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Opportunities for Using Bio-based Fibers for Value-Added Composites

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ABSTRACT

Efficient and economical utilization of various bio-based materials is an effective way to improve forest management, promote long-term sustainability, and restore native ecosystems. However, the dilemma is how to deal with lesser used, undervalued or no-value bio-resources such as small diameter trees, agricultural residues (wheat straw, rice straw, and corn stalk), exotic-invasive species, recycled biofibers, and hazardous fuels and residues from fire-prone forests. This paper will present results from a number of research projects that have been conducted at USDA Forest Service, Forest Product Laboratory (FPL). The results provide new alternatives on how to utilize small-diameter curve trees for laminated structural lumber, fiber from exotic-invasive species in wood-plastic composites, bio-fibers for new engineered fiberboard products, and even mixing wood fiber with chicken-feather fiber to create more moisture-resistant medium density fiberboard (MDF). This paper will review on-going research on developing new bio-based composites derived from a series of diverse and underappreciated wood- and bio-fiber resources. Because removal of non-indigenous shrubby exotic-invasive species is expensive, to help off-set the economic costs associated with these removals and to re-introduce indigenous ecosystems in the United States, scientists at FPL are actively working on engineering and economic feasibility and process development for using these bio-fibers in wood-plastic composites. Chicken feather fiber may offer a large, economical fiber resource as an additive for MDF; a study has been completed to evaluate the properties of MDF prepared by using a series of chicken feather fiber and aspen wood fiber mixtures. A new process for utilizing low-grade or curved material has been developed and tested for engineering and economic feasibility. Parts of that process have recently been commercialized.

Keywords: bio-based, composite, value-added, invasive-species, wood-plastic

INTRODUCTION

The population of the world on the December 6, 2004 had reached to 6.4 billion which was little over three time increase from two billion about 50 years ago according to United States Census Bureau. The rapid growth of world population has resulted in substantial increase in demand and consumption of raw materials. From 1970 to 2004, the world population increased about 78%, but the gross world products (GWP) increased about 300% which is much faster than the growing 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).

The world's forests are a naturally renewable resource that has been the principal source of energy and building materials for shelters. 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 people's need for safe, affordable, environmentally friendly homes is expected to increase substantially, it requires seeking for sustainable alternatives for building materials. This provides an opportunity to develop new bio-based composites.

Winandy and Hiziroglu (2005) presented specific examples of how structural biocomposite products could add value to valueless bio-based materials in achieving land-use goals and offsetting the costs of eco-system remediation. Scientists and engineers at the Forest Products Laboratory (FPL), United States Department of Agriculture, have been working on research projects to develop economical processing methods to utilize low-value biomaterials for a variety of value-added applications. We believe that efficient and economical utilization of various bio-based fibers is an effective way to improve forest management and sustainability, and native ecosystem.

This paper highlights a number of research projects that have been conducted at FPL. The results will provide alternatives on how to utilize small-diameter curve trees for laminated structural lumber, fiber from exotic-invasive species for wood-plastic composites, bio-fibers for new engineered fiberboard, and even wood fiber with chicken-feather fiber for more durable medium density fiberboard (MDF).

RESEARCH ON BIOCOMPOSITES

Small-diameter curve trees for laminated structural lumber

During normal logging or thinning, many low-value curve trees (Figure 1) presented handling problems associated with the bowed pieces as they proceed through the sawing and drying processes in a sawmill. Scientists 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 larger and more powerful prototype microwave press-drier with integrated controlled restraint and heating was developed and used to straighten the curved sawn lumber during the drying process (Figure 2).

For 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 lumbers. The higher initial heating temperature and longer pressing times resulted in better straightening. After drying, the lumber was processed through a planer. The finished 2 by 4 lumbers were graded using transverse vibration, which is 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 values. Phenol-resorcinol adhesive was used to bond the 2 by 4s 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 products made from small-diameter material are used primarily for bending application, maximum properties would be obtained if the 2 by 4s were arranged with higher DMOE material placed on the outside. Selective placement of small-diameter

2 by 4s leads 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 WY.

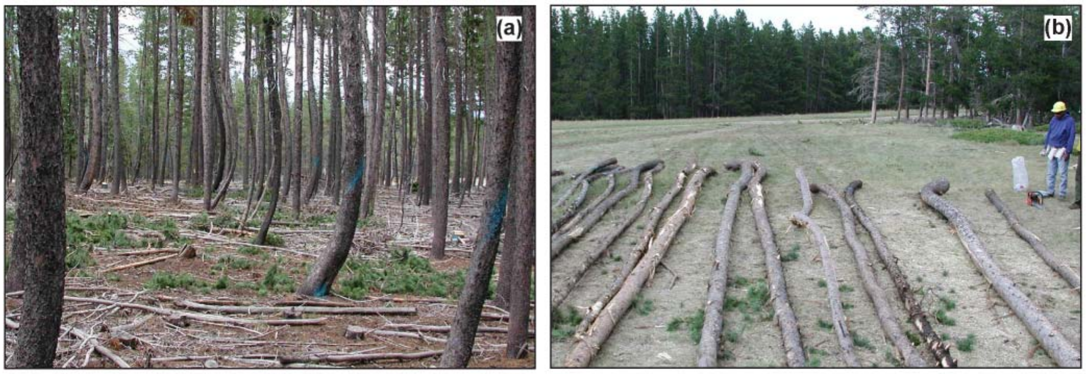

Figure 1. Low value curved trees and logs.

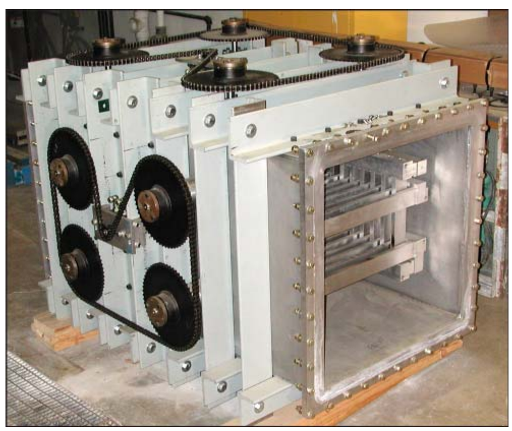

Figure 2. Microwave drying chamber showing pressing bars used for straightening curve lumbers.

Exotic-invasive species for wood-plastic composites

Salt cedar (*Tamarisk spp.*) is a non-native, invasive species in the arid Southwest of US. Salt cedar is a spreading shrub or small tree which is about 5-20 feet tall with numerous slender branches and small scale-like leaves. It was introduced in the early 1900's as a plant to stabilize stream banks subject to erosion from flooding and it spreads rapidly due to its aggressive nature and adaptability to both drought and very wet conditions (NM Salt Cedar Control Project). The stems and leaves of mature salt cedar plants secrete salt, forming a crust above and below ground that inhibits other plants (Sudbrock 1993). Salt cedar is also an enormous water consumer that disturbs native vegetation by lowering ground water levels. A single large plant can absorb 200 gallons of water a day (Hoddenbach 1987). As an aggressive colonizer, salt cedar often presents detrimental impacts to other species, wildlife, environment, and both quality and quantity of water resource.

Although salt cedar has many negative impacts on ecology, its fiber may provide a useful resources or supplement material to making wood and biocomposite materials. The value-added uses for salt cedar fiber could compensate some of the cost of removing this exotic-invasive species and eliminate waste-disposal problem. However, the dispersed nature of this salt-cedar resource and its distance from traditional wood composite mills requires that we explore technologies that are smaller, less expensive to start-up and highly adaptable to biomaterial variability. Work is currently underway for using salt cedar for wood-plastic composites (Clemons 2006).

For example, in an effort to address value-added uses for a similar invasive species in the arid southwestern U.S., FPL worked to develop technology to produce highly durable and dimensionally stable juniper and polypropylene (PP) composite panels using melt-blending and compression-molding technology (Winandy *et al* 2005). These composite panels were made from 50% whole-tree juniper and 50% recycled PP.

One-seed juniper (*Juniperus monosperma)* trees were cut and chipped by passing the trunk, branches, bark and needles through a tree chipper from the rangelands in central New Mexico. To make the desired juniper-PP composites panels, the chips were further reduced in size in a hammer mill that reduced the particle size down to the size of fine sand at FPL. The PP was a post-industrial material that was a byproduct from a company manufacturing small plastic balls. This waste PP was a granulated like material, again very similar to fine sand, resulting from a machining operation on the plastic balls during their production process.

The juniper/PP composite panels were made by mixing the juniper and PP particles together and forming that mixture into a mat. Forming was done by pouring mixed juniper and PP particles into a forming box that was placed on a metal plate. The forming box was then removed and another metal plate was placed on top of the mat. The metal plates, with the mat between them, were then placed in a hot press at 188°C and hot-pressed for 15 min. The pressure was about 2 MPa. The heat caused the plastic to melt and the pressure densified the mat into a board. The boards were then cooled by running 15°C water through ports within the press-platens for 15 min, which allowed the plastic to harden before the press was opened.

In another effort to address value added uses for invasive juniper and eastern red-cedar, FPL worked to manufacture wood plastic composite (WPC) samples (Winandy *et al* 2005). Similar to process discussed in the previous section, the raw material was hammer-milled. The largest particles were removed by sifting the wood flour using a screen with 0.4 mm openings. The wood flours were dried for at least four hours at 105°C. Each wood flour batch was blended with an injection molding grade of PP in a 32 mm compounding extruder. For comparison purposes, commercial pine wood flour was also compounded with PP. Each blend contained 40% wood flour by weight. The compounded blends were then dried and test bars were molded using a reciprocating screw injection molder. Flexural (ASTM D790, 2003), tensile (ASTM D638, 2003), and impact tests (ASTM D256, 2003) were conducted and field testing is ongoing to evaluate the exterior durability.

Chicken feather fiber for medium density fiberboard

We have also studied and developed methods for utilizing chicken-feather fibers which are a waste product left over the food processing industry by mixing them with wood fibers to make a more water-resistant MDF. In the U.S., over 4×10^9 kg of chicken feather waste is generated each year (Parkinson 1998). Chicken feathers are approximately half feather fiber and half quill (by weight). The feather fiber and quill are both made from hydrophobic keratin, a protein that has strength similar to nylon and a diameter smaller than wood fiber. The quills are used in shampoo, hair conditioner, hair coloring, and dietary supplements. The fiber is more durable and has a higher aspect ratio than the quill. Chicken feather fiber offers a large, cheap fiber market as a hydrophobic additive for making medium density fiberboard (MDF) in the wood industry.

Winandy *et al* (2003, 2006) evaluated the properties of MDF prepared by using a series of chicken feather fiber and aspen wood fiber mixtures. Two types of control panels, one set from only MDF fiber and the second only from chicken feather fiber, were made and against which the experimental panels were compared. The adhesive used for the panels was phenol formaldehyde (PF) with 5% application rate.

Initial mechanical properties showed some loss in strength and stiffness for feather fiber and wood fiber mixtures when compared to the properties of all-wood control panels, but the physical properties of feather fiber and wood fiber mixtures showed a marked improvement in resistance to water absorption and thickness swell over all wood fiber control panels. In the second study, the work focused on optimization of the ratio of chicken feather fiber and wood fiber to improve the mechanical performance and resin-fiber compatibility (Winandy *et al* 2006).

Figure 3. Pre-pressed mats with uniform wood fiber and three layer mat with chicken fiber in the core.

CONCLUSION

Small-diameter timber, agricultural fiber and bio-fiber residues, exotic-invasive species, and timber removed as hazardous fuels present environmental and economic challenges to land managers. This paper reviewed some recent and on-going research projects at the Forest Products Laboratory related to utilizing low-grade or virtually valueless biomass to manufacture value-added bio-based composite panels. The results showed the performance and potential market applications of these newly-developed biocomposite materials could be promising. Development of value-added products such as these can provide tools to help forest and land managers to improve and restore native eco-systems and promote forest sustainability.

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