0.1 g/cm^3, PF	0.3 g/cm^3, PF	0.6 g/cm^3, PF
Board density (g/cm^3)		0.11	0.33	0.62	0.12	0.33	0.61
Bending	**MOR(MPa)**	0.61	1.06	7.05	0.63	1.84	9.70
	MOE(MPa)	5.48	88.39	531.11	6.84	13725	633.05
Water absorption 24 hrs (%)		382.20	161.60	73.3	318.90	141.9	84.00
Thickness swelling 24 hrs (%)		1.40	5.6	11.10	1.10	4.00	5.60

Board density is a powerful factor affecting board properties. In most cases, an increase in board density results in a concomitant improvement in physical properties [9]. As mentioned before, the increased board density resulted in more intimate contact between the particles in the material being compressed into the final board. So when loading was applied, the high density boards had higher loading dissipation than the low density boards which showed in MOR and MOE, Figure 11 and 12, respectively.

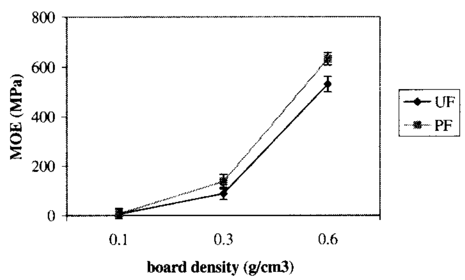

Figure 12 MOE (Modulus of Elasticity) vs board densities

4. Conclusions

Effects of several parameters on physical and mechanical properties of boards made from bagasses (BG) and expanded polystyrene foam (EPS) waste were investigated. It was found that PF boards had better water absorption resistance, thickness swelling resistance and bending strength than UF boards. Thickness swelling decreased when the amount of BG decreased, with the presence of EPS in the board. Meanwhile, bending strength increased in parallel with increasing amount of EPS, board density and with the presence of EPS. In summary, it is possible to prepare proper particleboards from the mixture of bagasses and expanded polystyrene foam waste by selecting compositions and conditions. Additionally, this new type of particleboards was suitable for making use of agriculture wastes and expanded polystyrene foam waste.

5. Acknowledgment

I would like to sincerely thank TOA-Dovechem Industries Co.,Ltd. for supplying phenol-formaldehyde resin in this study.

6. References

[1] Sarocha C., *Development of New Particleboard from Durian Peel and Coconut Coir with Low Thermal Conductivit,* Master of Engineering Degree, King Mongkut University of Technology Thonburi. 2000.

[2] Puranan A. and Udomsak P., *Particleboards from Polystyrene/Bagasses for Sound Absorptio,* Bachelor of Science Degree, King Mongkut's Institute of Technology, Ladkrabang. 2001.

[3] Sirinun W. and Supansa O., *Particleboards from Polystyrene/Bagasses for Sound Absorption,* Bachelor of Science Degree, King Mongkut's Institute of Technology Ladkrabang, 2002.

[4] Xiaoqun M., Enzhi C., Donghai W. and X.Susan S., *Physical Properties of Medium-density Wheat Straw Particleboard using Different Adhesives.* Industrial Crops and Products, Vol. 11, Issue 1, Jul. 2003, pp. 47-53.

[5] Han-Seung Y., Dae-Jun K., and Hyun-Joong K. *Rice Straw-wood Particle Composite For Sound Absorbing Wooden Construction*

Materials, Bioresource Technology, Vol. 86, Issue 2, Jan 2003, pp. 117-121.

[6] Sellers T., George D.M., and Marly J., *Lignocellulosic-Based Composites Made of Core From Kenaf, An Annual Agricultural Crop,* [Online], Available: http:/www.ersac.umn.edu/iufro/iufronet/d5/wu50501/pu50501.htm, 2004.

[7] *Worldwide EPS Consumption (Year 2000).* [Online], Available: http://www.oekutec.de/oekutec/styrelax_pres/img1.jpg, 2004.

[8] A. Pizzi and K.L. Mittal. Editor., *Handbook of Adhesive Technology*, 2^{nd} Ed., New York: Marcel Dekker, Inc., 2003.

[9] Thomas M. Maloney, *Modern Particleboard & Dry-Process Fiberboard Manufacturing*, California : Miller Freeman, 1997.