KFS Journal, Vol. 19(2), 2008: 106-110

Construction Mechanism of Reticular Structure of Plant Fiber[1]

Yongqun Xie†[2], Queju Tong[3], Yan Chen[4]

ABSTRACT

This paper investigated and validated the mechanisms and principles for constructing reticular structure of plant fiber through frothing solution approach. After process, plant fibers became low-density reticular-structured block with all properties meeting Chinese standards for cushion packing materials. The bonds between fibers acted as knots in a truss and were strong enough to keep space occupied by bubbles in the frothing solution from shrinking in the subsequent draining process. The formation of the reticular structure depends mainly on the pressure difference between inside and outside bubble, the effect of surface adsorbent force on bubble film, and hydrogen bond among fiber hydroxide.

Key words: Plant fiber, reticular structure, formation, bubble.

INTRODUCTION

White pollution resulting from intensive use of cellular plastics has brought various codes and acts into effect for limiting the use of cellular plastics in many countries. The R&D for substitute material is becoming an important issue. As traditional packing materials, plant fiber-paper products and plant fiber-starch products are not suitable as cushioning material thanks to their various shortcomings such as large specific gravity, great brittleness, low modulus of elasticity, poor resilience and buffer coefficient, pitiable impact strength, sensitive to moisture content, liable to mold and high cost (Wang and Wang 2005; Lawton et al. 1999; Shogren et al. 2002). Plant fiber, such as wood fiber and fiber from agricultural residuals, is renewable and can be obtained easily and cheaply, thus is an ideal raw material to make substitute cushioning material. Several studies (Cao and Wu 2005; Wang 2004; Dai and Dai 2004; Xie et al. 2004) have been conducted using plant fiber (e.g., bamboo fiber, bagasse fiber and wood fiber) as raw materials for making packaging material. The reticular-structured cushion material made from plant fiber discussed in this paper takes advantages of truss-like structure that integrates fibers and reinforces the material. This material is highly satisfied for its environmentally friendly characteristics, adequate physical and mechanical properties and economical viability.

Received for publication: November 19, 2007.

1) This study was supported by Fujian natural science foundation No.2006J0149.

2) Professor of the college of Material Engineering, Fujian Agriculture and Forestry University, Jinshan Road, Fuzhou, China 350002.

3) Research Scientist, Forintek Division of FPInnovations, 319 rue Franquet, Quebec, QC G1P 4R4, Canada.

4) Associate Professor, College of Material Engineering, Fujian Agriculture and Forestry University, Jinshan Road, Fuzhou, China 350002.

† Corresponding author: Yongqun Xie (Email: fafuxieyq@yahoo.com.cn).

The construction of the reticular structure of plant fiber makes use of the principle of liquid frothing (Leja 1985). When liquid froths, interspaces are created inside the solution with "extruding" effect thanks to air pressure difference between inside and outside bubble; at the same time, fiber gathers around the bubbles and forms "arches" (Wu 1991); by orienting fiber around the bubble, an effective inter-fiber bonding can be realized. This helps form a stable reticular structure with necessary physical and mechanical properties after the liquid is drained.

(1) "Extruding" effect of bubble

Under equilibrium condition, a single bubble in liquid takes the shape with the lowest system free energy, i.e., least gas/liquid interface area (approximately a sphere). The pressure difference between inside and outside bubble can be expressed as follow (Young-Laplace equation):

$$p_1 - p_2 = \gamma_{gas/liquid}\left(\frac{1}{R_1}+\frac{1}{R_2}\right)$$

Where p_1 and p_2 are pressures inside (concave side of) and outside (convex side of) a bubble, respectively, R_1 and R_2 are the curvature radii of bubble's inside and outside surface, respectively. The bubble diameter is usually very small (0.1~0.5 mm in diameter) and the film is very thin, so the pressure difference should be large enough to push fiber apart and thus to create space between fibers.

(2) Fiber "arches" around bubble

Fiber is adsorbed around the bubble under the adsorption effect of bubble surface (Wu 1991). Bubble adsorption is related to its surface tension, which is formulated below (Gibbs' Equation):

$$\gamma = f^{s} - \sum \Gamma_i \mu_i^{s}$$

For the nonionic surface-active agent (surfactant), the Gibbs's Equation gives the relationship between surface tension, logarithmic activity of surfactant and its residual:

$$-d\gamma = \sum RT\left(\Gamma_s - x_s \Gamma_{H_2O}\right) d\ln a_s$$

Where γ is surface tension, T_s is residual of surfactant, T_{H2O} is residual of water, a_s is activity of surfactant, and X_s is mole ratio of surfactant.

It is the adsorption effect of bubble on fiber that makes fiber gather on the bubble surface and form arches around the bubble

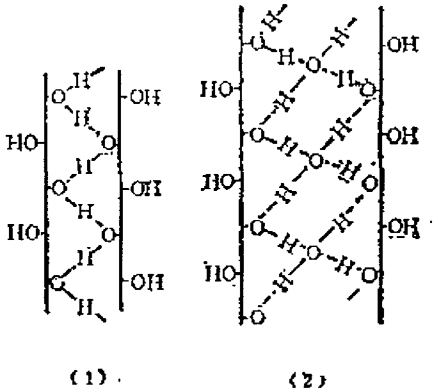

Fig.1. Water bridge and hydroxide radical bond
(1) Hydroxide radical (2) Water bridge.

(3) Orientation and bonding of fiber

"Slow beating" process (Casey 1980) can maintain fiber's original length and make fiber and its two ends adequately broomized, thus enrich hydroxide radicals at fiber ends. The attraction between hydroxide radicals with the effect of water-bridge, plus extremely low surface friction, makes fiber re-oriented. Then the removal of water brings hydroxide radicals closer thus facilitate hydroxide radical bonding and stable reticular structure establishing.

The objective of this paper is to propose the theory and approach for making low density reticular structure material and validate the theory and approach. This will enable effective use of plant fiber and production of low density, high performance, environmentally friendly material, thus allow for reduced use of non-environmentally friendly materials.

MATERIALS AND METHODS

Chinese-fir fluff pulp from Jiangle Senrong Fluff Pulp Plant of Fujian, sulphate chemical pulp from Canada and fibre for medium density fiberboard from Furen Wood Ltd. of Fujian were mixed up at the proportion of 6:3:1 in absolute dry weight and refined to beating degree of 40°SR. Moisture content of the fiber was then adjusted to 8%.

When blending pulp, terpene frothing agent, nonionic alkyl surfactant and FPC compound resin were added into the pulp in order at the amount of 7.2, 11 and 85 mg per litre frothing solution, respectively. After the pulp frothed adequately (approx. 5 minutes), 1100 ml frothed pulp was measured with a quantifying box and then transferred to a forming box. After laid aside for 3 minutes, the formed mat was drained and then dried to below 6% in moisture content. Figure 2 shows a picture of the final product suggesting fine integration of the mat. The laboratory process for producing reticular structured mat is presented in Figure 3.

Fig.2. A picture of sample mat.

Following the national standards for packing materials, sample products for packing ADSL broad-band modems and digital cameras were tested in Fujian Product Quality Test Center. The applicable standards include GB/T6343-1995 "Cellular plastics and rubbers - Determination of apparent (bulk) density", GB/T8813-1988 "Test methods for compressive properties of rigid cellular plastics", GB/T5480.7-2004 "Test methods for mineral wool and its products, Part 7: moisture absorption", GB/T16265-1996 "Test methods for packing material: consistency", GB/T16266-1996 "Test method for packing material: contact corrosion", GB/T9345-1988 "Plastics--determination of ash - general methods", and GB/T7573-2002 "Textile - test for the PH value of water extract".

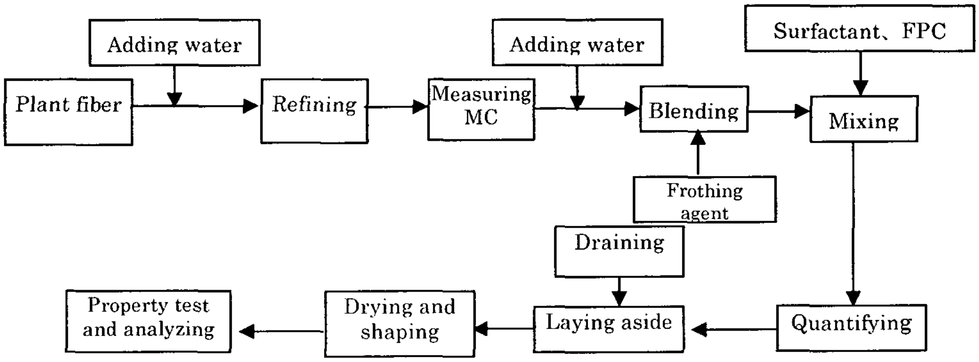

Fig.3. Laboratory process for producing reticular structured mat.

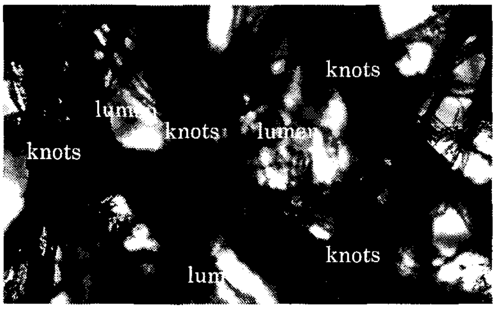

Fig.4. Microscopic structure of sample.

Fig.5. SEM image of reticular structure.

RESULTS AND DISCUSSION

Microscopic image showed that the reticular structure of fiber plant had evenly distributed knots (connected fiber) and lumens inside the mat (Fig. 4). A further examination under scanning electron microscope suggested the effectiveness of fiber bonding (Fig. 5). This implied that using solution frothing approach is an effective way to make reticular structured mat from plant fiber.

Test results indicated that all tested properties met the requirements for cushion packing materials (Table 1). The density (0.033 g/cm^3) was much lower than the required (0.2 g/cm^3). The extremely low mat density resulted from the effective bond between fibers and consequent reticular structure. This structure made up with knots and lumens (Fig. 4) which were the oriented fiber around bubbles and spaces occupied by bubbles in frothing solution, respectively. Mat density depends on the size of lumen, which depends on the size of bubble and the effectiveness of fiber bonding. The bond between fibers played a role of knots in a truss, which was strong enough to prevent lumen from shrinking during subsequent draining process. As the size and amount of bubbles are controllable by adjusting production parameters and using different amount of assistant agents, the density of mat can be controlled to range from 0.01 to 0.08 g/cm^3. Materials with such density and structure can be used as a cushion packing material for the excellent properties in shock resistance, vibration absorption and reduction. They can also be used as heat insulation material. The produced mat from this study had a coefficient of heat conductivity between 0.028 and 0.041 W/m·K.

Table 1. Sample mat properties following national standards of China for cushion packing materials

Test		Requirement	Test result
Sense index		No peculiar smell	No peculiar smell
Density (g/cm^3)		≤0.2	0.033
Free-drop test (from height 800 mm)	ADSL (1kg)	No damage	No damage
	Digital Cameras (220g)		No damage
Stacking test (stacking height: 2.50 m)	ADSL (1kg)	No apparent deformation / damage	No apparent deformation / damage
	Digital Cameras (220g)		No apparent deformation / damage

Vibration at a constant frequency 1)	ADSL (1kg)	No abnormal damage	No abnormal damage
	Digital Cameras (220g)		No abnormal damage
Vibration at variable frequencies 2)	ADSL (1kg)	No abnormal damage	No abnormal damage
	Digital Cameras (220g)		No abnormal damage
Compression strength (10% deflection) (kPa)		/	2.5
Moisture absorption (%) (under 50℃, 95%RH for 96 hours)		<28	17
Consistency		No degeneration	No degeneration
Contact corrosion		≤1	0
PH value		5~8	7.6
Ash content (%)		<1	0.35

1) Test frequency: 5 Hz for 1 hour with amplitude of 1 mm)

2) Test was carried out at 5, 10, 20 and 30 Hz for 1 hour each with amplitude of 1 mm)

CONCLUSIONS

Based on the results following conclusions can be drawn:

1. A reticular structure of plant fiber can be established with solution frothing approach;
2. An effective bond between fibers can be realized with the effect of hydroxide radicals;
4. Material produced had a density between 0.01 to 0.08 g/cm^3 and density is controllable. The produced material had excellent properties that meet the Chinese standards for cushion packing materials.

REFERENCES

Cao, S. W. and Q. Y. Wu. 2005. The buffering packaging material from foaming plant fiber. China Packaging Industry. 99(9): 8-11.

Casey, J. P. Ed. 1980-83. Pulp and paper - chemistry and chemical technology. New York: Wiley-Interscience, 3rd Ed.

Dai, H. M. and P. H. Dai. 2004. Study on the key technologies of products from foaming plant fibre. Packaging Engineering (China). (2): 9-11.

Lawton, J. W., R. L. Shogren and K.F. Tiefenbacher. 1999. Effect of batter solids and starch type on the structure. Cereal Chem. 76(5): 682-687.

Leja, J. 1985. Surface chemistry of froth flotation. Metallurgical Industry Press, Beijing, China.

Shogren, R. L., J. W. Lawton and K. F. Tiefenbacher. 2002. Baked starch foams : starch modifications and additives improve process parameters, structure and properties. Industrial Crops Products. 16(1): 69-79.

Wang, L. Y. and J. Q. Wang. 2005. Study on properties of starch-fiber biodegradable packaging materials. Packaging Engineering (China). (2): 7-9

Wang, N.Y. 2004. Characteristics of foaming packaging material from plant fiber. China Packaging. 24(1): 103-104.

Wu, H. H. 1991. Surface chemistry. Peking University Press, Beijing, China.

Xie, Y. Q., Y. Chen and B. G. Zhang. 2004. Study on foaming material from plant fiber. China Wood Industry. 18(2): 30-32.