Opportunity and Development of Bio-Based Composites

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Abstract

Our forests are a naturally renewable resource that has been used as a principal source of bio-energy and building materials for centuries. The rapid growth of world population has now resulted in substantial increases in demand and in consumption of all raw materials. This now provides a unique opportunity of developing new 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 developing a marketable bio-based composite for use as a building product that can be used for construction of safe and affordable structures is to identify the research and development (R&D) and market needs for such a product. This would include an understanding of the requirements for product performance, engineer the processing, and implement the product.

Introduction

According to United States Census Bureau, the population of the world on the December 6, 2004 had reached to 6.4 billion. This is a little over a three time 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 2004, the world population increased about 78%, but the growth in the use of gross world products (GWP) increased about 300% which is much faster than the growth rate of world population (http://www.worldbank.org/). Responding to the needs of the rapidly growing population 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 been the 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 governmental restriction of deforestation, the global forest harvest reached to its highest harvesting which was about 3.4×10^9 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. This provides an opportunity to develop new bio-based composites.

A good example is recently-developed straw board which is made with synthetic polymer resin. Its performance is equal or better than traditional wood particleboard and it contains no formaldehyde which is considered a key benefit to people who are concerned about indoor air quality. This new straw board turns a bio-residue that was formerly burnt causing it to be considered an air-pollution problem 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. Comparing with wood, bamboo has higher strengths, better ductility and longer durability. However, these superior properties have never been enough to successfully turn bamboo into a series of marketable products with many diverse structural applications as wood has. 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 made it as the first construction using bamboo plywood panels and laminated beams for structural applications, i.e., roof truss and sheathing (Chen and Wang 2005).

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, a detailed strategy is necessary to identify the R&D and market needs, understand the requirements of product performance, engineer the processing, and implement the product. This year marks 100th anniversary of softwood plywood. 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). Softwood plywood provides a classic example of successful product R&D and marketing for new bio-based composites

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 most commonly used in the manufacture of household items. However, the construction plywood made from softwood species 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; this patent was reissued three times in August 1868 (Perry 1942). In the 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). He envisioned that the invention of softwood plywood could be used for roof, tubing, and other structures. Unfortunately, lacking of successful advertisement and business sense, he was unable to turn his invention into a profitable product.

In 1905, the World's Fair held in Portland, Oregon was asking for new product exhibitions. This created a good opportunity for new inventions and products. 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 was cost-saving and better performing material to them in their products. With his enthusiastic sales skill, Tom finally secured the first order for plywood from a door company.

Technology invention and continual process improvement(s) were the key to the early success of plywood. The first softwood plywood was developed by spreading animal protin-based glue with paint brushes and pressing the veneers together with house jacks. The work was insufficient and only one set of panels could be made a day. By 1907, Portland Manufacturing Co. had installed an automatic glue spreader and a sectional hand press. Plywood product increased to 420 panels a day. Predicting the promising future of plywood, the Portland Manufacturing Co. even built its own door manufacturing plant to promote the plywood product and increase its market share. Soon other plants began making the product and the young plywood industry spread out all along the Pacific-coasts of the Western U.S.

Market development and product promotion made the plywood industry grow fast. During its first 15 years the softwood plywood industry relied primarily on a single market of 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 energized the plywood industry and promoted the new markets for plywood. During the first two or three decades after its initiation 1905, the plywood industry remained fragmented. Each mill had its own

product quality and grading system. None had the technical capability and marketing resource to research, develop, and promote new uses for plywood (APA 2005a). In 1933, 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 the 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, 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).

It 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 traditionally used as flooring, sheathing and roofing material. By 1979, the plywood production reached about 18 million m^3 which was more than double the forecast.

New technology 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 to the market. Oriented strand board (OSB) manufactured from a lower-grade forest resource shares many characteristics with plywood. It 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 more economical alternative to structural plywood and caused further market growth (Bowyer et al. 2003). Today, OSB represents more than 60% of structural panel market and it continues to grow market within the structural-panel market (Figure 2).

Summary

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 impact
- Chemical emission & toxic materials
- Recyclable

(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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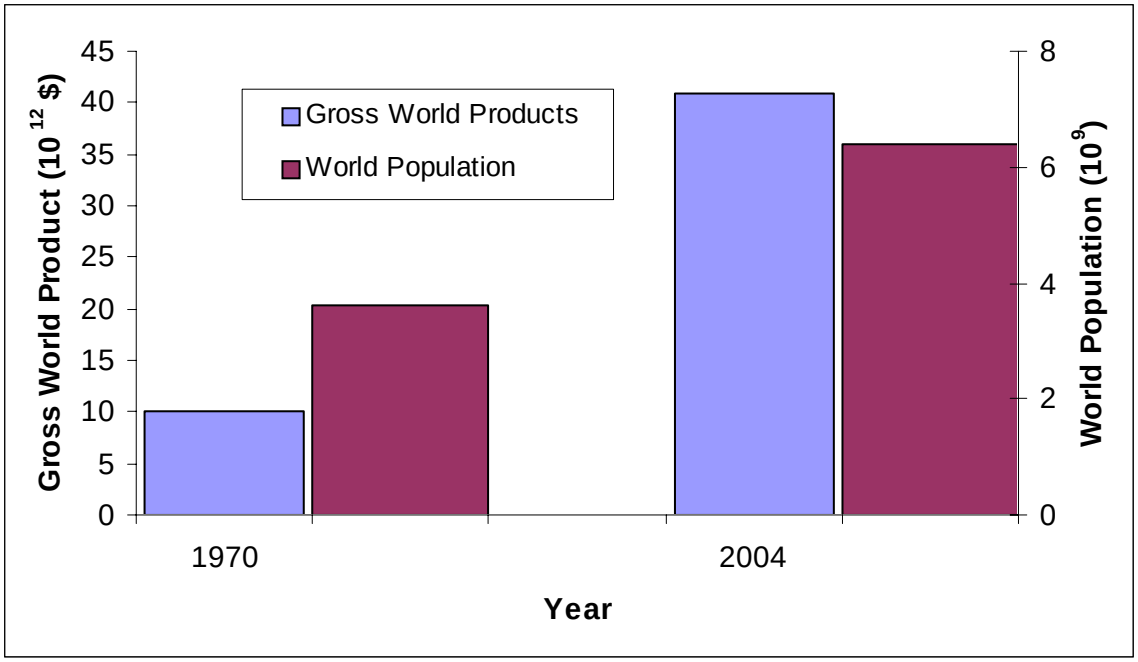

Figure 1. Gross world products and world population.

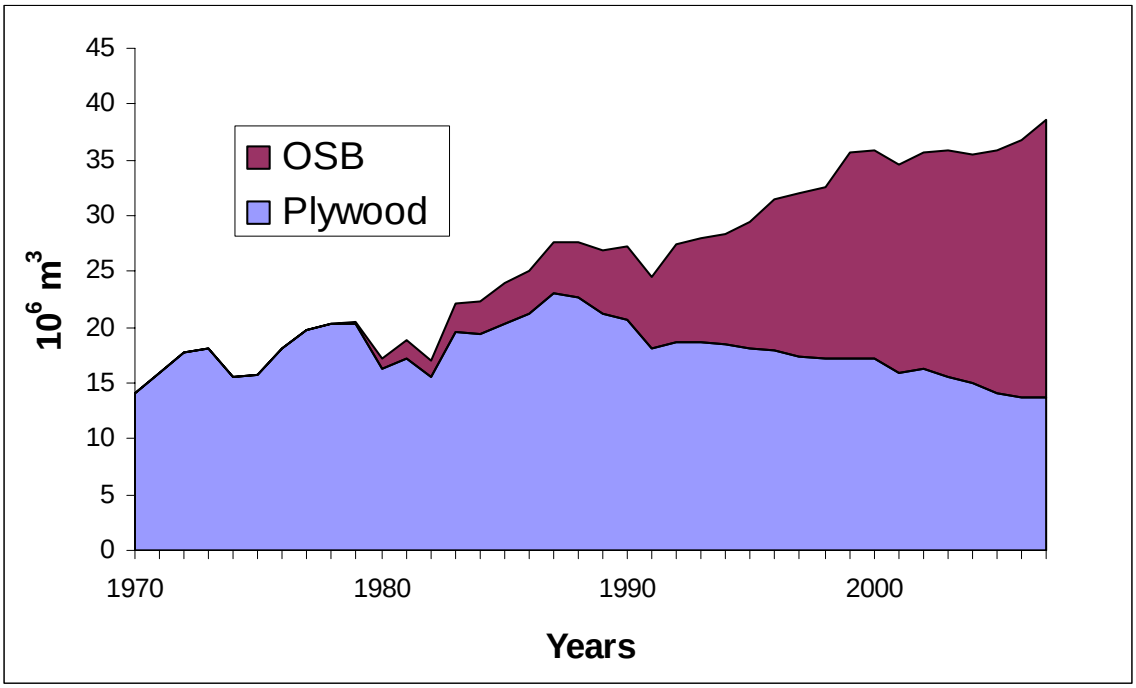

Figure 2. Plywood and OSB productions.