Opportunities of using bio-based materials for value-added composites

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Our forests are a naturally renewable resource that has been used as a principal source of bio-energy and building materials for centuries. The growth of world population and affluence has resulted in substantial increases in demand and in consumption for all raw materials. Resulting increases in demand for wood products provides a unique opportunity for developing new generations of renewal, sustainable and materials efficient bio-based composites. The 100-year history of the softwood plywood industry provides a good example of a successful development of an idea, a process, and eventually marketable product. The key to effectively developing marketable bio-based composites for use as building products that can be used for construction of safe and affordable structures is to identify the research and development and market needs for such products. This includes understanding the requirements for product performance, engineering processes, and product implementation.

Introduction

According to the United States (US) Census Bureau, the population of the world is 6.7 billion people today and will reach 7 billion in 2012 as the global community struggles to satisfy its needs for products produced from natural resources. The 2012 world population is over a threefold increase from two billion world population of about 50 years before. The rapid growth of world population has resulted in substantial increases in demand and consumption of raw materials. From 1970 to 2007, the world population increased about 86% and coupled with growing affluence the growth in the use of gross world products (GWP) increased about 446% which is much faster than the growth rate of world population (http://www.worldbank.org/). Responding to the needs of the rapidly growing population and affluence can present many problems and challenges to a country's ability to manage its natural resources (Bowyer et al. 2003).

Opportunity

Our forests are a naturally renewable resource that has historically been a principal souse of energy and building materials. According to the Food and Agriculture Organization (FAO) of the United Nations, the global forest harvest increased substantially from 1950 to 1990. Because of the environmental concerns and government imposed restrictions on deforestation, the global forest harvest reached its highest level at about 3.4 x 10^9 m^3 in 1990. As the world population's need for safe, affordable, environmentally-friendly shelter is expected to increase substantially, it requires seeking some new alternatives for building materials. As a direct result, this provides an opportunity to develop new bio-based composites and utilize the low-value forest resources. A good example is recently-developed straw board which is made with synthetic polymer resins. Its performance is equal or better than traditional wood particleboard and it contains no formaldehyde – a key benefit to people who are concerned about indoor air quality. This new straw board converts a bio-residue that was formerly burned – – causing air-pollution problems – into a profitable product for the furniture and cabinet industry.

Bamboo, another of our important renewable bio-based materials, is a fast growing fibrous grass that has been used mainly for furniture and flooring. Compared with wood, bamboo has higher strength, better ductility and longer durability. However, superior properties alone have not been enough to successfully turn bamboo into a series of marketable products with many diverse structural applications as compared to wood. To maximize the utilization of bamboo, much research has been conducted to understand its fundamental physical and mechanical properties and to develop bamboo composites (Lee et al. 1994, Bai 1996, Chen and Wang 2005, and Jiang et al. 2005). The construction of Pinbian Primary School in China was completed in 2004 and was the first to use bamboo plywood panels and laminated beams for structural applications, i.e., roof truss and sheathing (Chen and Wang 2005).

A good example of utilizing low-value curved (bowed) and cull small diameter trees is to add value to them such as by developing new processes to make them into laminated structural lumber. During normal logging or thinning operations, many low-value curved and cull trees are encountered and these trees present major handling problems as they proceed through the sawing and drying processes in a sawmill. Researchers at FPL initiated a project involving the straightening of small-diameter, bowed lumber for laminated structural timber by developing advanced sawing, drying, straightening, and laminating processes (Hunt and Winandy 2003). In cooperation with the Bighorn National Forest and Wyoming State Forest system, curved and cull small-diameter trees (diameters ranged from 10 to 23 cm) were used in this study. A new alternative method to reduce curvature from the cut boards through the use of microwaves and clamping during drying was developed (Hunt et al. 2005). A prototype microwave press-drier with integrated controlled restraint and heating was developed and used to straighten the curved sawn lumber during the drying process.

In a series of microwave drying and straightening tests, two parameters – initial heating temperature and pressing time were examined (Hunt et al. 2005). It was found that both heating temperature and pressing time had significant effects on straightening of the curved lumber. Higher initial heating temperature and longer pressing times resulted in better straightening. After drying, the lumber was next processed through a planer. The finished 2 by 4 stud lumber was graded using transverse vibration, a nondestructive stress grading method used to determine dynamic modulus of elasticity (DMOE). After nondestructive testing, the 2 by 4 studs were sorted and grouped according to DMOE values as follows: 25% low, 50% medium, and 25% high. Phenol-resorcinol adhesive was used to bond the 2 by 4 studs together according to their DMOE performance.

The finished laminated member was 8.9 cm (3.5 in.) by 22.6 cm (9 in.) by standard 2.4 m (nominal 8 ft) long. If a product made from small-diameter material is used primarily in a bending application, maximum properties would be obtained if the 2 by 4 studs were arranged with higher DMOE material placed on the outside. Selective placement of small-diameter 2 by 4 studs led to a range of performance options. Thus, a low- or no-value material can be engineered to produce a structurally strong and value-added product from virtually valueless small-diameter, curved timber. Parts of this process have recently been commercialized by our industrial cooperator, Wyoming Sawmill in Sheridan, Wyoming.

Development of softwood plywood

To successfully develop a marketable bio-based composite as a building product that can be used for constructing safe and affordable homes, detailed planning is necessary to identify research and development (R&D) and market needs; understand the requirements of product performance; engineer the processing; and implement production of the final product. Softwood plywood provides a classic example of successful product R&D and marketing for new bio-based composites. The history of the plywood industry is one of dramatic rise, of continual process adjustment in the face of changing resource supplies and ever-increasing marketplace competition (APA 2005a).

The idea of using wood veneers to achieve special appearance and decoration and to increase wood's natural strength and stiffness is almost as old as civilization (APA 2005a). Ancient Chinese and Egyptian furniture, built with wood veneers thousands years ago, is displayed in museums. Early plywood was typically made from decorative hardwoods and was most commonly used in the manufacture of household items. Construction plywood made from softwood species first appeared in the later 19th century. On December 26, 1865, John K. Mayo of New York City was issued a patent for what could be called plywood today; additional patents were issued three times in August 1868 (Perry 1942). In the original patent, it stated "The invention consists in cementing or otherwise fastening together a number of these scales or sheets, with the grain of the successive pieces, or some of them, running crosswise or diversely from that of the others. The crossing or diversification of the direction of the grain is of great importance to impart strength and tenacity to the material, protect it against splitting, and at the same time preserve it from liability to expansion or contraction" (Mayo 1865). Mayo envisioned that his invention of softwood plywood could be used for roof, tubing, and other structures. Unfortunately, due to apparent lack of successful advertising and business sense, Mayo was unable to turn his invention into a profitable product.

In 1905, the World's Fair held in Portland, Oregon was actively seeking new product exhibits. The Portland Manufacturing Co., a small wooden box company, decided to produce what it called "3-ply veneer work" made of Pacific Northwest Douglas-fir (Plywood Pioneer Association 1967). The first plywood panel manufactured with softwood species was developed and sent to the 1905 World Fair. During the exhibition, the plywood created considerable interests among the more than a half million visitors, including door and cabinet manufacturers. Tom Autzen, the first Douglas-fir plywood salesman of record, convinced some door manufacturers that the plywood provided cost-savings and was a better performing material to use in their products. Using all of his sales skills, Autzen secured the first order for plywood from a door company.

Technology invention and continual process improvement were critical to the early success of plywood. The first softwood plywood was developed by spreading animal protein-based glue with paint brushes and pressing the veneers together with house jacks. Production was slow and only one set of panels could be made a day. By 1907, Portland Manufacturing Co. installed an automatic glue spreader and a sectional hand press. Plywood product increased to 420 panels a day. Convinced of the promising future of plywood, the Portland Manufacturing Co. built its own door manufacturing plant to promote the use of plywood. Soon other plants began making the product and the young plywood industry spread out all along the Pacific-coasts of the Western US.

Market development and product promotion made the plywood industry grow quickly. During its first 15 years, the softwood plywood industry relied primarily on the single market for door panels. In 1920 automobile manufacturers began using plywood for running boards and trunk stock. The plywood market took off and the sales increased steadily. By 1929, there were 17 plywood mills in the Pacific Northwest and production reached a record 0.32 million square meters.

The formation of a national plywood association helped energize the plywood industry and promoted new markets for plywood. For the first two or three decades after its initiation in 1905, the plywood industry remained fragmented. Each mill had its own product quality and grading system. None had the technical capability and marketing resources to conduct research and develop and promote new uses for plywood (APA 2005a). It wasn't until 1933 that the Douglas Fir Plywood Association (the future APA – The Engineering Wood Association) formed, allowing the industry to organize, promote itself, and create standards.

Standardization, new grading systems, and improved quality enabled promotion of plywood as a standardized commodity building and construction product. Thanks to the development of water-proof adhesives, plywood soon became accepted as a common construction material, recognized as having acceptable levels of both interior and exterior performance. In 1940, the Plywood Association initiated "The House in the Sun", the first plywood demonstration house. This demonstration project along with many others successfully promoted softwood plywood to the construction industry as subflooring, roof sheathing, ceilings, and wall sheathing products (APA 2005b).

The economic boom after World War II resulted in a growing demand for houses and provided an excellent business opportunity for the plywood industry to expand. "The single biggest thing that the industry can be proudest of is that it really helped to house America after World War II.... It probably helped house a whole generation of people," says Dennis Hardman, vice president of marketing for the APA." (Tomasulo 2005). Plywood significantly reduced labor costs to construct new homes because it revolutionized the way homes were constructed, by eliminating the tedious nailing required to fasten hundreds of tongue-and-groove boards that had been traditionally used as flooring, sheathing and roofing material. By 1979, plywood production reached about 18 million m^3.

New technology development continues the evolution of wood panel products. The technological revolution that began with plywood has reached new heights. The structural panel markets, originally pioneered by softwood plywood, have themselves evolved with the development of a number of different types of structural wood panel products that have been now emerged onto the market. Oriented strand board (OSB) manufactured from lower-grade forest resources shares many characteristics with plywood. OSB was first introduced in the late 1970s. Thanks to its efficient resource-utilization potential and low production costs, OSB has been gaining recognition in the world-wide building and construction market as a durable and strong construction material. After competing with plywood for about 10 years in the construction industry, OSB was finally certified to perform as well as structural plywood in 1992. This certification made OSB an economical alternative to structural plywood and caused further market growth (Bowyer et al. 2003). Today, OSB has more than 60% of structural panel market and continues to take more of the structural-panel market.

Summaries

The 100 year-history of plywood provides a good example and guidance in developing new bio-based composites. The future challenge to sufficiently utilize the forest resources is how to deal with the variety of mixed bio-mass materials to develop market acceptable products with uniform and durable performances. To summarize, the following considerations are necessary:

(1) Economic considerations

- Target market
- Competition and opportunity
- Weakness and strengths
- Raw material supply

- Long term profitability
- Investment return and risk

(2) Environmental considerations

- Natural resource impacts
- Chemical emissions & toxic materials
- Recyclability

(3) Research and Development

- Raw material preparation
- Processing
- Performance, standard, and specification
  - ✓ Mechanical and physical
  - ✓ Fire- and water-resistance
  - ✓ Durability (decay and insect)
  - ✓ Chemical emission and toxicity
- Process optimization
- Recommendations

(4) Manufacturing

- Management
- Safety
- Process improvement

(5) Advertisement and sales

- Model/demonstration house
- Sales distribution
- Customer service and education.

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