Literature review
On Properties and Market Opportunities of Wood-Plastic and Wood-Cement Composites

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Part I. Wood-Plastic Composites

The wood-plastics composites (WPC) industry has experienced rapid growth in North America. The growing commercial importance of these materials has expanded efforts for understanding their structural properties and for exploring new methodologies for producing new materials.

(1) Manufacturing

The manufacturing of thermoplastic composites is usually a two-step process. The raw materials are first mixed together, and the composite blend is then formed into a product. The combination of these steps is called in-line processing, and the result is a single processing step that converts raw materials to end products. Compounding is the feeding and dispersing of the lignocellulosic component in a molten thermoplastic to produce a homogeneous material. During compounding various additives are added and moisture is removed. The compounding treatment will affect some properties of the products (Hwang and Hsiung 2000; Hwang 1997). Some research about the effect of different couple agents and lubricants on wood-plastic composites have also been done (Harper and Wolcott 2004; Herrera-Franco and Valadez-Gonza´lez 2004; Lu et al. 2000). The compounded material can be immediately pressed or shaped into an end-product while still in its molten state or become a kind of small, regular pellets for future reheating and forming (Clemons 2002). The use of compatibilisers (maleated polypropylene of different maleic anhydride content) in the compounding step improved the mechanical properties of the composites in dry conditions regardless of the compounding process; however, in wet conditions a decrease in tensile and flexural strength was observed for all composites (Bledzki et al. 2005).

Three common forming methods for WPC are extrusion (forcing molten composite through a die), injection molding (forcing molten composite into a cold mold), and compression molding (pressing molten composite between mold halves) Extrusion is by far the most common method (Clemons 2002), the total poundage of products produced with injection and compression is much less than that is produced with extrusion (English et al. 1996).

Because of the limited thermal stability of wood, only thermoplastics that melt or can be processed at temperatures below 200°C (392°F) are commonly used in wood-plastic composites. Currently, most wood-plastic composites are made with polyethylene, both recycled and virgin, for use in exterior building components and The plastic is often selected based on its inherent properties, product need, availability, cost, and the manufacturer’s familiarity with the material (Clemons 2002). Processing methods will affect the moisture absorption of wood-plastic composites. Clemons and Ibach (2004) indicates that extruded composites absorbed the most moisture, compression-molded composites absorbed less than the extruded composites, and injection molded composites absorbed the least. Some pretreatment during process can improve the properties of products, such as boric acid treatment imparted compressed wood polymer composites (Yalinkilic et al. 1999).

Many research efforts about using recycled waste wood fiber materials and plastics to produce value-add, recyclable, and environmental friendly products were also published (Hwang at al. 1994; English at al. 1994).

The structure–properties relationship of wood fiber–polypropylene composites was studied in relation to fiber types (hardwood and softwood) and compounding techniques, namely two-roll mill, high-speed mixer (agglomerator) and twin-screw extruder. It was shown that twin-screw extruder compounded composites had higher mechanical properties than those compounded in a two-roll mill or a high-speed mixer (Bledzki et al. 2005).

Extrusion is a continuous process in which many operating parameters can influence product qualities, such as screw speed, temperature profile in extruder barrel and die, and cooling rate (Tucker and Bender 2003).

Nondestructive evaluation techniques can be applied for in-line monitoring of WPC quality during manufacturing for process control, such as through-transmission ultrasonic inspection (Tucker and Bender 2003).

When forming a wood and a wood/PP fiber composite through compression molding, heated platens apply stress to the mat until the final profile is established. The amount of stress required to compress the mat can depend upon the press closing speed or strain rate, platen temperature, and the composite formulation (Englund et al. 2004).

(2) Properties

Wood particle sizes, geometry, and varieties will affect properties of WPC (Stark and Rowlands 2003; Takatani at al. 2000; Stark 1997). The affected properties can include moisture absorption (Wang and Morrell 2004) and decay resistance (Verhey and Laks 2002). Typical particle sizes for WPC are 10 to 80 mesh (Clemons 2002) and the smaller particle size yields better performance ((Takatani at al. 2000). In general, the hardwoods WPC exhibited slightly better tensile and flexural properties and heat deflection temperatures compared to the softwoods WPC (Stark 1997).

The formulation, including the contents of wood, plastic and addictives, can significantly affect the properties of wood-plastic composites (Wolcott 2003; Lu et al. 2000; Caulfield et al. 1998; Hwang 1997; Stark and Rowlands 2003; Stark 1997). WPC typically containing approximate 50% wood flour, although some composites contain very little wood or as much as 70% wood (Clemons 2002). The higher filler content, the better stiffness properties; however, the MOR and maximum deflection decrease with increasing wood content and decreasing resin content of particles (Hwang 1997). With increasing wood flour content, flexural and tensile modulus, density, heat deflection temperature, and notched impact energy increased, while flexural and tensile strength, tensile elongation, mold shrinkage, melt flow index, and unnotched impact energy decreased (Stark 1997). Finally increasing plastics content will increase the heat release rate of wood-plastic composites (Stark at al. 1997).

Comparisons between wood-plastic composites and conventional wood composites are studied and indicate that wood fiber-plastic composite panels are inferior to conventional wood-based panels in bending modulus of elasticity and bending modulus of rupture. However, the composite panels performed well in thickness swell and moisture absorption (Falk et al. 1999).

Besides wood, many agri-based particle and fiber types have been investigated, including bamboo, wheat, kenaf, cornstalk, jute etc (Chow et al.1999; Caulfield et al. 1998; Rowell 1996; Youngquist et al. 1996). English et al. (1997) studied the comparison between wood and mineral fillers in composites and indicated that wood filler can reduce the specific gravity of composites, which is an advantage in packing and transportation application.

The interaction and adhesion between the fiber and matrix has a significant effect in determining the mechanical and physical behavior of fiber composites (Sanadi et al. 2000; Stark 1999; Caulfield et al. 1998; Oksman and Clemons 1998; Clemons 1995). Fiber fracture (or lack of it), polymer ductility, and fiber polymer bonding all play a role in impact performance (Clemons 1995).

Research about decay resistance of WPC due to weather, moisture, insects or fungi are studied in several papers, including laboratory and field tests, (Lopez et al. 2005; Verhey et al. 2003; Clemons and Ibach 2002; Pendleton et al. 2002; Verhey et al. 2001; Falk et al. 2000a; Hwang and Hsiung 2000; Falk et al. 2000b; Chow et al. 1999; Morris and Cooper 1998) in which good qualities of wood-plastic composites in dimension stability, weather resistance, moisture absorption and fungi resistance are proven. Wang and Morrell (2005) indicate that moisture absorption tend to increase with the number of wet/dry cycle. Besides, ultraviolet exposure can lead to photodegradation, resulting in a change in appearance and/or mechanical properties (Stark et al. 2002; Falk et al. 2000b).

One of the disadvantages of cellulose-based fibers is their propensity to absorb water and swell. This inevitably leads to undesirable dimensional instability of the composite and its fiber-mat preform. A measure of the hygroexpansion behavior of the fibers could serve to rank the suitability of different kinds of cellulosic fibers with regard to dimensionally stable composites. A method has been developed to determine the hygroexpansion coefficient of wood fibers. Since fiber mats manufactured with conventional techniques generally have a thickness gradient of fiber orientation, fiber mats and composites will curl if the moisture content varies (Neagu et al. 2005).

The toughness of filled polymers can be improved in several ways: 1) increase the matrix toughness; 2) optimize the interface (or interphase) between the filler and the matrix through the use of coupling agents, comptibiliser, and sizes; 3) optimize the filler-related properties such as filler content, particle size, and dispersion; 4) aspect ratio and orientation distributions also play a role in toughness of composites containing more fiberous materials (Oksman and Clemons 1998).

Fastener properties are also studied. Screw withdrawal, nail withdrawal, and nail head pull-through capacity are relatively unaffected by wood flour content. However, wood flour content affected lateral nail resistance. The use of pilot holes (predrilling) was found to have little effect on fastener capacity. Moreover, the screw withdrawal capacity of the tested wood flour-thermoplastic composite panels was found to be equal to or greater than that of conventional wood panel products (Falk et al. 2001). Parsons and Bender (2004) studied the dowel connection in wood-plastic composites hollow section.

(3) Marketing Opportunities

In recent years, the market of wood-plastic composites in North America has increased greatly and attracted the interest of both the plastics and the forest products industries (Clemons 2000). These wood-based composites have been successful in the marketplace primarily because they deliver consistently appropriate structural performance at a reasonable cost (Smith and Wolcott 2006).

In the building community, there is a growing demand for high-performance, low-maintenance, and low-cost building products. To meet this demand, natural fiber thermoplastic composites are being used to produce such products as landscape timbers, railing, decking, fence, window and door elements, panels, molding, roofing, and siding, even floor ,louver, and indoor furniture have been reported. Some research point that wood-plastic composites have become a major player in the North American decking market (Clemons 2002; Winandy et al. 2004). Schneider and Witt (2004) indicate that the advantages of wood-plastic composites can cause increase demands for value-added products made from them, and the market will increase dramatically in the near future and continue to grow in long-term. Recycling may help the wood-plastic composites industry as the recycling industries prepares for their future materials and their needs (Jiang and Tsai 2005a.b.; Winandy et al. 2004; Falk 1997; English et al. 1996; McKeever at al. 1995; Younquist 1994; English 1992).

The demand of wood pallets and shortage of solid wood provide a large market for wood-plastic composites in North America and Asia region (Jiang and Tsai 2005b). Besides, wood pallets and shipping crates represent a large source of raw material available for use in value-add composites. Recycling and reproducing would provide good market for wood-plastic composites (Stark 1999). Furthermore, some synthetic materials can provide additional market for recycled plastics (Selke and Wichman 2004).

The phase-out of chromated copper arsenate (CCA) may give wood-plastic composites opportunities to increase awareness of alternatives to CCA-treated lumber (Schneider and Witt 2004; Winandy et al. 2004). Kamdem et al. (2004) studied the properties of wood-plastic composites made of wood flour from CCA-treated wood and recycled HDPE.

Lignocellulosics will be used in the future to produce a wide spectrum of composite products ranging from very inexpensive, low-performance materials to materials that are relatively expensive and have high-performance characteristics. Taking advantage of the wide distribution, renewability, and recyclability of lignocellulosics, more markets will be developed for low-cost renewable materials. By chemically modifying the lignocellulosic cell wall to overcome some of its disadvantageous properties, new markets for high-performance composites will develop (English 1994).

By incorporating continual new product development into a firm's R&D process, the forest products industry can greatly benefit through increased profitability, improved customer and stakeholder perceptions, and reduced risk of litigation and regulation. Moreover, concurrent new product and market development efforts, integrating customer needs back into the design and engineering of new products, will provide competitive advantage to WPC industry innovators (Smith and Wolcott 2006).

In Asia region, market for wood-plastic composites has just started recently, and has more potential than North America because of the great market demand and the shortage of wood. Especially in mainland China, market may increase with Olympic 2008 in Beijing. The constructions of civil buildings will also provide opportunities for wood-plastic composites applications (Jiang and Tsai 2005b).

The future of WPC will depend on many factors, including new product identification, product quality, consumer reaction, and success of research and development efforts. Success will also depend on how well the forest products and plastics industries continue to establish relationships and work with each other.

Literature cited

1. Hwang, G.S. and Hsiung, J.C. (2000) Durability of plastics/wood composite boards manufactured with waste wood particles, Taiwan Journal of Forest Science 15(2): 201-208. (in Chinese)
2. Hwang, G.S. (1997) Manufacturing of plastic/wood composite boards with waste polyethylene and wood particle, Taiwan Journal of Forest Science 12(4): 443-450. (in Chinese)
3. Harper D. and Wolcott, M. (2004) Interaction between coupling agent and lubricants in wood–polypropylene composites, Applied Science and Manufacturing. 35(3):385-394.
4. Herrera-Franco, P.J. and Valadez-Gonza´lez, A. (2004) Mechanical properties of continuous natural fibre-reinforced polymer composites. Applied Science and Manufacturing. 35(3):339-345.
5. Lu, J.Z., Wu, Q., and McNabb, Jr. H.S. (2000) Chemical coupling in wood fiber and polymer composites: A review of coupling agent and treatments. Wood and Fiber Science, 32(1): 88-104.
6. Clemons, C. (2002) Wood-plastic Composites in the United States: The interfacing of two Industries. Forest Products Journal; Vol. 52(6): 10-18.
7. Bledzki, A.K., Letman, M., Viksne, A., and Rence, L. (2005) A comparison of compounding processes and wood type for wood fibre—PP composites. 36(6):789-797.
8. English, B., Clemons, C.M., Stark, N., and Schnieder, J.P. (1996) Waste-wood derived fillers for plastics. Gen. Tech. Rep. FPL-GTR-91. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 282-291.
9. Clemons, C.M. and Ibach, R.E. (2004) Effects of processing method and moisture history on laboratory fungal resistance of wood-HDPE composites, Forest Products Journal; Vol. 54 (4): 50-57.
10. Yalinkilic, M.K., Imamura, Y., Takahashi, M., Demirci, Z., and Yalinkilic, A.C. (1999) Biological, Mechanical, and Thermal properties of Compressed-Wood Polymer composites (CWPC) pretreated with boric acid. Wood and Fiber Science, 31(2): 151-163.
11. Hwang, G.S., Lee, M.C., and Peng, W.T. (1994) Properties of Plastic-Wood composite particleboard, Bull. Taiwan Forest Research Institute New series, 9(4): 407-412. (in Chinese)
12. English, B., Youngquist, A.M., and Krzysik, A.M. (1994) Lignocellulosic

composites. Prepared for publication in Cellulosic Polymers, Blends and Composites; U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

13. Tucker, B.J. and Bender, D.A. (2003) Continuous ultrasonic inspection of extruded wood-plastic composites, Forest Products Journal, Vol. 53 (6): 27-32
14. Englund, K.R., Wolcott, M.P., and Hermanson, J.C. (2004) The compression of wood/thermoplastic fiber mats during consolidation. Composites Part A. Applied Science and Manufacturing. 35(2):273-279.
15. Stark, N.M. and Rowlands, R.E. (2003) Effect of wood fiber characteristics on mechanical properties of wood/polypropylene composites. Wood and Fiber Science, 35(2): 167-174.
16. Takatani, M., Ito, H., Ohsugi, S., Kitayama, T., Saegusa, M., Kawai, S., and Okamoto, T. (2000) Effect of Lignocellulosic Materials on the Properties of Thermoplastic Polymer/Wood Composites, Holzforschung 54 (2000): 197–200.
17. Stark, N.M. (1997) Effect of Species and Particle Size on Properties of Wood-Flour-Filled Polypropylene Composites. In: Proceedings of Functional Fillers; 1997 December 8-10. Intertech Conference; San Diego, CA.
18. Wang, W. and Morrell, J.J. (2004) Water sorption characteristics of two wood-plastic composites, Forest Products Journal, Vol. 54 (12): 209-212.
19. Verhey, S.A. and Laks, P.E. (2002) Wood particle size affects the decay resistance of woodfiber/thermoplastic composites, Forest Products Journal, Vol. 52 (11/12): 78-81.
20. Wolcott, M.P. (2003) Formulation and process development of flat-pressed wood-polyethylene composites, Forest Products Journal, Vol. 53 (9): 25-32.
21. Caulfield, D.F., Stark, N., Feng, D., and Sanadi, A.R. (1998) Dynamic and mechanical properties of the agro-fiber based composites. In: Progress in woodfibre-plastic composites: emergence of a new industry; 1998 June 01; Mississauga, Ontario. Mississauga, Ontario, CN: Materials and Manufacturing Ontario: 8 p.
22. Stark, N.M., White, R.H., and Clemons, C.M. (1997) Heat release rate of wood-plastic composites. Sempre Journal; 33(5): 26-31.
23. Falk, R.H., Vos, D. and Cramer, S.M. (1999) The Comparative Performance of Woodfiber-Plastic and Wood-Based Panels. In: 5th international conference on wood fiber-plastic composites; 1999 May 26-27; Madison, WI. Madison WI Forest Product Society: 269-274.
24. Chow, P., Bowers, T.C., Bajawa, D.S., Youngquist, J.A., Muehl, J.H., Stark, N.M., Krzysik, A., and Quang, L. (1999) Dimensional stability of composites from plastics and cornstalk fibers. In: 5th international conference on wood fiber-plastic composites; 1999 May 26-27; Madison, WI. Madison WI Forest Product Society: 312-313.
25. Rowell, R.M. (1996) Composites from Agri-Based Resources In: Falk, Robert H., ed. Proceedings, The use of recycled wood and paper in building applications. Proceedings No.7286. Madison, WI: Forest Products Society: 217-222.
26. Youngquist, J.A., Krzysik, A.M., English, B.W., Spelter, H.N., and Chow, P. (1996) Agricultural Fibers for Use in Building Components. In: The use of recycled wood and paper in building applications: Proceedings of a 1996 symposium sponsored by the U.S. Department of Agriculture Forest Service, Forest Products Laboratory and the Forest Products Society, in cooperation with the National and Association of Home Builders Research Center, the American Forest and Paper Association, the Center for Resourceful Building Technology,

and the Environmental Building News. Proc. 7286. Madison, WI: Forest Product Society: 123-124.
27. English, B., Stark, N., and Clemons, C. (1997) Weight reduction: Wood versus mineral fillers with polypropylene. In: Proceedings of the 4th International Conference on Wood fiber-Plastic Composites. Forest Products Society, Madison, WI. May 12-14, 1997: 237-244.
28. Sanadi, A.R., Caufield, D.F., Stark, N.M., and Clemons, C.C. (2000) Thermal and mechanical analysis of lignocellulosic-polypropylene composites. In: The Fifth International Conference on Wood fiber Plastics Composites; 1999 May 26-27; Madison, WI, U.S.: 67-68.
29. Stark, N.M. (1999) Wood fiber derived from scrap pallets used in polypropylene composites. Forest Products Journal; Vol. 49(6): 39-46.
30. Oksman, K. and Clemons, C. (1998) Mechanical properties and morphology of impact modified polypropylene-wood flour composites. Journal of Applied Science: 67: 1503-1513.
31. Clemons, C. (1995) Exploratory microscopic investigation of impacted paper fiber- reinforced polypropylene composites. Proceeds No. 7293 Wood fiber-Plastic Composites; USDA Forest Service, University of Toronto, University of Wisconsin and Forest Product Society; May 1-3, 1995.
32. Lopez, J.L., Cooper, P.A., and Sain, M. (2005) Evaluation of proposed test methods to determine decay resistance of natural fiber plastic composites. Forest Products Journal, Vol. 55 (12): 95-99.
33. Verhey, S.A., Laks, P.E., Richter, D.L., Keranen, E.D., Larkin, G.M. (2003) Use of field stakes to evaluate the decay resistance of wood fiber-thermoplastic composites, Forest Products Journal, Vol. 53 (5): 67-74.
34. Clemons, C.M. and Ibach, R.E. (2002) Laboratory tests on fungal resistance of wood filled polyethylene composites. In: ANTEC Annual Technical Conference Society of Plastics Engineers; 2002 May 5-9; San Francisco CA. Volume II-Materials: 2219-2222.
35. Pendleton, D.E., Hoffard, T.A., Adcock, T., Woodward, B., and Wolcott, M.P. (2002) Durability of an extruded HDPE/wood composite, Forest Products Journal, Vol. 52 (6): 21-27.
36. Verhey, S., Laks P., and Richter, D. (2001) Laboratory decay resistance of woodfiber/thermoplastic composites, Forest Products Journal, Vol. 51(9): 44-49.
37. Falk, R.H., Felton, C., and Lundin, T. (2000a) Effects of weathering on color loss of natural fiber-thermoplastic composites. In: 3rd international symposium on natural polymers and composites- ISNaPOL/2000; 2000 May 14-17; Sao Pedro, Brazil. Sao Carlos, Brazil: Embrapa-Empresa Brasileria de Pesquisa Agropecuaria- Embrapa Instrumentacao agropecuaria; USP- Universidade de Sao Paulo IQSC-Instituto de quimica de Sao Carlos; UNESP - Universidade de Estado de Sao Paulo, Fauldaded de Cencias Agronomicas: 382-385.
38. Falk, R.H., Lundin, T., and Felton, C. (2000b) The Effects of Weathering on Wood-Thermoplastic Composites Intended for Outdoor Applications, Proceedings of the 2nd Annual Conference on Durability and disaster mitigation in Wood-Frame Housing: 175-179.
39. Morris, P.I. and Cooper, P. (1998) Recycled plastic/wood composite lumber attacked by fungi, Forest Products Journal, Vol. 48(1): 86-88.
40. Wang, W. and Morrell, J.J. (2005) Effects of moisture and temperature cycling on material properties of a wood/plastic composite. Forest Products Journal, Vol. 55 (10): 81-83.

41. Stark, N.M. and Matuana, L.M. (2002) Photostabilization of wood flour filled HDPE composites. In: ANTEC Annual Technical Conference Society of Plastics Engineers; 2002 May 5-9; San Francisco CA. Volume II-Materials: p. 2209-2213.
42. Neagu, R.C., Gamstedt, E.K., and Lindstro¨m, M. (2005) Influence of wood-fibre hygroexpansion on the dimensional instability of fibre mats and composites. Applied Science and Manufacturing. 36(6):772-788.
43. Falk, R.H., Vos, D.J., Cramer, S.M., and English, B.W. (2001) Performance of fasteners in wood flour-thermoplastic composite panels, Forest Products Journal, Vol. 51(1): 55-61.
44. Parsons, W.R. and Bender, D.A. (2004) Energy-based Design of Dowel Connections in Wood-plastic Composites Hollow Sections. ASCE Journal of Structural Engineering. 130(4):681-689.
45. Clemons, C.M. (2000) Wood fiber-plastic composites in the United States-history and current and future Markets. In: Third International Wood and Natural Fibre Composites Symposium; 2000 September 19-20; Kassel, Germany. Kassel, Germany: Universitat Gesamthochsshule Kassel: 1-1 to 1-7.
46. Smith, P.M. and Wolcott, M. (2006) Opportunities for wood/natural fiber plastic composites in residential and industrial applications. Forest Products Journal, Vol. 56 (3): 4-11.
47. Winandy, J.E., Stark, N.M., and Clemons, C.M. (2004) Considerations in recycling of wood-plastic composites, 5 the Global Wood and Natural Fibre Composites Symposium, Germany: A6-1-9.
48. Schneider, M.H. and Witt A.E. (2004) History of wood polymer composite commercialization, Forest Products Journal, Vol. 54(4): 19-24.
49. Jiang, Z.C. and Tsai, S.R. (2005a) The opportunities and obstacles of Wood/Fiber polymer composites development in Asia-Pacific Part 1. Chemical Mothly, No.24: 98-103. (in Chinese)
50. Jiang, Z.C. and Tsai, S.R. (2005b) The opportunities and obstacles of Wood/Fiber polymer composites development in Asia-Pacific Part 2. Chemical Mothly, No.25: 94-101. (in Chinese)
51. Falk, B. (1997) Wood recycling: opportunities for the woodwaste resource. Forest Products Journal; 47(6): 17-22.
52. English, B., Clemons, C.M, Stark, N., and Schnieder, J.P. (1996) Waste-wood derived fillers for plastics. Gen. Tech. Rep. FPL-GTR-91. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory: 282-291.
53. McKeever, D.B., Youngquist, J.A., and English, B.W. (1995) Sources and availability of recovered wood and fiber for composite products. In: Proceedings of particleboard symposium; June 1995.
54. English, B. (1992) Meeting society`s challenge: value-added products from recycled materials Pacific Rim Bio-Based Composites Symposium, New Zealand: 326-335.
55. Selke, S.E. and Wichman, I. (2004) Wood fiber/polyolefin composites. Applied Science and Manufacturing. 35(3):321-326.
56. Kamdem, D.P., Jiang, H., Cui, W., Freed, J., and Matuana, L.M. (2004) Properties of wood plastic composites made of recycled HDPE and wood flour from CCA-treated wood removed from service. Applied Science and Manufacturing. 35(3):347-355.
57. Younquist, J.A., Myers, G.E., Muehl, J.H., Krzysik, A.M., Clemons, C.M., and Brown, L. (1994) Composites from recycled wood and plastics. Project summary

prepared for U.S. Environmental Protection Agency, Cincinnati, OH. U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 20p.

58. Jiang, Z.C. and Tsai, S.R. (2005c) The opportunities and obstacles of Wood/Fiber polymer composites development in Asia-Pacific Part 3. Chemical Mothly, No.26: 80-87. (in Chinese)

Part II. Wood-Cement Composites

Wood fiber is used to replace asbestos in the manufacture of fiber cement due to its high availability, low cost and good reinforcement properties.

(1) Manufacturing

Cement bonded board (CBB) combines the properties of two important materials: cement and any fibrous materials like wood or agricultural residues. It is a panel product made up of either strands, flakes, chips, particles or fibers of wood or some agricultural residues bonded with ordinary Portland cement (Eusebio 2003).

There are three main types of wood-cement composites: 1) Wood-wool cement board (WWCB); 2) cement-bonded particleboard (CBP); 3) wood-fiber reinforced cement composites (Eusebio 2003; Evans 2000).

The wood-wool cement board is made from debarked wood logs that have been stored for varying period of time to reduce the starch and sugar content of the wood, and then these logs are cross-cut into billets and these are shredded on a cutting machine to produce wood-wool. The post-harvest storage of raw materials has positive effect on mechanical properties (Cabangon et al. 2000). Typical wood-wool strands used in the manufacture are approximately 3 mm wide and 0.5 mm thick with length up to 40-50 cm. Semple and Evans (2000) studied the effect of heartwood on mechanical properties of wood-wool cement boards and found that the inhibitor of heartwood would affect the cement hydration. Therefore, they suggest use young tree less than 12-15 years, which will contain little or no heartwood.

Prior to producing cement-bonded particleboard, debarked logs are stored for at least 2-3 months to reduce the moisture and sugar content. Similar to conventional particleboard, logs are processed to produce chips approximately 10-30 mm in length and 0.2-0.3 mm in thickness, which are further reduced in size using knife ring flakers and hammer mills. The resulting flakes are screened into three classes; fine, standard and coarse flakes. Fines are used for the board surface and standard-size flakes are used for the core of boards. Coarse flakes are returned for further reduction in size. Wood flakes are mixed with Portland cement and water in different ratio by weight (Evans 2000).

Two categories of cement-bonded wood composite panels were suggested and fabricated. The first category was manufactured using ribbon-like wood particles called excelsior, which can be produced from low-quality forest thinnings. The second category used a varied particle geometry produced by grinding wood waste in a commercial tub grinder. Variables included particle geometry, chromated copper arsenate (CCA) treatment, wood species, method of panel formation, and composite density (Wolfe and Gjinolli 1996). Furthermore, Ma et al. (2000a) studied the relationship between hydration energy released of manufacture and mechanical properties of cement-bonded boards, and indicated that the total energy release is a quick way to determine suitable mixture of cement, addictive, and fibers. In addition, orientation of strands can improve the strength properties of cement-bonded boards (Ma et al. 2000b).

Eucalyptus species were chosen for their performance in growth trails and used to manufacture of wood-cement composites (Esmeralda et al. 2004; Semple et al.

2000). Beside, *Acacia*s and rubber wood are also proven as suitable species to make wood cement-bonded particleboard (Esmeralda et al. 2004; Eusebio et al. 2000).

Wood- fiber reinforced cement composites were made from wood fiber, sand, cement, and aluminium trihydrate in different ratio by weight. Wood fibers, usually obtained from softwood chemical (kraft) pulp, acted as a reinforcing agent in the boards, a role previously played by asbestos. The cement, fibers, sand and addictives were combined in the different proportions and diluted to form slurry with a solids content of 10% (Evans 2000).

The right selection of the flocculant in fiber-cement manufacture is crucial due to its effect on mineral fines retention, dewatering, and formation, however, the bending strength will decrease. The use of sizing agent was suggested to increase the flexural properties, and the best sizing agent is different depending on the process technology (Negro et al. 2005).

Geimer et al. (1994) indicated that carbon dioxide introduced into cement-bonded boards permitted the reduction of clamp time from eight to twenty-four hours to four minutes. The carbon dioxide treatment reduces the cure inhibiting effect of wood and promises to improve the long-term performance of cement bonded wood composites.

(2) Properties

In cement bonded board technology, many parameters greatly affect board properties. Some of these are: material (wood/cement, agri-wastes/cement) ratio; water/cement ratio; type of wood/agri-wastes; cement setting accelerators and others (Eusebio 2003). Lee et al. (1987) indicated that hydration temperature was drastically reduced, hydration time was prolonged, and compressive strength was reduced as cement/wood ratio decreased.

Some paper evaluated the effects of variability in wood strand dimensions, mechanical properties, and orientation on the engineering properties of cement excelsior board. Results suggest that variability in strand mechanical properties can significantly lower composite tensile and compressive strengths, while composite stiffness is not affected. Furthermore, strand alignment lead to increase the strength and stiffness in the direction of alignment (Stahl et al. 1997).

Fiber characteristics along with different chemical treatments influenced the composite mechanical properties is proven by Blankenhorna et al. (2001). Besides, chemical treated fiber-cement composites were more resistant to deterioration in moisture cycle and temperature cycle than the neat cement composites; moreover, different treatments and different fibers have different effects (Pehanich et al. 2004; Blankenhorn et al. 1999). The research for durability and strength of wood-cement composites were conducted (Gong et al. 2004; Wolfe and Gjinolli 1999; Wolfe and Gjinolli 1996). The results indicate that despite their relatively low strength compared to that of most other structural materials, these composites appear to have sufficient strength and bending resistance to serve as in-fill wall panels. Moreover, these composites have energy-dissipating properties. These properties include sound absorption, which is affected by fiber volume (Neithalath et al. 2004), fire resistance, and special applications in structures where impact and dynamic load are a design consideration, and even for resisting freeze-thaw environment given the correct cement particle mix. In addition, degradation of wood fiber's hemicellulose improves wood-cement bonding strength (Canadian Wood Council).

Cement-bonded particleboard as a composite of wood chips and reacted Portland cement is dimensionally unstable in service in the presence of changes in relative humidity. One solution to this deficiency is the application of surface coatings to reduce its magnitude (Fan et al. 2004).

Low and high density cement-bonded particleboards made conventionally and with carbon dioxide injection were tested against white and brown rot fungi. There was no measurable wood degradation (weight loss) which shows that cement-bonded particleboard is suitable for use in tropical countries where moisture is wood's greatest enemy (Souza et al. 1997; Geimer et al. 1996). Sukartana et al. (2000) studied the resistance to termite and point that these boards resist not only the decay caused by fungi, but also attacked by termites.

Shao et al. (2001) used scanning electron microscope (SEM) to study the microstructure of cement-bonded fiberboard manufactured by extrusion process, and showed that comparison between extruded and cast fiberboard revealed that the extruded products were better in strength, stiffness, toughness, fiber distribution, fiber orientation, and bond of fiber with matrix, even in the presence of a higher percentage of air voids.

(3) Market Opportunities

Cement bonded board has gained favor throughout the industry due to its extended applications compared to plywood, resin-bonded particleboard and other allied products (Eusebio 2003). Extensive studies on the expansion of raw material base have been done thereby demonstrating the feasibility of producing CBB using local wood species, some agricultural wastes and even industrial residues (Eusebio 2003; Fernandez and Taja-on 2000; Warden et al. 2000).

The potential markets for these products are significant. Cement-bonded particleboard manufacturers do not presently use wood waste feedstocks, but have expressed interest in using this resource. Slab and block products have the greatest potential for integrating wood waste feedstock. Satisfying the cement composite manufacturer's specifications and product quality expectations are critical to sustaining the captured market share (Canadian Wood Council).

Cement bonded board has been found to be a good substitute for concrete hollow blocks, plywood, particleboard and other resin bonded boards. It is a very versatile material that can be used as ceiling, partition wall, exterior wall, flooring, eaves, cladding and even roofing provided that proper coating is applied. However, the most common application of cement bonded boards in the Philippines today is for wall and ceiling construction (Eusebio 2003). Since the strength properties of cement bonded boards, particularly wood-wool cement boards, are not suitable for load-bearing elements, it is often used with framing materials like wood and steel section.

Using recycled CCA-treated materials as well as construction wastes to produce cement-bonded particleboards was reported (Gong et al. 2004; Wolfe and Gjinolli

1999). These types of composites were suggested to be used as highway barriers and impact or dynamic load consideration (Wolfe and Gjinolli 1999).

The North American market is alive and well for fiber cement materials with very successful products for both the exterior of the home as well as the interior. As a wood replacement material, fiber cement has many proven benefits that will allow the material to remain in favor among builder and contractors in the North American market (Booz 2002). Moreover, the Central American region of the world has an acute housing shortage. Given the practical financial constraints that exist in this area, the solution to this ever-expanding housing problem lies in the development of low-cost building materials that are able to satisfy the many production, construction, economic, cultural, safety, and health requirements imposed by the natural barriers, lack of infrastructure, and lack of community services in this region. Composites wood-cement panel appear to have potential to satisfy the requirement. Specifically, they lend themselves to modular construction, satisfy the cultural preference for cement-based materials in the tropics, satisfy health and safety needs, provide resistance to attack by decay and fungi, and provide protection against combustion (Ramirez-Coretti et al. 1998). Some studies about application of cement boards were also developed, such as shop-fabricated emergency shelters in the Philippines (Soriano et al. 2000).

Some carpenters are hesitant to use the product while others still prefer plywood, concrete hollow blocks or other traditional materials. To augment the market, cement bonded board producers and distributors may prepare a company brochure that would clearly explain product application and construction system (Eusebio 2003).

Literature cited

1. Eusebio, D.A. (2003) Cement Bonded Board: Today's Alternative. Paper presented at a technical forum in celebration of the 21st PCIERD Anniversary, DOST held at EDSA Shangri-La, EDSA, Pasig City on March 17, 2003. 9pp.
2. Evans, P.D. (2000) Summary: An introduction to wood-cement composites, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 7-10.
3. Cabangon, R.J., Eusebio, D.A., Soriano, F.P., Cunningham, R.B., Donnely, C., and Evans, P.D. (2000) Effect of post-harvest storage on the suitability of *Acacia mangium* for the manufacture of wood-wool cement boards, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 97-104.
4. Semple, K. and Evans, P.D. (2000) Adverse effect of Heartwood on the Mechanical properties of Wood-Wool Cement Boards Manufactured from radiata pine wood. Wood and Fiber Science, 32(1): 37-43.
5. Wolfe, R. and Gjinolli, A.E. (1996) Assessment of Cement-Bonded Wood Composites as Means of Using Low-Valued Wood for Engineered Applications. In: Gopu, Vijaya K.A., ed. Proceedings of the international wood engineering conference: 1996 October 28-31; New Orleans LA. Baton Rouge, LA: Louisiana State University: Vol. 3: 74-81.
6. Ma, L.F., Yamauchi, H., Pulido, O.R., Tamura, Y., Sasaki, H., and Kawai, S. (2000a) Manufacture of cement-bonded boards from wood and other

lignocellulosic materials: relationship between cement hydration and mechanical properties of cement-bonded boards, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 13-23.

7. Ma, L.F., Yamauchi, H., Pulido, O.R., Tamura, Y., Sasaki, H., and Kawai, S. (2000b) Production and properties of oriented cement-bonded boards from Sugi (*Cryptomeria japonica* D. Don), Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 13-23.
8. Esmeralda Y.A., Okino, M. ario R., de Souza, M.A.E., Santana, M.V. da S., Alves, M.E., and de Sousa, D.E.T. (2004) Cement-bonded wood particleboard with a mixture of eucalypt and Rubberwood. Cement & Concrete Composites 26 (2004) 729–734.
9. Semple, K., Cunningham, R.B., and Evans, P.D. (2000) Compatibility of eight temperate Australian *Eucalyptus* species with Portland cement, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 40-46.
10. Eusebio, D.A., Soriano, F.P., Cabangon, R.J., and Evans, P.D. (2000) Manufacture of low-cost wood-cement composites in the Philippines using plantation-grown Australian species: Ⅱ. *Acacia*s, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 115-122.
11. Negro, C., Sa´nchez, L.M., Fuente, H., and Blanco, A. (2005) Effects of flocculants and sizing agents on bending strength of fiber cement composites. Cement and Concrete Research 35 (2005) 2104 – 2109.
12. Geimer, R.L., Leao, A., Armbruster, D., and Pablo, A. (1994) Property enhancement of wood composites using gas injection. In: Proceedings of the 28th Washington State University international particleboard-composite material symposium; 1994 April 12-14; Pullman, WA. Washington State University: 243-259.
13. Lee, A.W.C., Hong, Z., Phillips, D.R., and Hse, C.Y. (1987) Effect of cement/wood ratios and wood storage conditions on hydration temperature, hydration time, and compressive strength of wood-cement mixtures, Wood and Fiber Science vol. 19(3): 262-268.
14. Stahl, D.C., Cramer, S.M., and Geimer, R.L. (1997) Effects of microstructural heterogeneity in cement excelsior board. Wood and Fiber Science, 29(4): 345-352.
15. Blankenhorn, P.R., Blankenhorn, B.D., Silsbee, M.R., and DiCola, M. (2001) Effects of fiber surface treatments on mechanical properties of wood fiber–cement composites. Cement and Concrete Research 31 (2001) 1049–1055.
16. Pehanich, J.L., Blankenhorn, P.R., and Silsbee, M.R. (2004) Wood fiber surface treatment level effects on selected mechanical properties of wood fiber–cement composites. Cement and Concrete Research 34 (2004) 59–65.
17. Blankenhorn, P.R., Silsbee, M.R., Blankenhorn, B.D., DiCola, M., and Kessler, K. (1999) Temperature and moisture effects on selected properties of wood fiber-cement composites. Cement and Concrete Research 29 (1999) 737–741.
18. Gong, A., Kamdem, D.P., and Harichandran, R. (2004) Compression tests on wood-cement particle composites made of cca-treated wood removed from service, Environmental Impacts of Preservative-Treated Wood Conference to be held in Orlando, Florida, February 8-10, 2004: 8pp.

19. Wolfe, R. and Gjinolli, A. (1999) Durability and strength of cement bonded wood particle composites made from construction waste. Forest Prod. J. 49(2):24-31.
20. Neithalath, N., Weiss, J., and Olek, J. (2004) Acoustic performance and damping behavior of cellulose-cement composites, Cement and Concrete composites 26 (2004) 359–370.
21. Canadian Wood Council :Specification for Inorganic Bonded Fiber Composites.
22. Fan, M.Z., Bonfield, P.W., Dinwoodie, J.M., Boxall, J., and Breese, M.C. (2004) Dimensional instability of cement-bonded particleboard: The effect of surface coating. Cement and Concrete Research 34 (2004) 1189–1197.
23. Souza, M.R., Geimer, R.L., and Moslemi, A.A. (1997) Degradation of conventional and CO2-injected cement-bonded particleboard by exposure to fungi and termites. Journal of Tropical Products 3(1): 63-69.
24. Geimer, R.L., de Souza, M.R., and Moslemi, A.A. (1996) Low-Density Cement-Bonded Wood Composites Made Conventionally and With Carbon Dioxide lnjection. DRVNA INDUSTRIJA, 47(2): 55-62.
25. Sukartana, P., Rushelia, R., and Sulastiningsih, I.M. (2000) Resistance of Wood– and Bamboo–Cement Boards to Subterranean Termite *Coptotermes gestroi* Wasmann, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 62-65.
26. Shao, Y., Qiu, J., Shah, S.P. (2001) Microstructure of extruded cement-bonded fiberboard. Cement and Concrete Research 31 (2001) 1153–1161.
27. Fernandez, E.C. and Taja-on, V.P. (2000) The use and processing of rice straw in the manufacture of cement-bonded fiberboard, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 49-54.
28. Warden, P.E.G., Savastano, Jr.H., and Coutts, R.S.P. (2000) Fiber-cement composites from Brazilian agricultural and industrial waste materials, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 55-61.
29. Booz, S. (2002) The North American fiber cement industry, Certain Teed Corporation: 247-255.
30. Ramirez-Coretti, A., Eckelman, C.A., and Wolfe, R.W. (1998) Inorganic-bonded composite wood panel systems for low-cost housing: a Central American perspective, Forest Products Journal. 48(4):62-68.
31. Soriano, F.P., Rondero, T.R.E., Manalo, A.C., Carino, C.R., Saralde, Jr.T.C., and Bonaagua, E.A. (2000) Application of wood-wool cement boards for shop-fabricated emergency shelters in the Philippines, Wood-Cement composites in the Asia region, in: Proceedings of a workshop held at Rydges Hotel, Canbera, Australia, on 10 December 2000: 153-165.