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Some Mechanical Properties of Hardwood-Based Particle Composite Materials

Robert J. Ross
Rubin Shmulsky

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Abstract

Undervalued Hardwoods for Engineered Materials and Components was prepared to serve as a primary reference for the use of hardwood timber. It has been widely used and was recently updated and published by the Forest Products Laboratory (FPL–GTR–276).

The use of hardwoods for particle composite materials and products was not included in the recent edition. A subsequent review of the literature revealed that several seminal research studies were completed on the use of hardwoods in engineered particle composite materials. This report, which serves as an addendum to *Undervalued Hardwoods for Engineered Materials and Components, Second Edition*, provides a summary of those important contributions.

Keywords: hardwoods, composites, wood, mechanical properties, *Undervalued Hardwoods for Engineered Material and Components*

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Some Mechanical Properties of Hardwood-Based Particle Composite Materials

Robert J. Ross, Supervisory Research General Engineer
Forest Products Laboratory, Madison, Wisconsin, USA

Rubin Shmulsky, Professor and Department Head
Mississippi State University, Mississippi, USA

Introduction

Engineered wood components represent one of the fastest growing segments of the forest products industry. Most engineered components are manufactured from softwoods, such as Douglas-fir, the southern pines, or spruce–pine–fir lumber. During the past decade, significant research and development efforts have been devoted toward investigating the use of lower grade hardwood resources in engineered materials and components. Studies aimed at developing appropriate drying technologies, lumber grading procedures, and various engineered materials and components have been conducted.

Undervalued Hardwoods for Engineered Materials and Components was prepared to serve as a primary reference on the use of the undervalued hardwood resource in engineered components (Ross and Erickson 2005). It is a compilation of results obtained from research and development studies focused on using low-grade hardwood materials in engineered components. Part one focused on basic information about this resource: availability, mechanical properties, log grading techniques, and appropriate drying methods. Part two summarized studies that examine use of this resource in trusses, laminated veneer lumber, I-joists, and other applications. The information presented has been widely used internationally. A second edition was recently published (Ross and Erickson 2020) that includes coverage of additional topics, including implications of utilizing these materials for forest managers, fundamental properties of wood from hardwood species, technologies for sorting hardwood logs, ultrasonic grading for hardwood veneer, hardwoods for specialty engineered materials and products, and nanocellulosic products from hardwood species.

The primary focus of *Undervalued Hardwoods for Engineered Materials and Components* was utilization of hardwoods in solid wood and engineered composites, specifically laminated veneer lumber and glued-laminated timber products. This report provides a summary of research that has been conducted to examine the use of hardwood species in particle-based composite materials.

Research Studies Summary

Wood-based particle composite materials are manufactured by bonding small wood particles together under pressure at elevated temperatures. These materials have well-controlled properties and consequently are used in a variety of applications in the wood construction industry.

Several research studies have been conducted to examine the use of hardwood species for particle-based composite materials. Following are summaries of seminal studies conducted on the topic. Table 1 presents some important experimental variables from those studies.

Hse (1975) designed a study that focused on using nine species of hardwoods. The species he chose—sweetgum, hickory, black tupelo, red oak, post oak, white oak, sweetbay, white ash, and red maple—were selected because at that time they represented approximately 72% of total hardwood resource growing on southern pine sites. His experimental design consisted of (1) specific gravity—0.633, 0.713, 0.793; (2) particle geometry—3 in. long, 3/8 in. wide, 0.015 in. thick; (3) particle orientation—random; (4) a phenolic adhesive and wax was applied to the flakes prior to hot pressing. All panels were conditioned at 50% relative humidity and 80 °F prior to the preparation of specimens for mechanical and dimensional stability testing.

Maloney (1983) first investigated utilization of red alder as furnish for flakeboard. The objective of his study was to determine the feasibility of using red alder furnish as either the entire structural panel or only as core material. Two different types of flakes were analyzed in the study, drum-cut flakes that were hammer milled to a 0.015-in. thickness and 1.5-in. length, and ring-cut flakes, 0.015 in. thick by 0.750 in. long. All flakes were dried to a nominal moisture content of 4%. Phenol-formaldehyde resin and wax were applied to the flakes at levels of 6% and 1%, respectively, based on the ovendry weight of furnish. Flakeboards were produced at two specific gravity levels, 0.64 and 0.72. Experimental panels were 12 by 15 in., 0.50 in. thick.

Adams (1984) reported on work conducted to develop a unique, high-strength composite wood material and corresponding products. The material was composed of

Table 1—Important raw material variables of particle composite materials manufactured from several hardwood species

Species	Particle geometry/description	Particle alignment	Adhesive type/ other additive	Reference
Alder	2- and 1.125-in.-long strands, 4.5-in.-long flakes	Random, maximum alignment	Phenolic/wax	Maloney and others 1984, Pellerin and others 1995
	0.033 in. thick	Random	Phenolic/wax	Maloney 1983
Ash				
Green	2- and 3-in.-long, 0.015- and 0.025-in.-thick flakes	Random, maximum alignment	Phenolic/wax	Hoover and others 1992
White	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
Aspen	2- and 3-in.-long, 0.015- and 0.025-in.-thick flakes	Random, maximum alignment	Phenolic/wax	Hoover and others 1992
Aspen/balsam fir	Laboratory roundwood flaker-produced flakes	Maximum alignment	Isocyanate	Adams 1984, Ross 1984
Birch, paper	2- and 3-in.-long, 0.015- and 0.025-in.-thick flakes	Random, maximum alignment	Phenolic/wax	Hoover and others 1992
Hickory	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
Maple				
Bigleaf	4.5 in long flakes, 0.033 in thick	Random, maximum alignment	Phenolic/wax	Pellerin and others 1995
Red	2- and 3-in.-long, 0.015- and 0.025-in.-thick flakes	Random, maximum alignment	Phenolic/wax	Hse 1975
	3- by 3/8-in., 0.015-in.-thick flakes			Hoover and others 1992
Oak				
Post	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
Red	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
Northern red	2- and 3-in.-long, 0.015- and 0.025-in.-thick flakes	Random, maximum alignment	Phenolic/wax	Hoover and others 1992
White	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
Sweetgum	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
	3- by 3/8-in., 0.015-in.-thick flakes			
Sweetbay	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975
Tupelo, black	3- by 3/8-in., 0.015-in.-thick flakes	Random	Phenolic/wax	Hse 1975

aligned elongated flakes bonded together using a water-resistant adhesive. The flakes were treated with wood preservatives to provide protection against biodeterioration and weathering.

A comprehensive study on the use of red alder as a raw material for the manufacture of oriented strandboard (OSB) was conducted by Maloney and others (1984). This study included an examination of several manufacturing variables (particle size, thickness, and orientation) and their effect on bond performance, flexural properties, and durability. Four types of flakes were examined: ring-cut flakes from 3/4-in. pulp chips, nominal 1-1/8-in. and 2-in. drum-cut strands, and 1-5/8-in.-long wafers.

In a study concerning the prediction of the mechanical properties of single-layer, mixed species, oriented composites, Hoover and others (1992) utilized five northern hardwoods species (northern red oak, red maple, paper birch, green ash, and aspen). Single-species panels were made and tested in an attempt to correlate to properties of mixed-species panels. Disc-cut flakes of 2- and 3-in. lengths and two thicknesses (0.015 and 0.025 in.) were blended with a phenolic resin and wax. Flakes were aligned during mat formation.

Pellerin and others (1995) conducted a study to examine the use of red alder and bigleaf maple for oriented-strand lumber. Laboratory panels were manufactured from several sizes of flakes and a phenolic adhesive. After conditioning, static mechanical tests were performed and results analyzed. Results supported the hypothesis that useful oriented-strand lumber can be made from these two western hardwood species.

Mechanical Properties

Mechanical property data for clear wood from the species used in the research studies described above are presented in Table 2 (Ross 2010). Tensile and bending modulus of elasticity (MOE) and strength values for the composite materials are summarized in Tables 3 and 4, respectively. Internal bond and interlaminar shear strength properties are presented in Table 5.

Table 2—Physical and mechanical properties of clear wood from several hardwood species

Species	Specific gravity	Bending properties: Modulus of elasticity ($\times 10^6$ lb/in^2)	Bending properties: Strength (lb/in^2)	Shear strength (parallel to grain) (lb/in^2)
Alder	0.41	1.38	9,800	1,080
Ash				
Green	0.56	1.66	14,100	1,910
White	0.6	1.74	15,000	1,910
Aspen				
Bigtooth	0.39	1.43	9,100	1,080
Quaking	0.38	1.18	8,400	850
Birch, paper	0.55	1.59	12,300	1,210
Hickory	0.6–0.72	1.70–2.26	13,700–20,200	1,740–2,430
Maple				
Bigleaf	0.48	1.45	10,700	1,730
Red	0.54	1.64	13,400	1,850
Oak				
Post	0.67	1.51	13,200	1,840
Red				
Northern red	0.63	1.82	14,300	1,780
White	0.68	1.78	15,200	2,000
Sweetgum	0.52	1.64	12,500	1,600
Tupelo, black	0.5	1.2	9,600	1,340

Table 3—Tensile properties of hardwood particle composite materials

Species	Modulus of elasticity ($\times 10^6$ lb/in^2): Parallel to alignment	Modulus of elasticity ($\times 10^6$ lb/in^2): Perpendicular to alignment	Ultimate tensile stress (lb/in^2): Parallel to alignment	Ultimate tensile stress (lb/in^2): Perpendicular to alignment	Reference
Ash (green)	0.97	0.28	4,580	1,250	Hoover and others 1992
Aspen	1.2	0.37	4,400	1,530	Hoover and others 1992
Aspen/balsam fir	2.03		5,838		Ross 1984
Birch (paper)	1.06	0.32	3,450	1,150	Hoover and others 1992
Maple (red)	0.81	0.27	3,520	1,320	Hoover and others 1992
Oak (northern red)	0.82	0.25	2,680	880	Hoover and others 1992

Tensile Modulus of Elasticity and Strength

Results from these research studies reveal that tension properties for composites from the hardwood resource are highly dependent upon particle alignment. MOE values ranged from 0.81 to 2.03 × 10^6 lb/in^2 in the direction of alignment. MOE values ranged from 0.25 to 0.37 × 10^6 lb/in^2 perpendicular to particle alignment. Ultimate tensile stress values ranged from 2,680 to 5,838 lb/in^2 parallel to alignment and from 880 to 1,530 lb/in^2 perpendicular to alignment. The reported values are lower than clear wood values for these species. However, they do indicate that relatively strong composite materials can be made from this resource.

Bending Modulus of Elasticity and Strength

Bending modulus of elasticity and strength values were also found to be highly influenced by particle alignment. Bending MOE values ranged from 0.76 to 1.92 × 10^6 lb/in^2 parallel to alignment and 0.23 to 0.34 × 10^6 lb/in^2 perpendicular to alignment. Similarly, bending strength values parallel to alignment ranged from 4,000 to 10,518 lb/in^2 parallel to alignment and 1,000 to 2,937 lb/in^2 perpendicular to alignment. In general, these values are lower than values reported for clear wood from these species. However, all are above values found for randomly aligned composites, and composites from several species were comparable and approached those for clear wood.

Table 4—Flexural properties of hardwood particle composite materials

	Modulus of elasticity ($\times10^6$ lb/in^2)			Ultimate bending stress (lb/in^2)			
Species	Random orientation	Parallel to alignment	Perpendicular to alignment	Random orientation	Parallel to alignment	Perpendicular to alignment	Reference
Alder	0.35–0.60	0.75–1.30	0.13–0.21	1,800–4,000	4,000–8,500	1,000–1,900	Maloney and others 1984
		1.01	0.34		6,096	2,937	Pellerin and others 1995
Ash							
Green		0.9	0.29		7,020	2,510	Hoover and others 1992
White	0.62–0.84			5,129–7,888			Hse 1975
Aspen		0.98	0.31		6,420	2,846	Hoover and others 1992
Aspen/balsam fir		1.92			10,158		Ross 1984, Ross and Pellerin 1988, Adams 1984
Birch, paper		0.95	0.32		6,020	2,430	Hoover and others 1992
Hickory	0.71–0.85			4,511–7,228			Hse 1975
Maple							
Bigleaf		1.09	0.29		7,112	2,240	Pellerin and others 1995
Red	0.72–0.88			6,601–8,521			Hse 1975
		0.76	0.27		5,660	2,464	Hoover and others 1992
Oak							
Post	0.68–0.72			4,533–6,374			Hse 1975
Red	0.94–0.88			5,537–6,968			Hse 1975
Northern red		0.82	0.23		5,120	1,859	Hoover and others 1992
White	0.51–0.68			3,914–5,285			Hse 1975
Sweetgum	0.68–0.82			5,693–7,783			Hse 1975
Sweetbay	0.94–1.03			8,342–10,080			Hse 1975
Tupelo, black	0.50–0.62			5,808–8,190			Hse 1975

Internal Bond and Interlaminar Shear Strength

Internal bond and interlaminar shear strength tests are conducted for wood composite materials and used as an indication of how well the particles are bonded together. For all the species evaluated, internal bond and interlaminar shear strength values indicated that bonding of the particles is possible.

Densification

To achieve the desired bonding characteristics and associated mechanical properties, densification is required. Densification of particulate composites is generally on the order of 15% to 35%; that is, the finished composites are often on the order of 15% to 35% denser than their raw materials. This factor manifests itself as extra weight as compared to many softwood composites. As such, particulate composites made from hardwoods often have less favorable strength-to-weight and stiffness-to-weight ratios than those from softwood species. In many applications, this factor is irrelevant, but it is always a consideration with respect to shipping and handling.

Potential Applications

In a general sense, softwood-, hardwood-, or mixed-species composites are interchangeable. Their mechanical properties are often similar. In some cases, such as casegood furniture and automobile components, light weight is important, so those applications are less favorable for hardwood-based composites. In other cases, such as many building and industrial products, heavier weight can be beneficial. In the case of seismic loading, building mass is often a favorable characteristic with respect to overall motion and vibration. In the case of industrial panelized products, such as concrete forming and environmental access mats, weight is a negative factor during shipping but a positive characteristic once the mats are in use on the ground. In these applications, hardwood-based composites are equally, if not more, desirable. Additionally, many hardwood species have elevated toughness, resilience, and abrasion resistance characteristics. Applications where these factors may be important include heavy wear surfaces, industrial decking or planking, and marine-related applications (provided moisture proofing is considered).

Concluding Comments

Research studies have been conducted to examine using a range of hardwood species in the manufacture of particle-based composite materials. These studies showed that it is possible to produce particle composite materials of sufficient stiffness and strength to be useful in engineering applications. Using or incorporating otherwise underutilized species has advantages and disadvantages. Raw material costs can be low, which is favorable. Processing costs, however, are similar to other more commonly used

Table 5—Internal bond and interlaminar shear strength of hardwood particle composite materials

	Internal bond (lb/in^2)		Interlaminar shear strength (lb/in^2)		
Species	Random orientation	Parallel to alignment	Parallel to alignment	Perpendicular to alignment	Reference
Alder	140–178				Maloney and others 1984, Maloney 1983
		56–88			Pellerin and others 1995
Ash					
Green			572	430	Hoover and others 1992
White	83–273				Hse 1975
Aspen			402	335	Hoover and others 1992
Birch, paper			303	242	Hoover and others 1992
Hickory	65–107				Hse 1975
Maple					
Bigleaf		70–119			Pellerin and others 1995
Red	97–315				Hse 1975
			484	435	Hoover and others 1992
Oak					
Post	58–119				Hse 1975
Red	55–146				Hse 1975
Northern red			284	228	Hoover and others 1992
White	51–88				Hse 1975
Sweetgum	81–196				Hse 1975
Sweetbay	109–260				Hse 1975
Tupelo, black	113–385				Hse 1975

species groups such as southern pines, Douglas-fir, and spruce–pine–fir. Material properties vary but are often comparable to like composites that are manufactured from softwoods. As the woody raw material is often the costliest component of the finished product, in some cases low-value hardwoods have a cost advantage. That said, the relatively high density of these hardwood composites often results in higher shipping costs for finished products. Ultimately, that means somewhat fewer square feet per truck or train carload than for softwood-based composites. Although it is difficult to get the same strength-to-weight ratios with most underutilized species, they can play an important role in filling the need for engineered composite products from sustainable resources.

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