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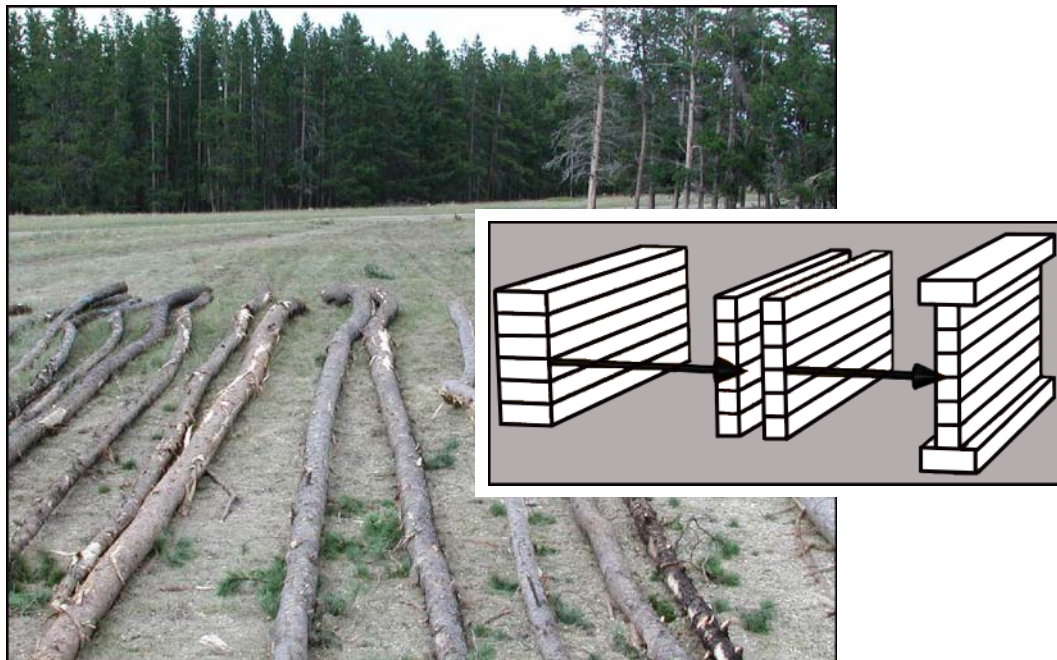
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Lam I-Joists: A New Structural Building Product From Small-Diameter, Fire-Prone Timber

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Abstract

The goal of our research is to promote healthy and sustainable forests by developing value-added uses for curved and small-diameter trees. In typical North American logging or thinning operations, much of this low-value timber is felled and left on the ground, chipped, or burned because most mills are not equipped to handle it. By understanding the fundamental processing requirements for and the mechanical properties of curved and small-diameter material, we can gain insight into possible options for using this resource. Through cooperative efforts with industry, universities, and government institutions, we are working to use innovative technologies to investigate the potential for using an additional 8.5 to 17 million board feet per year of fire-prone “woody” fuel per forest unit for value-added products. In the study reported here, research was focused on processing small-diameter curved and cull timber into dimensional 2 by 4 studs and then converting that material into a value-added laminated I-beam, called LamLumber. This paper describes research to date on processing needs and basic research being conducted on small-diameter timber.

Keywords: laminated lumber, I-beam, small diameter

Contents

	Page
Introduction.....	1
Background.....	1
LamHeader.....	2
Problems With Curved Trees.....	2
Objectives.....	3
General Research Program.....	3
Project Objectives.....	3
Experimental.....	3
Material Selection and Processing.....	3
Beam Fabrication.....	4
Straightening of Curvature by Microwave Drying.....	4
Discussion.....	4
Ongoing Research.....	5
Literature Cited.....	5

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Lam I-Joists: A New Structural Building Product From Small-Diameter, Fire-Prone Timber

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Introduction

Over the past 50 years, forest biomass has increased as a result of normal growth and the suppression of forest fire, which contributes to high forest fuel loads (Fig. 1a). In the absence of thinning, whether manually or by natural means, many of these forests have become prone to catastrophic forest fire, insect infestation, and disease. Moreover, the risk of loss of property and life through fire has increased dramatically with the expansion of the wildland–urban interface. The amount of residual hazardous fuel in these forests thus needs to be reduced.

During normal logging or thinning, many low-value trees are either left standing or are felled and left on the ground (Fig. 1b), chipped, or burned, because most North American mills are usually not able to handle this material. Much low-value material is also left in the forest because there are few or no local product options that can provide economic benefit through utilizing this material. This is a particular problem in many areas of the western United States, where forests are located far from metropolitan areas and

transportation costs are high. New value-added product options need to be developed for low-value material.

To address the problem of value-added options, the Forest Products Laboratory is cooperating with several Wyoming entities—Wyoming Sawmill, Inc. (Sheridan, Wyoming), Bighorn National Forest, Wyoming State Forestry Department, and University of Wyoming–Laramie, as well as Genesis Laboratories of Batavia, Illinois, to evaluate the processing and material properties of small-diameter and cull timber for potential use in laminated I-beams.

Background

The forest fire season of 2000 was the most costly on record for the United States, costing the government more than US\$1.36 billion (10⁹), with additional losses in private property. The 2002 fire season was nearly as costly.

In the wake of these fires, the general public called for the government to help reduce losses resulting from forest fires.

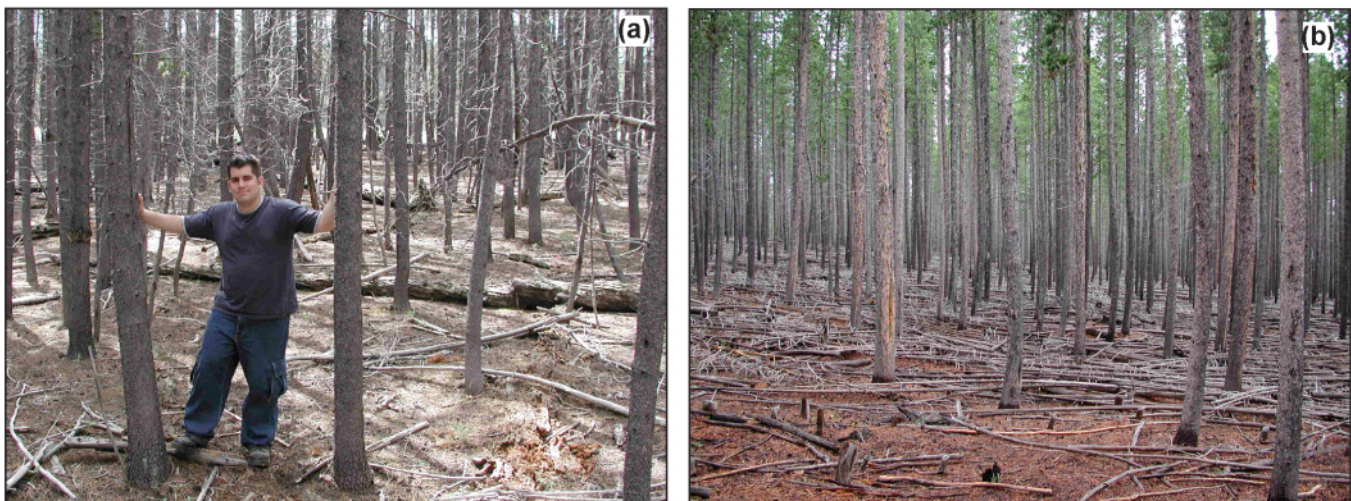


Figure 1—Comparison of suppressed and thinned forest stands. (a) Suppressed-growth stand before thinning, small-diameter trees spaced 1 to 1.5 m (3- to 5 ft) apart. (b) Thinned stand, trees spaced 2 to 3 m (6.5 to 9.8 ft) apart, approximately 15 years after thinning. Note significant dry slash residual on forest floor.

The U.S. Congress funded projects related to hazardous fuel reduction, including our work on the potential of using low-value small-diameter and cull material for value-added laminated products (Hunt 2000, Hunt and Winandy 2002).

The end-use engineering requirements and material properties of products made from small-diameter material determine the applications for which it can be used. Under normal growing conditions, small-diameter trees contain a high percentage of juvenile wood (first 5 to 20 growth rings). The strength properties of juvenile wood are significantly lower (0.45 to 0.95) than that of mature wood (Forest Products Laboratory 1999). However, in suppressed growth timber, the percentage of juvenile wood can be much lower than that of similarly sized faster-grown timber. Thus, if the suppressed growth rate is not too slow, i.e., not greater than 50 rings/in. (20 rings/cm) (FPL 1999), it is possible that a suppressed-grown timber might actually result in a high strength material, even though classified as small diameter.

LamHeader

We needed to show how innovative wood products and processes could add significant value to small-diameter, fire-prone timber and thereby offset the costs associated with reducing forest fuel loadings. The product selected for study was LamHeader, developed and patented by Wyoming Sawmill, Inc. (Sheridan, Wyoming). LamHeader is a laminated wood product that can be made from various grades of sawn material and designed to meet a variety of engineering requirements (Wyoming Sawmill, Inc. 2002). LamHeader is made by laminating stud-grade material into a beam, resawing the laminated beam to produce two web sections, and then bonding a flange top and bottom of 2 by 4 lumber to produce a laminated I-beam (Fig. 2).

The advantages of the process used to make LamHeader include the following:

- Engineered beam properties are based on performance requirements.
- Material is used more efficiently.

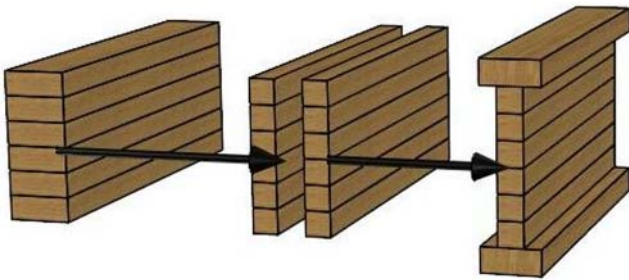


Figure 2—Simplified process for fabricating LamHeader. Stud material is laminated, resawn, and then bonded with top and bottom 2 by 4 flanges.

- Defects are distributed, making a more uniform wane-free product.
- Some curved, warped, and twisted material can be straightened in the laminating process.
- The laminating process produces a straighter, more dimensionally consistent material.
- Low-value economy grade lumber is upgraded to a value-added engineered product.

LamHeader has been made commercially using relatively straight-grained, moderate- to high-quality timber. Our question was, Could we adapt this technology to convert low-value small-diameter curved and cull timber into a product with value similar to that of LamHeader?

Processing straight, mature, “stud-grade” timber into LamHeader with current technology is not difficult. The challenge is to determine whether small-diameter curved and cull material can be processed and if it has sufficient strength properties to be marketable.

Several technologies are combined to produce a modified LamHeader. First, special sawing equipment is used to “follow” the irregular shape of the small-diameter logs. Second, curved boards are straightened in a microwave drying process. The boards are stress-graded and segregated into low and high modulus of elasticity (E) groups. The low- E -rated boards are bonded and vertically resawn to produce webs. The high- E -rated flanges are laminated with the laminated webs to form a laminated structural I-beam, known as Lam-I-Joists. The advantage of this process is that the lower value web material is sandwiched between higher E -rated flanges to engineer a stronger and higher-value laminated structural I-beam.

Problems With Curved Trees

In the past decade, several machinery manufacturers have been developing sawing equipment specifically designed for small-diameter curved trees. Current equipment can handle from 2% to 3% curvature. Following the curvature of the tree significantly increases strength by following the grain; conversely, cutting across the grain, as is done with conventional sawing equipment, reduces strength. Drying defects are also reduced by following the grain angle of the timber. If a sawmill is considering small-diameter utilization and improved yield, curve-sawing equipment should be considered. Highly curved material (above 3%) is presently beyond the current capability of commercial equipment. However, the technology is advancing quickly. As this technology improves, further studies will be needed to determine processing issues and performance properties.

As the curvature of the tree increases so do handling problems associated with the bowed pieces as they proceed through a sawmill. Two technical challenges arise as

curvature increases. The first is cutting curved material with large single or double curvatures. The second is processing the material once it has been cut. Curved material does not lend itself to easy handling through a sawmill. Straightening all or part of the material would facilitate handling and utilization.

Another part of our research program is to determine the potential for straightening curved pieces. We decided to investigate this problem by using a microwave process that could straighten and dry the material simultaneously.

Objectives

General Research Program

The overall goal of our research is to maintain healthy and sustainable forests through developing an economically viable process or processes and products that can utilize small-diameter timber from logging and thinning operations. In this way, “whole site” forest management can be implemented to better utilize the fiber resource while minimizing the risk of insect attack, disease, and fire. Providing economical options for using small-diameter material also encourages rural development. This 3-year research project is currently in its second year and is funded under the USDA Forest Service National Fire Plan (Hunt 2000, Hunt and Winandy 2002).

Project Objectives

The goal of our project is to develop uses for low- or no-value curved and cull small-diameter trees. We are interested in gaining a better understanding of

- optimized processing methods for small-diameter curved and cull material,
- basic properties of small-diameter curved and cull material,

- properties of value-added products from this material (predicted compared with actual), and
- overall economics for utilizing small-diameter material.

Experimental

Material Selection and Processing

In cooperation with the Bighorn National Forest and Wyoming State Forest, 726 curved and cull small-diameter trees were cut for this study (Fig. 3). The material was selected because of significant curvature or cull features that rendered the tree essentially valueless for standard grading and sawing practices. Tree diameters ranged from 10 to 23 cm (4 to 9 in.) diameter at breast height.

The trees were bucked into more than 2,000 2.4-m (8-ft) sections and taken to Wyoming Sawmill, Inc. The trees were cut with conventional saw processing equipment into standard 38- by 89-mm (nominal 2- by 4-in.) lumber (hereafter referred to as 2 by 4). Although the equipment was designed to handle trees ≥ 30 cm (≥ 12 in.) in diameter, we were able to process the small-diameter material by paying special attention to handling issues along the line.

All sections were initially rough-cut through a standard quad band-mill to form two flat faces on opposite sides to 96-mm (3.77-in.-) thick flitches. Flitches that would yield one or more nominal 2 by 4 studs were processed. A small amount of wane was allowed. Sections with large single sweep or small multiple curves were first rough-cut into flitches by orienting the curve “horns up” (Fig. 4). Sections with more than 2% curvature were removed and stacked separately. A total of 251 single- and multiple-curved flitches with greater than 2% curvature were separated from the straighter flitches for special processing. Because the sawing process was not



Figure 3—Small-diameter curved and cull trees for study: (a) previously thinned stand from which study trees were removed; (b) small diameter material removed for study.

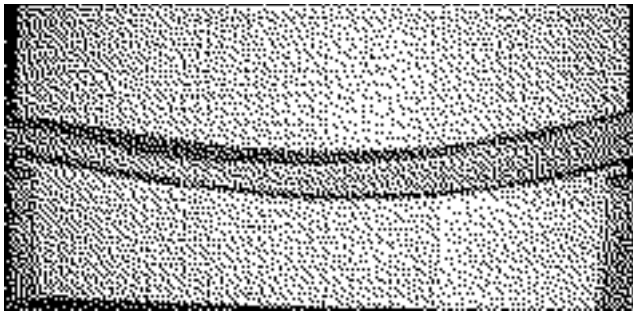


Figure 4—Example of “horns up” cut made by conventional bandsaw on small-diameter tree with 6% curvature.

optimized for small-diameter trees, a few trees were unusable. Flitches with little or no curvature were cut into 2 by 4 lumber, stacked, and conventionally dried to equilibrium moisture content below 19%.

After drying, the lumber was processed through a planer. The finished 2 by 4 lumber was shipped to the University of Wyoming for nondestructive stress grading. Transverse vibration was used to determine dynamic modulus of elasticity (DMOE).

Beam Fabrication

Given the wide range of possible properties for small-diameter trees, it is important to presort materials according to strength properties. 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.

Within each group, six studs were arranged with defects (wane) randomly oriented toward the inside of the beam (Fig. 5). In addition, it was critical that a full flat surface of the top and bottom members was faced away from the core to achieve a maximum gluing surface for bonding the web sections to the flanges. Phenol-resorcinol adhesive was used to bond the 2 by 4s together. 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. Once bonded, the beams were resawn and replaned lengthwise to produce two web sections 4.5 cm (1.5 in.) by 22.6 cm (9 in.) by 2.4 m (nominal 8 ft) long (see Fig. 2).

Visually graded Select Structural 2 by 4s from the three DMOE-rated groups were selected for fabrication into flange sections. These boards were finger-jointed end-to-end to produce 7.3-m- (24-ft-) long flanges. For half the web sections from each DMOE group, the flanges were bonded to form laminated I-beams; the other half remained as web sections for comparison testing. To date, both nondestructive and destructive tests have been performed on the web sections and I-beams at the University of Wyoming–Laramie. The results are being analyzed.

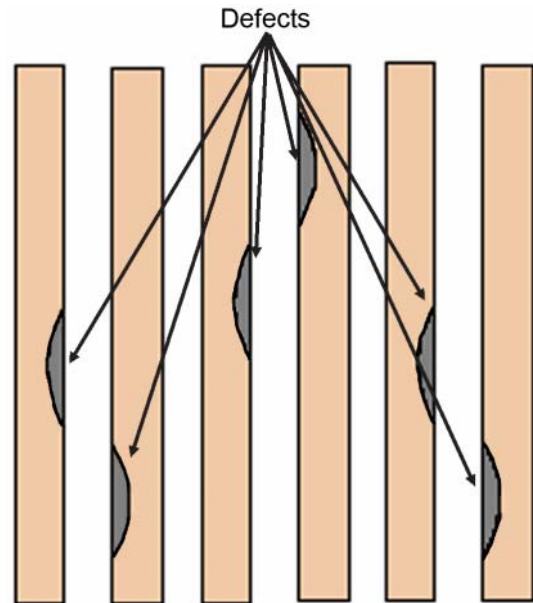


Figure 5—Defects of each group of six low- or no-value 2 by 4s were randomly distributed. Lumber was resawn into web sections to fabricate a value-added laminated I-beam. (Courtesy of Chris Wallace, Structural Research Engineer, Wyoming Sawmill, Inc.)

Straightening of Curvature by Microwave Drying

Some board warping and curvature can be tolerated in processing. Excess curvature, however, may require significant additional handling, which makes the utilization of this material too costly. Approximately 100 single-curved flitches were shipped to the Forest Products Laboratory. Curved 2 by 4s were cut from these flitches. Tests will be conducted to evaluate whether curved boards can be straightened during the microwave press-drying process (Fig. 6).

Discussion

Initial manufacturing included the lamination of multiple small-diameter 2 by 4s into nominal 2 by 9 (standard by 38- by 216-mm) engineered lumber. Because most small-diameter material contains a great amount of strength-reducing wane, these pieces were remanufactured at Wyoming Sawmill, Inc., into a “new” engineered wood product called LamLumber. The patented LamLumber process makes it possible to utilize small-diameter material by remanufacturing it into an engineered wood product with randomly located defects. The manufacturing process places the wane face on the interior of the LamLumber, where it is no longer considered as wane. The defects can then be offset with other defects (Fig. 5), which results in a viable structural product by reducing the number of defects in the product cross-section.

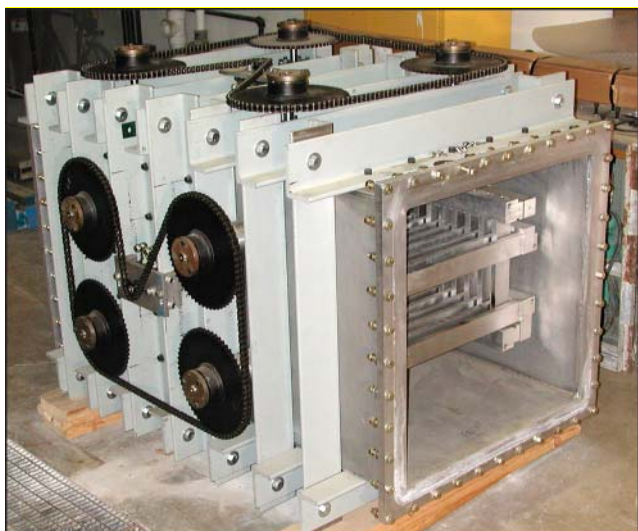


Figure 6—View of microwave drying chamber showing pressing bars that will be used to straighten and hold the curved 2 by 4s during drying.

A total of 76 7.3-m (29-ft) laminated 3.8- by 22.9-cm (1.5- by 9-inch) beams were fabricated at Wyoming Sawmill, Inc. Half of these beams were laminated with 3.8- by 8.9-cm (1.5- by 3.5-inch) flanges. All the material was taken to the University of Wyoming–Laramie for bend and shear tests. The University of Wyoming has completed mechanical evaluations and is currently analyzing that data.

Preliminary results from Master’s thesis work by Rebecca Faverty and Ryan Rayda of the University of Wyoming–Laramie¹ have shown that beams made from small-diameter trees have sufficient strength properties to be competitive with commercial laminated products. Good correlations were obtained for the nondestructively measured board properties and their predicted laminated product properties with actual laminated beam properties. Individual reports summarizing this work are in preparation.

Using 2 by 4s to manufacture I-beams has several advantages. First, defects in the material—whether the result of curvature, knots, grain angle, or wane—are redistributed more evenly through the web section, thus reducing stress concentration effects and upgrading load-carrying capability. Second, if curvature is the major defect in an individual 2 by 4 board, laminating will help straighten the board. Third, compared to an oriented strandboard (OSB) webbed I-beam, a web section made from solid wood as can carry substantially higher compressive loads without buckling.

¹Faverty, R.N. Feasibility of using small diameter lumber in glued laminated applications. Rayda, R.R. Non-destructive evaluation of lumber from cull and suppressed growth trees. Master’s theses. University of Wyoming–Laramie.

This is especially critical for beams used as load-carrying headers. Thus, a low- or no-value material can be engineered to produce a structurally strong and value-added product from virtually valueless small-diameter, fire-prone timber.

If products made from small-diameter material are used primarily for a bending application, maximum properties would be obtained if the 2 by 4s were arranged with higher modulus of elasticity material placed on the outside. Selective placement of small-diameter 2 by 4s leads to a range of performance options.

Ongoing Research

The goal of the second phase of our research, presently being conducted at the Forest Products Laboratory, is to determine alternative methods to reduce curvature from the cut boards through the use of microwaves and clamping during drying. We are developing a larger and more powerful prototype microwave press-drier with integrated controlled restraint and heating that will be used to straighten the curved sawn lumber during the drying process. Our partner in this work is Genesis Laboratories.

In the third phase of the research, the Forest Products Laboratory Economics work unit has been conducting an economic and technology assessment of the process (report in preparation).

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