Mechanical Properties of Wood-Based Composite Materials

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Contents

The term *composite* is used to describe any wood material bonded together with adhesives. The current product mix ranges from fiberboard to laminated beams and components. In this chapter, wood-based composite materials are classified into the following categories: panel products (plywood, oriented strandboard (OSB), particleboard, fiberboard, medium-density fiberboard (MDF), hardboard); structural timber products (glued-laminated timber (glulam), laminated veneer lumber (LVL), laminated strand lumber, parallel strand lumber); and wood–nonwood composites (wood fiber–thermoplastics, inorganic-bonded composites).

Wood-based composites are used for a number of structural and nonstructural applications. Product lines include panels for both interior and exterior uses, furniture components, and support structures in buildings. Knowledge of the mechanical properties of these products is of critical importance to their proper use.

Wood-based composites are made from a wide range of materials—from fibers obtained from underutilized small-diameter or plantation trees to structural lumber. Regardless of the raw material used in their manufacture, wood-based composites provide uniform and predictable in-service performance, largely as a consequence of standards used to monitor and control their manufacture. The mechanical properties of wood composites depend upon a variety of factors, including wood species, forest management regimes (naturally regenerated, intensively managed), the type of adhesive used to bind the wood elements together, geometry of the wood elements (fibers, flakes, strands, particles, veneer, lumber), and density of the final product (Cai 2006).

A wide range of engineering properties are used to characterize the performance of wood-based composites. Mechanical properties are typically the most frequently used to evaluate wood-based composites for structural and nonstructural applications. Elastic and strength properties are the primary criteria to select materials or to establish design or product specifications. Elastic properties include modulus of elasticity (MOE) in bending, tension, and compression. Strength properties usually reported include modulus of rupture (MOR, bending strength), compression strength parallel to surface, tension strength parallel to surface, tension strength perpendicular to surface (internal bond strength), shear strength, fastener holding capacity, and hardness. Model

Table 12–1. Static bending properties of different wood and wood-based composites

Material	Specific gravity	Static bending properties: Modulus of elasticity GPa	Modulus of elasticity ($\times 10^6$ lb in^{-2})	Modulus of rupture MPa	Modulus of rupture (lb in^{-2})
Clear wood					
White oak	0.68	12.27	(1.78)	104.80	(15,200)
Red maple	0.54	11.31	(1.64)	92.39	(13,400)
Douglas-fir (Coastal)	0.48	13.44	(1.95)	85.49	(12,400)
Western white pine	0.38	10.07	(1.46)	66.88	(9,700)
Longleaf pine	0.59	13.65	(1.98)	99.97	(14,500)
Panel products					
Hardboard	0.9–1.0	3.10–5.52	(0.45–0.80)	31.02–56.54	(4,500–8,200)
Medium-density fiberboard	0.7–0.9	3.59	(0.52)	35.85	(5,200)
Particleboard	0.6–0.8	2.76–4.14	(0.40–0.60)	15.17–24.13	(2,200–3,500)
Oriented strandboard	0.5–0.8	4.41–6.28	(0.64–0.91)	21.80–34.70	(3,161–5,027)
Plywood	0.4–0.6	6.96–8.55	(1.01–1.24)	33.72–42.61	(4,890–6,180)
Structural timber products					
Glued-laminated timber	0.4–0.6	9.00–14.50	(1.30–2.10)	28.61–62.62	(4,150–9,080)
Laminated veneer lumber	0.4–0.7	8.96–19.24	(1.30–2.79)	33.78–86.18	(4,900–12,500)
Wood–nonwood composites					
Wood plastic		1.53–4.23	(0.22–0.61)	25.41–52.32	(3,684–7,585)

building codes in the United States stipulate that plywood used for structural applications such as subflooring and sheathing must meet the requirements of certain U.S. Department of Commerce standards. Voluntary Product Standard PS 1–07 for construction and industrial plywood (NIST 2007) and Performance Standard PS 2–04 for wood-based structural-use panels (NIST 2004) spell out the ground rules for manufacturing plywood and establishing plywood or OSB properties, respectively. These standards have evolved over time from earlier documents (O'Halloran 1979, 1980; APA 1981) and represent a consensus opinion of the makers, sellers, and users of plywood products as well as other concerned parties.

Many of the questions that arise with wood-based composites have to do with their mechanical properties, especially how properties of one type of material compare with those of clear wood and other wood products. Although an extensive review that compares all properties of wood-based materials and products is beyond the scope of this chapter, Table 12–1 provides some insight to how static bending properties of these materials vary and how their properties compare with those of solid, clear wood. Although the mechanical properties of most wood composites might not be as high as those of solid wood, they provide very consistent and uniform performance.

The mechanical property data presented in this chapter were obtained from a variety of reports of research conducted to develop basic property information for a wide range of wood-based composite materials. The wood-based composites industry is very dynamic, with changes occurring frequently in the manufacture of these materials and corresponding changes in design information. Consequently, this chapter primarily focuses on presenting fundamental mechanical property information for wood-based composite materials. *For design procedures and values, the reader is encouraged to contact the appropriate industry trade association or product manufacturers. Current design information can be readily obtained from their websites, technical handbooks, and bulletins.*

The organization of this chapter follows closely that of Chapter 5. Basic mechanical property information is presented following a brief background discussion of these products. A discussion of performance and testing standards covering their manufacture and use is also presented.

Elastic Properties

Modulus of Elasticity

Elasticity implies that deformations produced by low stress below the proportional limit are completely recoverable after loads are removed. When loaded to stress levels above the proportional limit, plastic deformation or failure occurs. Typically, the stress–strain curve for wood-based composites is linear below the proportional limit. The slope of the linear curve is the MOE. In compression or tensile tests, this slope is sometime referred to as Young's modulus to differentiate it from bending MOE. Bending MOE is a measure of the resistance to bending deflection, which is relative to the stiffness. Young's modulus is a measure of resistance to elongation or shortening of a member under tension or compression. The procedure to determine MOE is fully described in ASTM D 1037 for fiber- and particle-based panel products, ASTM D 3043 for structural wood-based panels, ASTM D 5456 for structural composite lumber products, ASTM D 7031 for wood–plastic composites, and ASTM D 7341 for glulam products.

Shear Modulus

Shear modulus, also called modulus of rigidity, indicates the resistance to deflection of a member caused by shear stresses. Shear stress is different from tension or compression stress in that it tends to make one side of a member slip past the other side of a member adjacent to it. There are two main types of shear in different planes of wood-based panels: interlaminar shear and edgewise shear or shear through-the-thickness. Interlaminar shear is also commonly called planar shear (or rolling shear, or horizontal shear) in plywood panels to describe stress that acts between the veneers that are glued with grain direction in adjacent pieces perpendicular to one another. For example, when the plywood panel is loaded in the middle with its two ends simply supported, the layers or veneers tend to slip horizontally past each other as the panel bends. The glue-bonding between the laminates of veneers resists the slipping and often dictates the panel stiffness. Edgewise shear is also commonly called racking shear. The moduli of rigidity vary within and between species, resin application, moisture content, and specific gravity. The procedure to determine different shear moduli for fiber- and particle-based panels is described in ASTM D 1037 and for structural panels in ASTM D 3044.

Strength Properties

Strength refers to the maximum stress that can be developed in a member due to applied loads prior to failure. Mechanical properties most commonly measured and represented as "strength properties" for design include modulus of rupture in bending, tension strength parallel-to-surface, tension strength perpendicular-to-surface, compression strength parallel-to-surface, shear strength, fastener holding strength, and hardness. Strength tests are typically made on specimens at moisture equilibrium under prescribed conditions or after soaking. The procedures to determine strengths for wood-based composites are described in ASTM D 1037, ASTM D 3044, ASTM D 5456, ASTM D 3737, and ASTM D 7031.

Modulus of rupture reflects the maximum load-carrying capacity of a member in bending and is proportional to maximum moment borne by the specimen. Modulus of rupture is an accepted measure of strength, although it is not a true stress because the formula by which it is computed is valid only to the elastic limit (McNatt 1973).

Tension strength parallel-to-surface is the maximum stress sustained by a specimen from a test with tension forces applied parallel to the surface. Tests are made with the long dimension of the specimen cut both parallel and perpendicular to the long dimension of the board to determine the strength in each of the primary panel directions.

Tension strength perpendicular-to-surface (internal bond strength) is the maximum stress sustained by a specimen from a test with tension forces applied perpendicular to the surface. Tests are made on specimens in the dry condition to determine the resistance of the specimen to delamination or splitting in the direction perpendicular to the plane of the board.

Compression strength parallel-to-surface is the maximum stress sustained by a specimen from a test with compression forces applied parallel to the surface. Tests are made with the long dimension of the specimen cut both parallel and perpendicular to the long dimension of the board to determine the material's resistance to crushing in each of the primary panel directions.

Interlaminar shear (planar shear) indicates the ability to resist internal slipping of one layer upon another within the panel. It is used to describe the glue line or bonding performance inside or between the test materials.

Hardness is measured as resistance to indentation using a modified Janka hardness test, measured by the load required to embed an 11.3-mm (0.444-in.) diameter ball to one-half its diameter.

Fastener holding strength is the maximum resistance to separate or withdraw a fastener in a plane normal to the testing face. It usually contains three tests: nail withdrawal, nail-head pull-through, and direct screw withdrawal.

Panel Products

Plywood

Plywood is separated into two general classes: (a) construction and industrial plywood and (b) hardwood and decorative plywood. Construction and industrial plywood are covered by Product Standard PS 1–07 (NIST 2007), and hardwood and decorative plywood are covered by American National Standard ANSI/HPVA–1–2004 (HPVA 2004). Each standard recognizes different exposure durability classifications, which are primarily based on moisture resistance of the adhesive and the grade of veneer used. In addition, model building codes require that plywood manufacturers be inspected and their products certified for conformance to PS 1–07, PS 2–04, APA PRP–108, or TECO PRP–133 (TECO 1991) by qualified independent third-party agencies on a periodic unannounced basis. With PS 1–07, as long as a plywood panel is manufactured using the veneer grades, adhesive, and construction established in the standard's prescriptive requirements, the panel is by definition acceptable.

All hardwood plywood represented as conforming to American National Standard ANSI/HPVA–1–2004 (HPVA 2004) is identified by one of two methods: by marking each panel with the Hardwood Plywood & Veneer Association (HPVA) plywood grade stamp or by including a written statement with this information with the order or shipment.

Table 12–2. Selected properties of plywood sheathing products[a]

		Static bending									
		MOE		MOR		Fiber stress at proportional limit		Rail shear strength		Glue line shear strength	
Species	Specific gravity	GPa	($\times 10^6$ lb in^{-2})	MPa	(lb in^{-2})	GPa	(lb in^{-2})	MPa	(lb in^{-2})	MPa	(lb in^{-2})
Baldcypress	0.50	7.58	(1.10)	39.23	(5,690)	29.4	(4,260)	5.6	(805)	2.7	(389)
Douglas-fir	0.53	7.45	(1.08)	41.37	(6,000)	39.3	(5,700)	3.8	(556)	1.4	(207)
Lauan	0.44	7.43	(1.08)	33.72	(4,890)	28.1	(4,070)	4.3	(628)	1.3	(192)
Western redcedar	0.41	8.55	(1.24)	37.37	(5,420)	33.3	(4,830)	4.6	(674)	1.7	(240)
Redwood	0.41	6.96	(1.01)	42.61	(6,180)	37.4	(5,420)	5.3	(769)	1.5	(220)
Southern Pine	0.57	7.70	(1.12)	37.09	(5,380)	26.2	(3,800)	5.5	(800)	1.6	(233)

[a]From Biblis (2000).

If design calculations are desired, a design guide is provided by the APA–The Engineered Wood Association in *Plywood Design Specification* (PDS) and APA Technical Note N375B (APA 1995a,b). The design guide contains tables of grade stamp references, section properties, and allowable stresses for plywood used in construction of buildings and similar structures. Table 12–2 shows selected properties of various species of plywood.

Oriented Strandboard (OSB)

Oriented strandboard is an engineered, structural-use panel manufactured from thin wood strands bonded together with water-resistant adhesive under heat and pressure. It is used extensively for roof, wall, and floor sheathing in residential and commercial construction. Design capacities of performance-rated products, which include OSB and waferboard, can be determined by using procedures outlined in Technical Note N375B (APA 1995a). In this reference, allowable design strength and stiffness properties, as well as nominal thickness and section properties, are specified based on the span rating of the panel. Additional adjustment factors based on panel grade and construction are also provided. Table 12–3 shows selected properties of OSB obtained from the literature.

Under PS 2–04, a manufacturer is required to enter into an agreement with an accredited testing agency to demonstrate that its panels conform to the requirements of the chosen standard. The manufacturer must also maintain an in-plant quality control program in which panel properties are regularly checked, backed by a quality assurance program administered by an independent third-party. The third-party agency must visit the mill on a regular unannounced basis. The agency must confirm that the in-plant quality control program is being maintained and that panels meet the minimum requirements of the standard.

Particleboard

Particleboard is typically made in three layers. The faces of the board consist of fine wood particles, and the core is made of the coarser material (Chap. 11). Particleboard is used for furniture cores and case goods, where it is typically overlaid with other materials for decorative purposes. Particleboard can be used in flooring systems, in manufactured houses, for stair treads, and as underlayment. Requirements for grades of particleboard and particleboard flooring products are specified by the American National Standard for Particleboard A208.1-1999 (CPA 1999). Table 12–4 represents some of selected properties of different particleboard manufacturers.

Hardboard

Basic hardboard physical properties for selected products are presented in ANSI A135.4–2004 (CPA 2004a). The uses for hardboard can generally be grouped as construction, furniture and furnishings, cabinet and store work, appliances, and automotive and rolling stock. Typical hardboard products are prefinished paneling (ANSI A135.5–2004 (CPA 2004b)), house siding (ANSI A135.6–2006 (CPA 2006)), floor underlayment, and concrete form board. Table 12–5 shows selected physical and mechanical properties of hardboard from different manufacturers. Hardboard siding products come in a great variety of finishes and textures (smooth or embossed) and in different sizes. For application purposes, the Composite Panel Association (CPA) classifies siding into three basic types:

Lap siding—boards applied horizontally, with each board overlapping the board below it

Square edge panels—siding intended for vertical application in full sheets

Shiplap edge panel siding—siding intended for vertical application, with the long edges incorporating shiplap joints

The type of panel dictates the application method. The CPA administers a quality conformance program for hardboard for both panel and lap siding. Participation in this program is voluntary and is open to all (not restricted to CPA members). Under this program, hardboard siding products are

Table 12–3. Selected properties of oriented strandboard (OSB) products

				Bending MOE				Bending MOR					
				Parallel		Perpendicular		Parallel		Perpendicular		Internal bond	
Reference	Species	Mill no.	Specific gravity	GPa	(×10^6 lb in^−2)	GPa	(×10^6 lb in^−2)	MPa	(lb in^−2)	MPa	(lb in^−2)	MPa	(lb in^−2)
Biblis (1989)	Southern Pine	1	0.80	4.41	(0.640)	2.89	(0.419)	23.8	(3,445)	24.2	(3,515)	0.57	(83)
		2	0.70	4.78	(0.694)	2.61	(0.378)	26.0	(3,775)	22.1	(3,205)	0.28	(41)
		3	0.68	5.75	(0.834)	3.17	(0.460)	32.0	(4,645)	23.8	(3,445)	0.32	(47)
Pu and others (1992)	Southern Pine	4	0.51	4.41	(0.640)	2.40	(0.348)	21.8	(3,161)	25.4	(3,685)	0.23	(34)
		5	0.60	5.67	(0.822)	2.61	(0.378)	27.8	(4,039)	27.1	(3,925)	0.28	(41)
		6	0.58	4.41	(0.640)	2.97	(0.431)	23.9	(3,473)	28.7	(4,165)	0.26	(38)
	Aspen	7	0.65	6.28	(0.911)	2.03	(0.294)	32.2	(4,672)	30.4	(4,405)	0.43	(62)
		8	0.66	5.69	(0.825)	1.92	(0.278)	31.6	(4,584)	32.0	(4,645)	0.41	(60)
		9	0.74	6.31	(0.915)	2.79	(0.404)	34.7	(5,027)	33.7	(4,885)	0.34	(50)
Wang and others (2003a)	Southern Pine	10	0.63	5.01	(0.726)	2.26	(0.327)	30.2	(4,379)	16.8	(2,436)	0.36	(52)
		11	0.66	5.30	(0.769)	2.32	(0.336)	28.1	(4,075)	14.4	(2,088)	0.43	(62)
		12	0.67	5.12	(0.742)	2.56	(0.371)	30.7	(4,452)	21.1	(3,060)	0.32	(46)
		13	0.66	4.91	(0.712)	2.24	(0.325)	28.3	(4,104)	19.8	(2,871)	0.38	(55)
	Hardwood mixture	14	0.68	5.15	(0.747)	1.77	(0.257)	26.9	(3,901)	11.8	(1,711)	0.28	(40)
		15	0.67	5.87	(0.851)	1.40	(0.204)	33.9	(4,916)	7.8	(1,131)	0.23	(33)
		16	0.70	6.73	(0.976)	2.25	(0.326)	36.9	(5,351)	15.8	(2,291)	0.45	(66)
	Aspen	17	0.63	6.50	(0.943)	3.10	(0.450)	38.0	(5,510)	21.5	(3,118)	0.28	(41)
		18	0.62	7.90	(1.146)	3.10	(0.450)	38.8	(5,626)	23.2	(3,364)	0.46	(66)
		19	0.61	6.10	(0.885)	2.50	(0.363)	30.7	(4,452)	19.7	(2,857)	0.34	(49)
		20	0.61	6.50	(0.943)	1.80	(0.261)	35.5	(5,148)	13.7	(1,987)	0.25	(36)
		21	0.66	6.75	(0.979)	2.45	(0.356)	37.3	(5,409)	19.3	(2,799)	0.38	(55)
		22	0.63	5.80	(0.840)	2.40	(0.348)	26.9	(3,901)	17.9	(2,596)	0.40	(58)

Table 12–4. Selected properties of industrial particleboard products[a]

			Static bending properties				Tensile properties					
			Modulus of elasticity		Modulus of rupture		Modulus of elasticity		Ultimate tensile stress		Internal bond	
Mill	Moisture content (%)	Specific gravity	GPa	(×10^6 lb in^−2)	MPa	(lb in^−2)	GPa	(×10^6 lb in^−2)	MPa	(lb in^−2)	MPa	(lb in^−2)
A	8.7	0.71	3.0	(0.44)	16.8	(2,430)	2.2	(0.32)	7.72	(1,120)	0.79	(115)
B	9.1	0.72	3.5	(0.51)	20.6	(2,990)	2.6	(0.38)	9.38	(1,360)	1.07	(155)
C	9.8	0.76	3.5	(0.51)	18.9	(2,740)	2.3	(0.34)	8.27	(1,200)	1.00	(145)
H	8.0	0.77	4.0	(0.58)	22.8	(3,310)	3.0	(0.44)	10.89	(1,580)	1.17	(170)
J	8.5	0.72	3.0	(0.43)	17.2	(2,500)	1.9	(0.28)	7.45	(1,080)	0.45	(65)
K	9.1	0.68	2.8	(0.40)	15.2	(2,206)	1.6	(0.23)	5.58	(810)	0.31	(45)
L	9.3	0.62	3.2	(0.46)	17.0	(2,470)	1.8	(0.26)	6.69	(970)	0.48	(70)
M	9.7	0.65	3.6	(0.52)	18.9	(2,740)	2.2	(0.32)	8.07	(1,170)	0.69	(100)
N	8.3	0.60	3.1	(0.45)	17.0	(2,470)	3.7	(0.54)	8.00	(1,160)	0.31	(45)

[a]From McNatt (1973).

tested by an independent laboratory in accordance with product standard ANSI A135.6.

Medium-Density Fiberboard

Minimum property requirements for MDF are specified by the American National Standard for MDF, ANSI A208.2-2002 (CPA 2002), and some of selected properties are given in Table 12–6 from different manufacturers. Medium-density fiberboard is frequently used in furniture applications. It is also used for interior door skins, moldings, flooring substrate, and interior trim components (Cai and others 2006, Youngquist and others 1993).

Timber Elements/Structural Composite Lumber

Glued-Laminated Timber

Structural glued-laminated timber (glulam) is an engineered, stress-rated product that consists of two or more layers of lumber that are glued together with the grain of all layers,

Table 12–5. Selected properties of hardboard products[a]

Mill	Type of hardboard	Moisture content (%)	Specific gravity	Modulus of elasticity GPa	Modulus of elasticity ($\times 10^6$ lb in^{-2})	Modulus of rupture MPa	Modulus of rupture (lb in^{-2})	Ultimate tensile stress MPa	Ultimate tensile stress (lb in^{-2})	Internal bond MPa	Internal bond (lb in^{-2})
A	1/8-in. standard	4.6	0.9	3.83	(556)	31.44	(4,560)	23.24	(3,370)	1.24	(180)
B		6.5	1.02	4.36	(633)	33.92	(4,920)	23.17	(3,360)	2.76	(400)
C		5.2	0.94	4.20	(609)	45.85	(6,650)	37.58	(5,450)	2.17	(315)
D		5.6	0.9	3.32	(482)	38.75	(5,620)	28.61	(4,150)	1.55	(225)
E		6.5	0.95	3.55	(515)	47.50	(6,890)	32.96	(4,780)	3.52	(510)
F		7.7	0.91	3.23	(468)	37.85	(5,490)	25.72	(3,730)	1.93	(280)
B	1/4-in. standard	6.4	1.02	4.45	(645)	33.85	(4,910)	22.61	(3,280)	1.86	(270)
E		6.0	0.90	3.88	(563)	38.96	(5,650)	23.65	(3,430)	1.65	(240)
A	1/4-in. tempered	4.9	0.99	5.30	(768)	53.02	(7,690)	31.58	(4,580)	1.79	(260)
F	1/4-in. tempered	6.9	0.98	5.14	(745)	55.57	(8,060)	30.61	(4,440)	1.86	(270)

[a]From McNatt and Myers (1993).

Table 12–6. Selected properties of medium-density fiberboard products[a]

Mill no.	Density (g cm^{-3})	Modulus of rupture MPa	Modulus of rupture (lb in^{-2})	Modulus of elasticity GPa	Modulus of elasticity ($\times 10^6$ lb in^{-2})	Internal bond MPa	Internal bond (lb in^{-2})	Screw-holding edge kg	Screw-holding edge (lb)	Capacity face kg	Capacity face (lb)
1	0.73	33.6	(4,873)	3.21	(466)	0.86	(125)	117	(257)	148	(326)
2	0.90	34.0	(4,932)	3.97	(576)	0.94	(136)	147	(325)	185	(407)
3	0.79	23.2	(3,366)	2.98	(432)	1.94	(282)	150	(330)	202	(445)
4	0.82	39.3	(5,703)	4.38	(635)	0.83	(121)	114	(252)	148	(326)
5	0.95	24.6	(3,565)	3.56	(517)	0.92	(133)	184	(405)	231	(509)
6	0.80	36.4	(5,278)	3.99	(578)	0.71	(103)	143	(315)	183	(404)
7	0.77	37.4	(5,421)	3.94	(572)	1.23	(179)	163	(360)	210	(464)
8	0.71	35.2	(5,107)	3.34	(485)	1.09	(158)	147	(324)	189	(416)

[a]From Suchsland and others (1979).

which are referred to as laminations, parallel to the length. Table 12–7 provides some selected properties of glulam products from different research studies.

Douglas–Fir–Larch, Southern Pine, yellow-cedar, Hem–Fir, and Spruce–Pine–Fir are commonly used for glulam in the United States. Nearly any species can be used for glulam timber, provided its mechanical and physical properties are suitable and it can be properly glued. Industry standards cover many softwoods and hardwoods, and procedures are in place for using other species.

Manufacturers of glulam timber have standardized the target design values in bending for beams. For softwoods, these design values are given in “Standard for Wood Products: Structural Glued-Laminated Timber” (AITC 2007). This specification contains design values and recommended modification of stresses for the design of glulam timber members in the United States. The *National Design Specification for Wood Construction* (NDS) summarizes the design information in ANSI/AITC 190.1 and defines the practice to be followed in structural design of glulam timbers (AF&PA 2005). APA–The Engineered Wood Association has also developed design values for glulam under National Evaluation Report 486, which is recognized by all the building codes.

Structural Composite Lumber

Structural composite lumber (SCL) products are characterized by smaller pieces of wood glued together into sizes common for solid-sawn lumber. One type of SCL product is manufactured by laminating veneer with all plies parallel to the length. This product is called laminated veneer lumber (LVL) and consists of specially graded veneer. Another type of SCL product consists of strands of wood or strips of veneer glued together under high pressures and temperatures. Depending upon the component material, this product is called laminated strand lumber (LSL), parallel strand lumber (PSL), or oriented strand lumber (OSL).

In contrast with sawn lumber, the strength-reducing characteristics of SCL are dispersed within the veneer or strands and have much less of an effect on strength properties. Thus,

Table 12–7. Selected properties of glulam products

				Static bending properties			
				Modulus of elasticity		Modulus of rupture	
Reference	Species	Moisture content (%)	Number of laminations	GPa	($\times 10^6$ lb in^{-2})	MPa	(lb in^{-2})
Manbeck and others (1993)	Red maple	12	8	12.3	(1.78)	62.6	(9,080)
		12	12	12.2	(1.77)	55.0	(7,980)
		12	16	12.3	(1.78)	54.2	(7,860)
Moody and others (1993)	Yellow poplar	8.2	8	13.0	(1.89)	55.6	(8,060)
		7.5	12	13.4	(1.94)	52.1	(7,560)
		8	17	12.3	(1.79)	45.3	(6,570)
Shedlauskus and others (1996)	Red oak	12.8	8	13.0	(1.88)	60.5	(8,770)
		11.1	18	12.8	(1.86)	46.0	(6,670)
Janowiak and others (1995)	Red maple	12.6	12	12.2	(1.77)	55.0	(7,980)
		8.9	5	12.8	(1.86)		
		8.9	5	12.9	(1.87)	45.7	(6,630)
Hernandez and others (2005)	Ponderosa pine	8.8	8	9.44	(1.37)	31.4	(4,560)
		8.8	13	9.07	(1.32)	29.6	(4,290)
Hernandez and Moody (1992)	Southern Pine	—	10	14.1	(2.04)	61.7	(8,950)
		—	17	13.5	(1.96)	49.8	(7,230)
Marx and Moody (1981 a,b)	Southern Pine	10	4, 8, 10	11.2	(1.63)	46.5	(6,740)
		10	4, 8, 11	10.8	(1.56)	33.9	(4,920)
	Douglas-fir–larch	11	4, 8, 12	13.9	(2.02)	47.2	(6,840)
		11	4, 8, 13	13.6	(1.97)	40.7	(5,910)
Moody (1974)	Southern Pine	11.8	17	9.3	(1.35)	28.6	(4,150)
		11.9	17	10.3	(1.49)	31.4	(4,560)

relatively high design values can be assigned to strength properties for both LVL and PSL. Whereas both LSL and OSL have somewhat lower design values, they have the advantage of being produced from a raw material that need not be in a log size large enough for peeling into veneer.

All types of SCL products can be substituted for sawn lumber products in many applications. Laminated veneer lumber is used extensively for scaffold planks and in the flanges of prefabricated I-joists. Both LVL and PSL beams are used as headers and major load-carrying elements in construction. The LSL and OSL products are used for band joists in floor construction and as substitutes for studs and rafters in wall and roof construction. Various types of SCL are also used in a number of nonstructural applications, such as the manufacture of windows and doors. Table 12–8 provides some selected properties of LVL products from different research studies.

Wood–Nonwood Composites

Wood–Plastic Composite

The use of wood–plastic composite lumber in North America has experienced tremendous growth in the past decade, largely because of residential construction applications. Common applications in North America include decking, railings, window profiles, roof tiles, and siding. These lumber products are generally manufactured using profile extrusion. Some generalizations can be made regarding the performance of wood–plastic composites, but there are exceptions. Flexural and tensile properties of wood–plastic composite lumber generally fall between those of solid wood lumber and unfilled plastics. Most commercial wood–plastic composites are considerably less stiff than solid wood but are stiffer than unfilled plastic (Clemons 2002). Compared with solid wood lumber, wood–plastic composites have better decay resistance and dimensional stability when exposed to moisture. Compared with unfilled plastics, wood–plastic composites are stiffer and have better dimensional stability when exposed to changes in temperature.

Table 12–9 shows mechanical properties of unfilled polypropylene and several wood–polypropylene composites. One of the primary reasons to add wood filler to unfilled plastics is to improve stiffness. Strength of the unfilled plastic can also increase but only if the wood component acts as reinforcement with good bonding between the two components. Table 12–9 illustrates how wood–plastic composite properties can vary with changing variables. For example, adding wood fiber instead of wood flour to polypropylene

Table 12–8. Selected properties of laminated veneer lumber for structural composite lumber products

		Static bending properties								Tensile properties			
		Modulus of elasticity				Modulus of rupture				Modulus of elasticity		Ultimate tensile stress	
		Edge		Flat		Edge		Flat					
Reference	Species	GPa	($\times 10^6$ lb in^{-2})	GPa	($\times 10^6$ lb in^{-2})	MPa	(lb in^{-2})	MPa	(lb in^{-2})	GPa	($\times 10^6$ lb in^{-2})	MPa	(lb in^{-2})
Bohlen (1974)	Douglas-fir	—	—	—	—	—	—	—	—	15.2	(2.20)	28.99	(4,205)
Youngquist and others (1984)	Douglas-fir	—	—	—	—	—	—	—	—	14.0–15.0	(2.03–2.17)	28.1–39.0	(4,080–5,650)
										11.1–12.4	(1.61–1.80)	18.3–38.1	(2,660–5,520)
Jung (1982)	Douglas-fir	15.5–19.2	(2.25–2.79)	15.4–19.3	(2.23–2.80)	58.0–71.7	(8,420–10,400)	54.2–62.5	(7,860–9,060)	15.6–20.3	(2.27–2.94)	37.9–46.2	(5,500–6,700)
Kunesh (1978)	Douglas-fir	15.9	(2.31)	16.1	(2.34)	—	—	78.8	(11,430)	14.1	(2.04)	44.4	(6,435)
Koch (1973)	Southern Pine	13.2	(1.91)	0.0	0.00	64.2	(9,310)	—	—	—	—	—	—
Moody (1972)	Douglas-fir	—	—	—	—	—	—	—	—	14.3	(2.07)	37.6	(5,450)
	Southern Pine	—	—	—	—	—	—	—	—	13.5	(1.96)	34.6	(5,025)
Moody and Peters (1972)	Southern Pine	14.1	(2.04)	14.7	(2.13)	80.8	(11,720)	86.0	(12,480)	—	—	—	—
Wang and others (2003b)	Red maple	10.8	(1.56)	11.3	(1.64)	83.3	(12,081)	—	—	—	—	—	—
Hindman and others (2006)	Southern Pine	15.8	(2.29)	17.4	(2.54)	—	—	—	—	—	—	—	—
Kretschmann and others (1993)	Douglas-fir	9.0–12.8	(1.30–1.86)	9.0–13.7	(1.30–1.98)	37.9–67.9	(5,500–9,850)	33.8–63.9	(4,900–9,270)	8.5–12.8	(1.24–1.86)	20.8–49.1	(3,020–7,100)
	Southern Pine	9.8–13.7	(1.34–1.98)	8.8–13.0	(1.27–1.89)	51.9–70.3	(7,530–10,190)	47.8–66.5	(6,940–9,650)	9.6–13.6	(1.39–1.97)	36.6–51.2	(5,310–7,430)

Table 12–9. Selected properties of wood–plastic products[a]

Composite	Specific gravity	Tensile properties: Strength MPa	Tensile Strength (lb in^{-2})	Tensile Modulus GPa	Tensile Modulus ($\times 10^6$ lb in^{-2})	Flexural properties: Strength MPa	Flexural Strength (lb in^{-2})	Flexural Modulus GPa	Flexural Modulus ($\times 10^6$ lb in^{-2})	Izod impact energy ($J m^{-1}$) Notched	Izod impact energy ($J m^{-1}$) Unnotched
Polypropylene (PP)	0.90	28.5	(4,134)	1.53	(0.22)	38.30	(5,555)	1.19	(0.17)	20.9	656
PP + 40% wood flour	1.05	25.4	(3,684)	3.87	(0.56)	44.20	(6,411)	3.03	(0.44)	22.2	73
PP + 40% wood flour + 3% coupling agent	1.05	32.3	(4,685)	4.10	(0.59)	53.10	(7,702)	3.08	(0.45)	21.2	78
PP + 40% wood fiber	1.03	28.2	(4,090)	4.20	(0.61)	47.90	(6,947)	3.25	(0.47)	23.2	91
PP + 40% wood fiber + 3% coupling agent	1.03	52.3	(7,585)	4.23	(0.61)	72.40	(10,501)	3.22	(0.47)	21.6	162

[a]From Stark and Rowlands (2003).

improved the strength and stiffness. Generally, adding a coupling agent to the mix also improved mechanical properties. Adding wood to polypropylene was not without tradeoffs. Impact resistance of such composites decreased compared with that of unfilled polypropylene.

In addition to these commercial deck products, wood–plastic composites are being developed for structural applications such as foundation elements, deck substructures, industrial decking, and shoreline structures (Bender and others 2006). Table 12–10 shows the range of average mechanical properties of extruded wood–plastic composites by polymer type. In general, polyvinylcholoride and polyethylene formulations produce higher mechanical properties than those produced from polyethylene alone. Formulations that use coupling agents with either polypropylene or high-density polyethylene result in improved strength, stiffness, and reduced moisture absorption properties.

Properties of wood–plastic composites can vary greatly depending upon such variables as type, form, weight fractions of constituents, type of additives, and processing methods (Stark and Rowlands 2003, Wolcott and others 2006). Because formulations from each commercial manufacture are proprietary, design data should be obtained directly from the manufacturer.

Inorganic-Bonded Composites

Inorganic-bonded wood composites are molded products or boards that contain between 10% and 70% by weight wood particles or fibers and conversely 90% to 30% inorganic binder. Acceptable properties of an inorganic-bonded wood composite can be obtained only when the wood particles are fully encased with the binder to make a coherent material. This differs considerably from the technique used to manufacture thermosetting-resin-bonded boards, where flakes or particles are "spot welded" by a binder applied as a finely distributed spray or powder. Because of this difference and because hardened inorganic binders have a higher density than that of most thermosetting resins, the required amount of inorganic binder per unit volume of composite material is much higher than that of resin-bonded wood composites. The properties of inorganic-bonded wood composites are significantly influenced by the amount and nature of the inorganic binder and the woody material as well as the density of the composites.

Inorganic binders fall into three main categories: gypsum, magnesia cement, and Portland cement. Gypsum and magnesia cement are sensitive to moisture, and their use is generally restricted to interior applications. Composites bonded with Portland cement are more durable than those bonded with gypsum or magnesia cement and are used in both interior and exterior applications. Inorganic-bonded composites are made by blending proportionate amounts of lignocellulosic fiber with inorganic materials in the presence of water and allowing the inorganic material to cure or "set up" to make a rigid composite. All inorganic-bonded composites are very resistant to deterioration, particularly by insects, vermin, and fire. Typical properties of low-density cement-wood composite fabricated using an excelsior-type particle are shown in Table 12–11.

Testing Standards

The physical and mechanical properties of wood-based composite materials are usually determined by standard ASTM test methods. The following are the commonly used methods described in ASTM (2009):

ASTM C 208–08. Standard specification for cellulosic fiber insulating board.

Table 12–10. Selected properties of extruded wood–plastic products

Composite	Tensile strength (MPa (lb in^{-2}))	Compression strength (MPa (lb in^{-2}))	Bending strength (GPa ($\times 10^6$ lb in^{-2}))	Bending modulus (MPa (lb in^{-2}))	Shear strength (MPa (lb in^{-2}))	Dowel bearing strength (MPa (lb in^{-2}))
Polypropylene (PP)[a, b]	20.0 (2,900)	55.2 (8,000)	3.49–5.97 (0.506–0.866)	22.2–60.8 (3,220–8,820)	22.0 (3,190)	84.8 (12,300)
High-density polyethylene (HDPE)[c]	5.5–15.2 (800–2,200)	11.7–26.9 (1,700–3,900)	1.79–5.17 (0.260–0.750)	10.3–25.5 (1,500–3,700)	7.79–10.3 (1,130–1,500)	35.7 (5,180)
Polyvinylchloride (PVC)[c]	25.1 (3,640)	61.2 (8,880)	4.81–7.58 (0.697–1.100)	35.9–54.5 (5,200–7,900)	20.2 (2,930)	72.4–128.2 (10,500–18,600)

[a]From Slaughter (2004).
[b]From Kobbe (2005).
[c]From Wolcott (2001).

Table 12–11. General properties of low-density cement–wood composite fabricated using an excelsior-type particle[a,b]

	Value range (MPa (lb in^{-2}))	
Property	Low	High
Bending strength	1.7 (250)	5.5 (800)
Modulus of elasticity	621 (90,000)	1,241 (180,000)
Tensile strength	0.69 (100)	4.1 (600)
Compression strength	0.69 (100)	5.5 (800)
Shear[c]	0.69 (100)	1.4 (200)
E/*G* ratio[d]	40.0	100.0

[a]Data present compilation of raw data from a variety of sources for range of board properties. Variables include cement–wood mix, particle configuration, density, and forming and curing method.
[b]Specific gravity range from 0.5 to 1.0.
[c]Shear strength data are limited to small samples having a specific gravity of 0.5 to 0.65.
[b]*E*/*G* is ratio of bending modulus of elasticity to shear modulus. For wood, this ratio is about 16.

ASTM D 1037–06a. Standard test methods for evaluating the properties of wood-based fiber and particle panel materials.

ASTM D 2718–00 (2006). Standard test method for structural panels in planar shear (rolling shear).

ASTM D 2719–89 (2007). Standard test methods for structural panels in shear through-the-thickness.

ASTM D 3043–00 (2006). Standard test methods of testing structural panels in flexure.

ASTM D 3044–94 (2006). Standard test method for shear modulus of wood-based structural plywood.

ASTM D 3500–90 (2003). Standard test methods for structural panels in tension.

ASTM D 3501–05a. Standard test methods of testing plywood in compression.

ASTM D 3737–08. Standard practice for establishing allowable properties for structural glued laminated timber (glulam).

ASTM D 5456–09. Specification for evaluation of structural composite lumber products.

ASTM D 7031–04. Standard guide for evaluating mechanical and physical properties of wood-plastic composite products.

ASTM D 7032–08. Standard specification for establishing performance ratings for wood-plastic composite deck boards and guardrail systems.

ASTM D 7341–09. Standard practice for establishing characteristic values for flexural properties of structural glued laminated timber by full-scale testing.

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