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Chapter 21

Insulation Board, Hardboard, Medium-Density Fiberboard, and Laminated Paperboards

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Insulation Board, Hardboard, Medium-Density Fiberboard, and Laminated Paperboards*

This group of panel materials are all reconstituted wood (or some other lignocellulose like bagasse) in that the wood is first reduced to fibers or fiber bundles and then put back together by special forms of manufacture into panels of relatively large size and moderate thickness. These board or panel materials in final form retain some of the properties of the original wood but, because of the manufacturing methods, gain new and different properties from those of the wood. Because they are manufactured, they can be and are "tailored" to satisfy a use-need, or a group of needs.

Another group of panel materials based on particles rather than fibers is described in chapter 22.

Fiber-based panel products are made essentially by breaking wood down through thermal-mechanical processes to its fibers. These fibers are interfelted in the reconstitution process and are characterized by a bond produced by that interfelting. They are frequently classified as fibrous-felted board products. At certain densities under controlled conditions of hot-pressing, rebonding of the lignin effects a further bond in the panel product produced. Binding agents and other materials may be added during manufacture to increase strength, resistance to fire, moisture, or decay, or to improve some other property. Among the materials added are rosin, alum, asphalt, paraffin, synthetic and natural resins, preservative and fire-resistant chemicals, and drying oils. Wax sizing is commonly added to improve water resistance.

Since fiber-based panel products are produced from small components of wood, the raw material need not be in log form. Many processes for manufacture of board materials start with wood in the form of pulp chips. Coarse residues from other primary forest products manufacture therefore are an important source of raw materials for fiber-based panel products. Bagasse, the fiber residue from sugarcane, and wastepaper are used also as raw material for board products.

Fiber-based panel materials are broadly divided into four groups—insulation board (the lower density products), hardboard, medium-density fiberboard, and laminated paperboard. The dividing point between an insulation board and a hardboard and medium-density fiberboard is a specific gravity of 0.5 (about 31 pcf). Laminated paperboards require a special classification because the density of these products is slightly greater than insulation board, but at the low end of hardboards. Because laminated paperboards are made by laminating together plies of paper about 1/16 inch thick, they have different properties along the direction of plies than across the machine direction. Other fiber-based panel products have nearly equal properties along and across the panel. Practically, because of the range of uses and specially developed products within the broad classification, further breakdowns are necessary to classify the various products adequately. The following breakdown by density places the fiber-based panel products in their various groups:

	Specific Gravity	Density (Pcf)
Insulation board	0.16 to 0.5	10 to 31
Hardboard	.5 to 1.45	31 to 90
Medium-density hardboard	.5 to .8	31 to 50
High-density hardboard	.8 to 1.28	50 to 80
Special densified hardboard	1.35 to 1.45	84 to 90
Medium-density fiberboard	.5 to .88	31 to 55
Laminated paperboard	.5 to .59	31 to 37

Properties of the various fiber-based panel products are determined according to ASTM standards, and to a considerable extent these properties either suggest or limit the uses. In the following sections the fiber-based panel materials are divided into the various categories suggested by kind of manufacture, properties, and use.

Manufacture, Properties, and Uses of Insulating Boards

Insulating board is a generic term for a homogeneous panel made from lignocellulose fibers (usually wood or bagasse) that have been interfelted and consolidated into homogeneous panels having a density of less than 31 pcf and more than 10 pcf. Other ingredients may be added during manufacture to provide specific physical properties. Insulation board is dried in an oven but not consolidated under pressure during manufacture.

There are many different types of insulating board, with different names and intended uses (table 21−1). Nominal dimensions of the different types of insulating boards are presented in table 21−2, and their minimum physical properties in table 21−3.

Sheathing is regularly manufactured in three grades: Regular density, intermediate, and nail base. Regular-density sheathing is usually about 18 pcf in density, and when the 2- by 8-foot material is used as sheathing, it is applied with long edges horizontal. The 4-foot-wide material is recommended for application with long edges vertical. When 25/32-inch-thick regular-density sheathing is applied with the long edges vertical and adequate fastening (either nails or staples) around the perimeter and along intermediate framing, requirements for racking resistance of the wall construction are usually satisfied. Horizontal applications with the 25/32-inch material require additional bracing in the wall system to meet code requirements for rigidity, as do some applications of the 1/2-

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* Revision by Gary C. Myers, Forest Products Technologist.

le 21 – 1—*Types, classes, and intended uses of insulating board*

	Class	Name	Intended use
I	—	Sound deadening board	In wall assemblies to control sound transmission
II	—	Building board	As a base for interior finishes
III	—	Insulating formboard	As a permanent form for poured-in-place reinforced gypsum or lightweight concrete aggregate roof construction
IV		Sheathing:	
	1	Regular-density	As wall sheathing in frame construction where method of application or thickness determines adequacy of racking resistance
	2	Intermediate-density	As wall sheathing where usual method of application provides adequate racking resistance
	3	Nail-base	As wall sheathing where usual method of application provides adequate racking resistance, and where exterior siding materials, such as wood or asbestos shingles, can be directly applied with special nails
V	—	Shingle backer	As an undercoursing for wood or asbestos cement shingles
/I	—	Roof insulating board	As above-deck insulation under built-up roofing
VII		Ceiling tiles and panels:	
	1	Nonacoustical	As decorative wall and ceiling coverings
	2	Acoustical	As decorative, sound-absorbing wall and ceiling coverings
VIII	—	Insulating roof deck	As roof decking for flat, pitched, or shed-type open-beamed, ceiling-roof construction
IX	—	Insulating wallboard	As a general-purpose product used for decorative wall and ceiling covering

Source: PS 57–73.

inch-thick regular-density sheathing applied with long edges vertical. Intermediate sheathing is usually about 22 pcf in density; nail base is about 25. Nail-base sheathing has adequate nail-holding strength so that asbestos and wood shingles for weather course (siding) can be attached directly to the nail-base sheathing with special annular grooved nails. With the other grades of sheathing, siding materials must be nailed directly to framing members or to nailing strips attached through the sheathing to framing. Because the method and amount of fastening is critical to racking resistance, local building codes should be consulted for requirements in different areas.

Ceiling tile and lay-in panels are an important use for structural insulating board. Such board has a paint finish applied in the factory for decoration and to provide resistance to flame spread. Interior-finish insulating board, when perforated or provided with special fissures or other sound traps, will also provide a substantial reduction in noise reflectance. The fissures and special sound traps are designed to provide improved appearance over that of the conventional perforations while satisfying the requirements for sound absorption. The manufacturers of insulation board long have recognized the appeal of esthetically pleasing ceiling finishes. Each of them offers finishes in designs that blend with either traditional or contemporary architecture and furnishings.

Generally ceiling tiles are 12 by 12 or 12 by 24 inches in size, 1/2 inch thick, and have tongue and groove or butt and chamfered edges. They are applied to nailing strips with nails, staples, or special mechanical fastenings, or directly to a surface with adhesives.

A panel product similar to tile, but nominally 24 by 24 or 24 by 48 inches, is gaining popularity. These panels, commonly called "lay-in ceiling panels," are installed in metal tees and angles in suspended ceiling systems. These lay-in

Table 21 – 2—*Nominal dimensions of insulating board*

Type of insulating board	Nominal dimensions		
	Width	Length	Thickness
	Inches		
Type I	48	96 or 108	1/2
Type II	48	96, 120, or 144	1/2
Type III	24, 32, 48	48 to 144	1
Type IV:			
Class 1	24	96	1/2 or 25/32
	48	96 or 108	1/2 or 25/32
Classes 2 and 3	48	96 or 108	1/2
Type V	11-3/4, 13-1/2, or 15	48	5/16 or 3/8
	23	47	1/2, 1, 1-1/2, 2, 2-1/2, or 3
Type VI	24	48	1/2, 1, 1-1/2, 2, 2-1/2, or 3
Type VII:			
Class 1	12	12 or 24	1/2, 9/16, or 5/8
	12	96 or 120	1/2
	16	16 or 32	1/2, 9/16, or 5/8
	24	24 or 48	1/2, 9/16, or 5/8
	48	96, 120, or 144	1/2
Class 2	12	12 or 24	1/2, 9/16, or 5/8
	24	24 or 48	1/2, 9/16, or 5/8
Type VIII	24	96	1-1/2, 2, or 3
Type IX	48	96 or 120	3/8

Source: PS 57–73.

Table 21 – 3—*Physical properties of insulating board*

Property	Type I	Type II	Type III	Type IV				Type V		Type VI—1/2 inch thick	Type VII[1]	Type VIII	Type IX
				Class 1		Class 2	Class 3	3/8 inch thick	5/16 inch thick				
				1/2 inch thick	25/32 inch thick								
Thermal conductivity, "k," average maximum (Btu · in/h · ft^2 · °F at 75 ± 5 °F)	0.38	0.38	0.40	0.40	0.40	0.44	0.48	0.40	0.40	—	0.38	0.40	0.40
Transverse strength either direction, average minimum (lb)													
Dry	12	12	37	14	25	17	25	6	6	7	10	NR	6
Wet	NR	NR	18	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Modulus of rupture, average minimum (psi)													
Dry	240	240	190	275	200	340	500	200	240	140	200	225	200
Wet	NR	NR	95	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
After accelerated aging	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	[2]50 percent of dry value	NR
Modulus of elasticity, average minimum (psi x 10^3)	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	40	NR
Deflection span ratio, average maximum	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR	1:240	NR
Deflection at specified minimum load, average maximum (in)													
Dry	0.85	0.85	0.16	0.75	0.56	0.75	0.65	1.18	1.18	1.25	NR	NR	NR
Wet	NR	NR	0.11	NR	NR	NR	NR	NR	NR	NR	NR	NR	NR
Tensile strength parallel to surface, average minimum (psi)	150	150	150	150	150	200	300	150	150	50	150	150	150

Table 21 – 3—*Physical properties of insulating board*—Continued

Property	Type I	Type II	Type III	Type IV				Type V		Type VI—1/2 inch thick	Type VII[1]	Type VIII	Type IX
				Class I		Class 2	Class 3	3/8 inch thick	5/16 inch thick				
				1/2 inch thick	25/32 inch thick								
Tensile strength perpendicular to surface, average minimum (psf)	600	600	600	600	600	800	1,000	600	600	500	600	600	600
Water absorption by volume, average maximum (percent)	7	7	10	7	7	15	12	7	7	10	NR	10	15
Linear expansion, 50–90 percent relative humidity, average maximum (percent)	0.5	0.5	0.5	0.5	0.5	0.6	0.6	0.5	0.5	0.5	0.5	0.5	0.5
Vapor permeance, average minimum (grains/h ft^2 in Hg pressure differential)	NR	NR	5	5	5	5	5	5	5	NR	NR	[3]0.5	NR
Direct nail withdrawal resistance, average minimum (lb/nail)													
Dry	NR	NR	NR	NR	NR	NR	40	NR	NR	NR	NR	NR	NR
Soaked	NR	NR	NR	NR	NR	NR	25	NR	NR	NR	NR	NR	NR
Racking load, average minimum (lb)													
Dry	NR	NR	NR	NR	5,200	5,200	5,200	NR	NR	NR	NR	NR	NR
Wet	NR	NR	NR	NR	4,000	4,000	4,000	NR	NR	NR	NR	NR	NR
Flame-spread index, finish surface, maximum	NR	200	NR	NR	NR	NR	NR	NR	NR	NR	200	200	200

[1] The physical properties listed for acoustical material, except for flame spread, apply to the base material before punching, drilling, perforating, or embossing. NR = Not required for this product.

[2] For example, if the dry modulus of rupture is found to be 300 psi, then the modulus of rupture after accelerated aging must be not less than 150 psi.

[3] Average maximum. For products without a vapor barrier, there is no requirement for vapor permeance.

Source: PS 57–73.

panels are usually 1/2 inch thick and are supported in place along all four edges. They are frequently used in combination with translucent plastic panels that conceal light fixtures (fig. 21−1).

Finishes and perforation treatments for sound absorption are the same as for regular ceiling tile. Producers of insulating board are extending their manufacture to specially embossed ceiling panels that can be applied with butt-joint edges and ends that present an essentially unbroken surface, and factory-finished panels that look like real wood planks. Plastic films are being used increasingly for surfacing ceiling tile for applications in kitchens and bathrooms where repeated washability and resistance to moisture is desired. These products are especially adaptable for remodeling.

Manufacture, Properties, and Uses of Hardboard

Hardboard is a generic term for a panel manufactured primarily from interfelted lignocellulose fibers which are consolidated under heat and pressure in a hot press to a density of 31 pcf or greater. Other materials may be added to improve certain properties, such as stiffness, hardness, finishing properties, resistance to abrasion, and moisture, as well as to increase strength, durability, and utility. Hardboards are further subdivided into medium-density and high-density materials. Both are manufactured as previously defined, but a medium-density hardboard has a density between 31 and 50 pcf, and the high-density hardboard has a density greater than 50 pcf.

High-density and medium-density conventional hardboards are manufactured in several ways, and the result is reflected in the appearance of the final product. Hardboard is described as being S−1−S (screen-backed) or S−2−S (smooth two sides). When the mat from which the board is made is formed from a water slurry (wet-felted) and the wet mat is hot-pressed, a screen is required to permit steam to escape. In the final board the reverse impression of the screen is apparent on the back of the board, hence the screen-back designation. A screen is similarly required with mats formed from an air suspension (air-felted) when moisture contents are sufficiently high going into the hot press so that venting is required.

Where's the dry process

In some variations of hardboard manufacture, a wet-felted mat is dried before being hot-pressed. With this variation it is possible to hot-press without using the screen, and an S−2−S board is produced. In air-felting hardboard manufacture, it is possible also to press without the screen, if moisture content of mats entering the hot press is low. In a new adaptation of pressing hardboard mats, a caul with slots or small circular holes is used to vent steam; the board produced has a series of small ridges or circular nubbins which, when planed or sanded off, yield an S−2−S board.

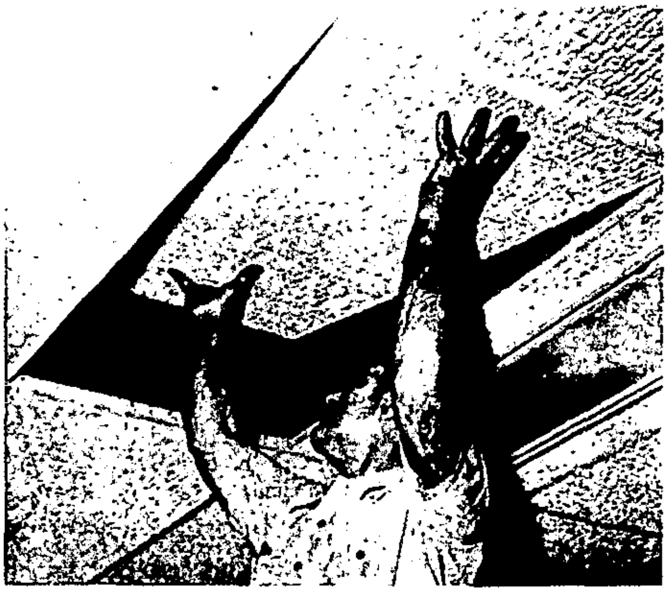

Figure 21−1—A lay-in ceiling panel being installed in a suspended ceiling system. (M84 0280-11)

Prefinished paneling and siding products account for about 65 percent of the current product mix. An additional 25 percent is for industrial uses, including cut-to-size and molded products.

Medium-Density Hardboard

Medium-density hardboard is manufactured by the conventional methods used for other hardboard and is tailored for use as house siding. Medium-density hardboard for house siding use is mostly 7/16 inch thick and is fabricated for application as either panel or lap siding.

Panel siding is 4 feet wide and commonly furnished in 8-, 9-, or 10-foot lengths. Surfaces may be grooved 2 inches or more on center parallel to the long dimension to simulate reversed board and batten or may be pressed with ridges simulating a raised batten.

Lap siding is frequently 12 inches wide with lengths to 16 feet and is applied in the same way as conventional wood lap siding. Some manufacturers offer their lap siding products with special attachment systems that provide either concealed fastening or a wider shadow line at the bottom of the lap.

Most siding is furnished with some kind of a factory-applied finish. At least the surface and edges are given a prime coat of paint. Finishing is completed later by application of at least one coat of paint. Two coats of additional paint, one of a second primer and one of topcoat, provide for a longer inter-

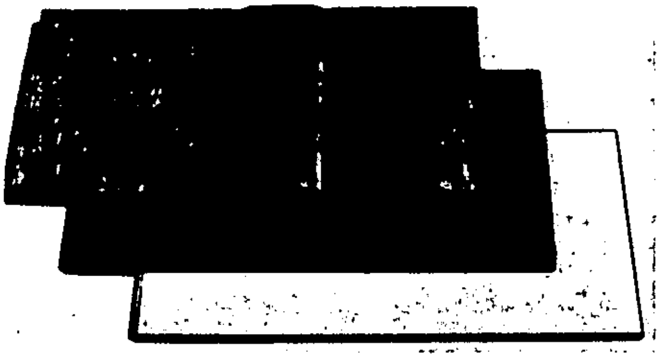

Figure 21-2—Examples of medium-density hardboard commonly used for exterior siding. Top two examples have textured surfaces to simulate wood grain, and bottom example is smooth surfaced. (M84 0280-2)

val before repainting. There is a trend for complete prefinishing of medium-density hardboard siding. The complete prefinishing ranges from several coats of liquid finishes to cementing various films to the surfaces and edges of boards. Surfaces of medium-density hardboard for house siding range from very smooth to textured, many simulating weathered wood with the latewood grain raised as though earlywood has been eroded away. Three samples of hardboard siding are presented in figure 21−2, showing the different surfaces.

Small amounts of medium-density hardboard are prefinished for interior paneling along with the high-density hardboards. Siding is the most important use and others will not become extensive until that market is fully developed and exploited. The experience with medium-density hardboard has been good. Dimensional movement with moisture change has not produced major problems in service. When hardboard siding is stored, applied, and finished with high-quality paints in accordance with the manufacturers or American Hardboard Association recommendations, it has required little paint maintenance. Proper finishing, maintenance, and refinishing procedures for hardboard siding are covered in chapter 16 and in American Hardboard Association literature. Code authorities and others have recognized the evidence submitted by manufacturers on the performance of medium-density hardboard siding. A summary of the properties specified for this material in product standard PS 60−73 is presented in table 21−4.

High-Density Hardboard

Manufacture of high-density hardboard has grown rapidly since World War II. Numerous older uses are well established, and new ones are being developed continually. Property requirements are presented in table 21−5, which classifies hardboard by surface finish, thickness, and minimum physical properties.

Originally there were two basic qualities of high-density hardboard; standard and tempered. These are still the two qualities used in greatest quantity. Standard hardboard is a panel product with a density of about 60 to 65 pcf, usually unaltered except for humidification and trimming to size after hot-pressing. Tempered hardboard is a standard-quality hardboard that is treated with a blend of siccative resins (drying oil blends or synthetics) after hot-pressing. The resins are stabilized by baking after the board has been impregnated. Usually about 5 percent resin solids are required to produce a hardboard of tempered quality. Tempering improves water resistance, hardness, and strength appreciably, but embrittles the board and makes it less shock resistant.

A third hardboard, service quality, has become important. This is a product of lower density than standard, usually 50 to 55 pcf, made to satisfy needs where the higher strength of standard quality is not required. Because of its lower density, service-quality hardboard has better dimensional stability than the denser products.

When service hardboard is given the tempering treatment, it is classed as tempered service, and property limits have been set for specifications. It is used where water resistance is required but the higher strength of regular treatment is not. Underlayment is service-quality hardboard, nominally 1/4 inch thick, that is sanded or planed on the back surface to provide a thickness of not less than 0.200 inch.

These are the regular qualities of high-density hardboard; because a substantial amount of this hardboard is manufactured for industrial use, special qualities are made with different properties dictated by the specific use. For example, hardboard manufactured for concrete forms is frequently given a double tempering treatment. For some uses where high impact resistance is required, like backs of television cabinets, boards are formulated from specially prepared fiber and additives. Where special machining properties like die punching or postforming requirements must be satisfied, the methods of manufacturing and additives used are modified to produce the desired properties.

Commercial thicknesses of high-density hardboard generally range from 1/8 to 1/2 inch. Not all thicknesses are produced in all grades. The thicknesses of 1/10 and 1/12 inch are regularly produced only in the standard grade. Tempered hardboards are produced regularly in thicknesses between 1/8 and 5/16 inch. Service and tempered service are regularly produced in fewer thicknesses, none less than 1/8 inch and not by all manufacturers or in screen-back and S−2−S types. The appropriate standard specification or source of material should be consulted for specific thicknesses of each kind.

High-density hardboards are produced in 4- and 5-foot

Table 21 – 4—*Physical properties of hardboard siding*

Property	Requirement
Percent water absorption based on weight (maximum average per panel)	
Primed	15
Unprimed	20
Percent thickness swelling (maximum average per panel)	
Primed	10
Unprimed	15
Percent linear expansion (maximum average per panel)	
Lap siding	0.38, for 0.325- to 0.375-in thickness 0.40, for over 0.376-in thickness
Panel siding	0.36, for 0.220- to 0.265-in thickness 0.38, for 0.325- to 0.375-in thickness 0.40, for over 0.376-in thickness
Weatherability of substrate (maximum swell after five cycles) (in)	0.010 and no objectionable fiber raising
Sealing quality of primer coat	No visible flattening
Weatherability of primer coat	No checking, erosion, or flaking
Nailhead pullthrough (minimum average per panel) (lb)	150
Lateral nail resistance (minimum average per panel) (lb)	150
Modulus of rupture (minimum average per panel) (psi)	1,800 for 3/8- and 7/16-in-thick siding 3,000 for 1/4-in-thick siding
Hardness (minimum average per panel) (lb)	450
Impact (minimum average per panel) (in)	9
Moisture content (pct)[1]	2–9 inclusive, and not more than 3 pct variance between any two boards in any shipment or order

[1] Because hardboard is a wood-base material, its moisture content will vary with environmental humidity conditions. When the environmental humidity conditions in the area of intended use are a critical factor, the purchaser should specify a moisture content range more restrictive than 2 to 9 percent, so that fluctuation in the moisture content of the siding will be kept to a minimum.

Source: PS 60–73.

widths with the more common width being 4 feet. Standard commercial lengths are 4, 6, 8, 12, and 16 feet with an 18-foot length being available in the 4-foot width. Most manufacturers maintain cut-to-size departments for special orders. Retail lumberyards and warehouses commonly stock 8-foot lengths, except for underlayment, which is usually 4 feet square.

About 10 percent of the hardboard used in the United States is imported. Foreign-made board may or may not be manufactured to the same standards as domestically produced products. Before substituting a foreign-made product in a use where specific properties are required, it should be determined that the foreign-made item has properties required for the use. Canadian products are usually produced to the same standards as United States products.

In addition to the standard smooth-surface hardboards, special products are made using patterned cauls so the surface is striated or produced with a relief to simulate ceramic tile, leather, basket weave, etched wood, or other texture. Hardboards are punched to provide holes for anchoring fittings for shelves and fixtures (perforated board) or with holes comprising 15 percent or more of the area for installation in ceilings with sound-absorbent material behind it for acoustical treatments or as air diffusers above plenums.

Table 21 – 5—*Classification of high-density hardboard by surface finish, thickness, and physical properties*

Class	Nominal thickness	Water resistance (maximum average per panel)		Modulus of rupture (minimum average per panel)	Tensile strength (minimum average per panel)	
		Water absorption based on weight	Thickness swelling		Parallel to surface	Perpendicular to surface
	Inch	*Percent*		*Pounds per square inch*		
1 Tempered	1/12	30	25	6,000	3,000	130
	1/10	25	20			
	1/8	25	20			
	3/16	25	20			
	1/4	20	15			
	5/16	15	10			
	3/8	10	9			
2 Standard	1/12	40	30	4,500	2,200	90
	1/10	35	25			
	1/8	35	25			
	3/16	35	25			
	1/4	25	20			
	5/16	20	15			
	3/8	15	10			
3 Service-tempered	1/8	35	30	4,500	2,000	75
	3/16	30	30			
	1/4	30	25			
	3/8	20	15			

More and more effort is being put forth by industry to modify and finish hardboard so it can be used in more ways with less "on-the-job" cost of installation and finishing and to permit industrial users a saving in final product. Most important is prefinishing, particularly wood graining, where the surface of the board is finished with lithographic patterns of popular cabinet woods printed in two or more colors.

The uses for hardboard are diverse. It has been claimed that "hardboard is the grainless wood of 1,000 uses, and can be used wherever a dense, hard panel material in the thicknesses as manufactured will satisfy a need better, or more economically than any other material." Because of its density it is harder than most natural wood, and because of its grainless character it has nearly equal properties in all directions in the plane of the board. It is not so stiff nor as strong as natural wood along the grain, but is substantially stronger and stiffer than wood across the grain. Minimum specific properties presented in table 21–5 can be compared with similar properties for wood, wood-base panels, and other materials. Hardboard retains some of the properties of wood; it is hygroscopic and shrinks and swells with changes in moisture content.

Changes in moisture content due to service exposures may be a limiting factor in satisfactory performance. Correct

Table 21–5—*Classification of high-density hardboard by surface finish, thickness, and physical properties*—Continued

Class	Nominal thickness	Water resistance (maximum average per panel)		Modulus of rupture (minimum average per panel)	Tensile strength (minimum average per panel)	
		Water absorption based on weight	Thickness swelling		Parallel to surface	Perpendicular to surface
	Inch	*Percent*		*Pounds per square inch*		
4 Service	1/8	45	35	3,000	1,500	50
	3/16	40	35			
	1/4	40	30			
	3/8	35	25			
	7/16	35	25			
	1/2	30	20			
	5/8	25	20			
	11/16	25	20			
	3/4	20	15			
	13/16	20	15			
	7/8	20	15			
	1	20	15			
	1-1/8	20	15			
5 Industrialite	1/4	50	30	2,000	1,000	25
	3/8	40	25			
	7/16	40	25			
	1/2	35	25			
	5/8	30	20			
	11/16	30	20			
	3/4	25	20			
	13/16	25	20			
	7/8	25	20			
	1	25	20			
	1-1/8	25	20			

Source: ANSI/AHA A 135.4–1982.

application and attachment as well as prior conditioning to a proper moisture content will give satisfactory service, but improper application or conditioning precludes it. Proper moisture conditioning prior to assembly is of particular importance in glued assemblies.

Product development in hardboard has held generally to the line of class and type of board product, in contrast with structural insulating board which deals with specific items for particular uses. During the past few years, much of the success of hardboard resulted because the industry developed certain products for a specific use and had treatments, fabrication, and finishes required by the use. Typical are prefinished paneling, house siding, underlayment, and concrete form hardboard.

Many uses for hardboard have been listed, but generally they can be subdivided according to uses developed for construction, furniture and furnishings, cabinet and store fixture work, appliances, and automotive and rolling stock. Several examples of hardboard products are presented in figure 21−3.

In construction, hardboard is used as floor underlayment to provide a smooth undercourse under plastic or linoleum flooring, as a facing for concrete forms for architectural concrete, as facings for flush doors, as molded facings for interior doors, as insert panels and facings for garage doors, and as material punched with holes for wall linings in storage walls and in built-ins where ventilation is desired. High-density hardboard is being used as a shear-web material for box and I−beams, to be used as load-carrying members in building construction. Prefinished hardboard, either with baked finishes or the regular ones like those used generally in woodgrain printing, is used for wall lining in kitchens, bathrooms, family rooms, and recreation rooms.

In furniture, furnishings, and cabinetwork, conventional hardboard is used extensively for drawer bottoms, dust dividers, case goods and mirror backs, insert panels, television, radio and stereo cabinet sides, backs (die-cut openings for ventilation), and as crossbands and balancing sheets in laminated or overlay panels. Hardboard also has use as a core material for relatively thin panels overlaid with films and thin veneers, and as backup material for metal panels. In appliances other than television, radio, and stereo cabinets, it is used wherever the properties of the dense, hard sheet satisfy a need economically. Because it can be postformed to single curvature (and in some instances to mild double curvature) by the application of heat and moisture, it is used in components of appliances requiring that kind of forming.

In automobiles, trucks, buses, and railway cars, hardboard is commonly used in interior linings. Door and interior sidewall panels of automobiles are frequently hardboard, postformed, and covered with cloth or plastic. The base for sun visors is often hardboard, as are the platforms between seats and rear windows. Molded hardboard also has been used for three-dimensional-shaped components like door panels and armrests. Ceilings of station wagons and truck cabs are often enameled or vinyl-covered thin hardboard.

Special Densified Hardboard

This special building fiberboard product is manufactured mainly as diestock and electrical panel material. It has a density of 84 to 90 pcf and is produced in thicknesses between 1/8 and 2 inches in panel sizes of 3 by 4, 4 by 6, and 4 by 12 feet.

Special densified hardboard is machined easily with machine tools and its low weight as compared with metals (aluminum alloys about 170 pcf) makes it a useful material for templates and jigs for manufacturing. It is relatively stable dimensionally from moisture change because of low rates of moisture absorption. It is more stable for changes in temperature than the metals generally used for those purposes. The 1/8-inch-thick board is specially manufactured for use as lofting board, which is a surface on which small-scale plans of a boat design are projected to actual boat size.

As diestock, it finds use for stretch- and press-forming and spinning of metal parts, particularly when few of the manufactured items are required and where the cost of making the die itself is important in the choice of material.

The electrical properties of the special densified hardboard meet many of the requirements set forth by the National Electrical Manufacturers Association for insulation resistance and dielectric capacity in electrical components so it is used extensively in electronic and communication equipment.

Other uses where its combination of hardness, abrasion resistance, machinability, stability, and other properties are important include cams, gears, wear plates, laboratory work surfaces, and welding fixtures.

Manufacture, Properties, and Uses of Medium-Density Fiberboard

Medium-density fiberboard (MDF) is a panel product manufactured from lignocellulosic fibers combined with a synthetic resin or other suitable binder. The panels are manufactured to a density range of 31 to 55 pcf (0.50 to 0.88 specific gravity) by the application of heat and pressure by a process in which the interfiber bond is substantially created by the added binder. Other materials may have been added during manufacturing to improve certain properties.

The technology utilized to manufacture MDF is a combination of that used in the particleboard industry and that used in the hardboard industry. Consequently, there was much debate over the definition of the product. This was settled by the development of an American National Standard for Medium Density Fiberboard for Interior Use (ANSI A 208.2–1980), cosponsored by the American Hardboard Association and the National Particleboard Association. Minimum property requirements for MDF are presented in table 21–6. MDF fiberboard is available in thicknesses from 3/16 inch up to 1-1/2 inches, but most board manufactured is 3/4 inch thick and in the 44 to 50 pcf density range for applications in the industrial markets.

The furniture industry is by far the dominant MDF market. MDF is frequently taking the place of solid wood, plywood, and particleboard for many furniture applications. Compared to particleboard, it has a very smooth surface which facilitates wood-grain printing, overlaying with sheet materials, and veneering. MDF has tight edges which need not be edgebanded and can be routed and molded like solid wood, as illustrated in figure 21–4. Grain-printed and embossed, MDF is used in many furniture lines. The potential for MDF in other interior and exterior markets such as doors, moldings, exterior trim, and pallet decking is currently being explored by the industry. Many industry people expect MDF markets will expand significantly during the next decade.

Manufacture, Properties, and Uses of Laminated Paperboards

Laminated paperboards are made in two general qualities, an interior and a weather-resistant quality. The main differences between the two qualities are in the kind of bond used to laminate the layers together and in the amount of sizing used in the pulp stock from which the individual layers are made. For interior-quality boards, the laminating adhesives are commonly of starch origin while, for the weather-resistant board, synthetic resin adhesives are used. Laminated paperboard is regularly manufactured in thicknesses of 3/16, 1/4,

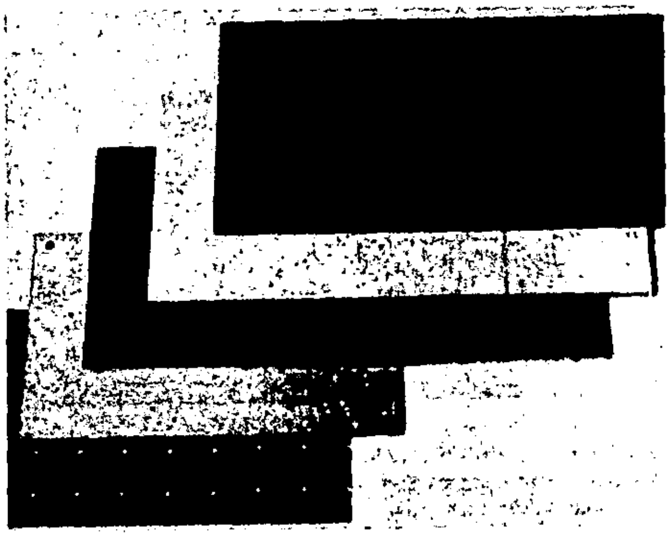

Figure 21–3—Examples of hardboard products, from top to bottom, are facing for flush doors, two types of wood grain printed paneling, standard hardboard, and pegboard. (M84 0280-3)

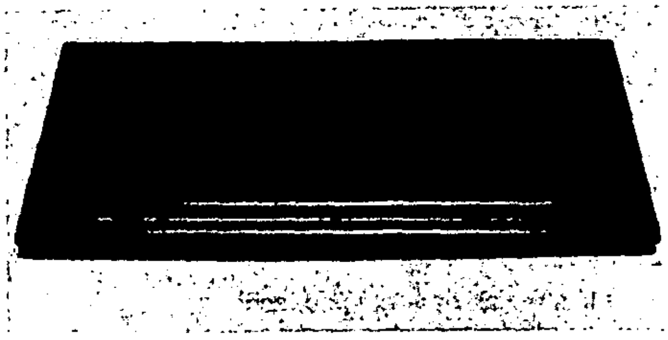

Figure 21–4—Example of medium-density fiberboard that has been embossed, printed with a wood grain, and finished for use as a cabinet drawer front. (M84 0280-6)

Table 21–6—*Property requirements of medium-density fiberboard*

Nominal thickness	Modulus of rupture	Modulus of elasticity	Internal bond (tensile strength perpendicular to surface)	Linear expansion	Screwholding	
					Face	Edge
In	*Psi*	*Psi*	*Psi*	*Pct*	*Lb*	*Lb*
13/16 and below	3,000	300,000	90	[1]0.30	325	275
7/8 and above	2,800	250,000	80	.30	300	·225

[1] For boards having nominal thickness of 3/8 in or less, the linear expansion value shall be 0.35 percent.

Source: ANSI A 208.2–1980.

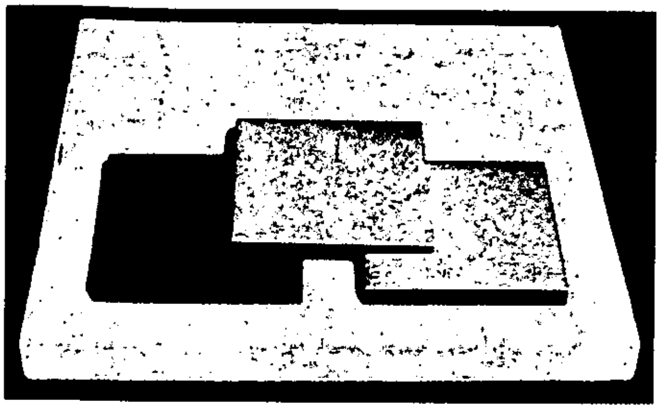

Figure 21–5—Three smaller pieces of laminated paperboard are 3/16- and 3/8-inch thickness and illustrate different surfaces. Bottom paperboard product is a fascia for exterior use. (M84 0280-10)

and 3/8 inch for construction uses although for such industrial uses as dust dividers in case goods, furniture, and automotive liners, 1/8-inch thickness is common. Important properties are presented in table 21–7. Several examples of laminated paperboard products are presented in figure 21–5. A few other uses for laminated paperboards include mirror backing, toys and games, packaging, museum exhibits, photo murals, outdoor signs, and displays.

For building use, considerable amounts go into the prefabricated housing and mobile home construction industry as interior wall and ceiling finish. In the more conventional building construction market, interior-quality boards are also used for wall and ceiling finish, often in remodeling to cover cracked plaster. Some of the full-wall laminated paper panels meet and exceed racking requirements, when applied according to the manufacturer's instructions.

Table 21–7—*Strength and mechanical properties of laminated paperboard*[1]

Property	Value
Density (pcf)	32–33
Specific gravity	0.52–0.53
Modulus of elasticity (compression) (1,000 psi):	
Along the length of the panel[2]	300–390
Across the length of the panel[2]	100–140
Modulus of rupture (psi):	
Span parallel to length of panel[2]	1,400–1,900
Span perpendicular to length of panel[2]	900–1,100
Tensile strength parallel to surface:	
Along the length of the panel[2]	1,700–2,100
Across the length of the panel[2]	600–800
Compressive strength parallel to surface (psi):	
Along the length of the panel[2]	700–900
Across the length of the panel[2]	500–800
24-hour water absorption (pct by weight)	10–170
Linear expansion from 50 to 90 percent relative humidity (pct):[3]	
Along the length of the panel[2]	0.2–0.3
Across the length of the panel[2]	1.1–1.3
Thermal conductivity at mean temperature of 75 °F (Btu · in/h · ft^2 · °F)	0.51

[1] The data presented are general round-figure values, accumulated from numerous sources; for more exact figures on a specific product, individual manufacturers should be consulted or actual tests made. Values are for general laboratory conditions of temperature and humidity.

[2] Because of directional properties, values are presented for two principal directions, along the usual length of the panel (machine direction) and across it.

[3] Measurements made on material at equilibrium at each condition at room temperature.

Water-resistant grades are manufactured for use as sheathing, soffit linings, and other "exterior protected" applications like porch and carport ceilings. Soffit linings and lap siding are specially fabricated in widths commonly used and are prime coated with paint at the factory.

The common width of laminated paperboard is 4 feet, although 8-foot widths are available in 12- , 14- , 16-foot, and longer lengths for such building applications as sheathing entire walls. Laminated paperboards, for use where a surface is exposed, have the surface ply coated with a high-quality pulp to improve surface appearance and performance. Surface finish may be smooth or textured.

Selected References

Acoustical and Board Products Association. Product specification for sound deadening board in wall assemblies. ABPA–IB Spec. No. 4. Park Ridge, IL: ABPA; 1975.

American Hardboard Association. Application instructions for basic hardboard products. Palatine, IL: AHA; n.d.

American Hardboard Association. Finishing recommendations for new construction. Utilizing unprimed and primed hardboard siding. Palatine, IL: AHA; n.d.

American Hardboard Association. Hardboard paneling, 1/4 inch prefinished. Palatine, IL: AHA; n.d.

American Hardboard Association. Hardboard siding. Application and storage instructions. Palatine, IL: AHA; n.d.

American Hardboard Association. Maintenance tips for home owners with hardboard siding exteriors. Palatine, IL: AHA; n.d.

American Hardboard Association. Today's hardboard—and how to handle it. An AHA guide to selling hardboard siding and paneling. Palatine, IL: AHA; n.d.

American Hardboard Association. Today's hardboard—building better than ever. Palatine, IL: AHA; n.d.

American Hardboard Association. Today's hardboard for creative people who build almost anything. An AHA guide for industrial arts students and instructors. Palatine, IL: AHA; n.d.

American Hardboard Association. American National Standard ANSI/AHA A 135.4–1982. Basic hardboard. Palatine, IL: AHA; 1982.

American Hardboard Association. Voluntary product standard PS 57–73. Cellulosic fiber insulating board. Palatine, IL: AHA; 1973.

American Hardboard Association. Voluntary product standard PS 59–73. Prefinished hardboard paneling. Palatine, IL: AHA; 1973.

American Hardboard Association. Voluntary product standard PS 60–73. Hardboard siding. Palatine, IL: AHA; 1973.

American Hardboard Association. Hardboard siding. Recommendations for the use of hardboard siding in manufactured housing. Palatine, IL: AHA; 1978.

American Hardboard Association. Tileboard wall paneling. Palatine, IL: AHA; 1978.

American National Standards Institute. Medium density fiberboard for interior use. ANSI A 208.2–1980. Silver Spring, MD: National Particleboard Association; 1980.

American Society for Testing and Materials. Standard methods of testing insulating board (cellulosic fiber), structural and decorative. ASTM C 209–72. Philadelphia, PA: ASTM; 1972.

American Society for Testing and Materials. Standard specification for insulating board (cellulosic fiber), structural and decorative. ASTM C 208–72. Philadelphia, PA: ASTM; 1972.

American Society for Testing and Materials. Standard methods of test for structural insulating roof deck. ASTM D 2164–65 (reapproved 1977). Philadelphia, PA: ASTM; 1977.

American Society for Testing and Materials. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1037–78. Philadelphia, PA: ASTM; 1978.

American Society for Testing and Materials. Standard specification for structural insulating formboard (cellulosic fiber). ASTM C 532–66 (reapproved 1979). Philadelphia, PA: ASTM; 1979.

American Society for Testing and Materials. Standard specification for fiberboard nail-base sheathing. ASTM D 2277–75 (reapproved 1980). Philadelphia, PA: ASTM; 1980.

McNatt, J. D. Design stresses for hardboard—effect of rate, duration, and repeated loading. Madison, WI: Forest Products Journal. 20(1): 53–60; 1970.

McNatt, J. D. Hardboard-webbed beams: research and application. Madison, WI: Forest Products Journal. 30(10): 57–64; 1980.

Stern, R. K. Development of an improved hardboard-lumber pallet design. Res. Pap. FPL 387. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1980.

Tuomi, R. L.; Gromala, D. S. Racking strength of walls: let-in corner bracing, sheet materials, and effect of loading rate. Res. Pap. FPL 301. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1977.

Chapter 22

Forest Products Lab.
(1989)

Wood-Base Particle Panel Materials

Wood-Base Particle Panel Materials*

The class of "wood-base particle panel materials" includes many subgroups known throughout the United States as particleboard, flakeboard, waferboard, or oriented strand board (OSB). These panel materials are similar because the wood raw material is first reduced to small fractions and then bonded back together, through specialized manufacturing methods, into panels of relatively large size (4 to 8 ft wide by 8 to 60 ft long) and moderate thicknesses (1/8 to 1-1/4 in). These board or panel materials in final form retain a few of the properties of the original wood, but because of the manufacturing methods, gain many new and different properties. As these are manufactured wood products, unlike solid wood, they can be and are tailored to satisfy the property requirements of a specific use or a broad group of end uses.

Particle panel products are defined as any wood-base panel product which is made from pieces of wood smaller than veneer sheets but larger than wood fiber. Information on veneered products may be found in chapters 10 and 11 and fiber panel products are discussed in chapter 21. In general, the name particleboard is used as a generic term for all particle panel products. The raw material for these products comes from a variety of sources including planer shavings, plywood mill waste, roundwood, sawdust, and pulp-type chips. The residues of planing operations constitute the source material for a large segment of the particleboard market for uses such as floor underlayment, furniture corestock, and molded items. Recently several types of particleboards, termed flakeboards, have been widely used as sheathing or single-layer floor panels. Depending upon the particle or flake size and the panel construction, flakeboards may be further classified as waferboard or OSB. Shown in figure 22−1 are three panel materials which can be broadly called particle panel products, and can be further classified as particleboard, waferboard, and OSB.

Particle Panel Processing Overview

Particle panel products are manufactured from residues of milling operations such as planer shavings, sawdust, and plywood trimmings, or alternatively the wood may be obtained from round logs or woods residue (such as branches, broken logs, and tops). Milling residues may be further reduced to desired size in a hammermill operation. Roundwood, the usual source of raw material for flakeboard, waferboard, or OSB, is usually heat conditioned in water prior to reduction to flakes in disk, drum, ring, or other flaking equipment (fig. 22−2). After this initial raw material production phase, the wood particles are called furnish for the process line (fig. 22−3).

The furnish is then dried to a uniform moisture content, usually ranging from 3 to 6 percent, and then is screened to segregate particle sizes. Fine particles may be used in the faces of traditional particleboard to produce a smooth surface, or they may be used as dryer fuel in flakeboard plants because fines are detrimental to the performance of structural panels. Adhesive binders at 3 to 7 percent (percent weight of dry wood) and wax at about 1 percent are either sprayed as a liquid or metered as a powdered blend while the wood particles are tumbled in a blender. Thermosetting urea-formaldehyde and phenol-formaldehyde adhesives are the major types of binders used, thus requiring the application of heat to cure them.

Two processes are commonly used for consolidation of the furnish into the final panel configuration, with the process depending on panel thickness.

For panels over 1/4 inch in final thickness, a flat press processing method is generally used. The blended furnish is formed into a mat of uniform height and moved into the platen press, where the mat is consolidated under controlled heat and pressure to a given average density. Pressing times depend upon many factors, but a typical process requires 3 to 6 minutes of press time to produce 1/2-inch-thick panels. Complete control of the mat forming process places particles according to their size, so that smooth-surface panels may be produced. In the processing of flakeboards, flakes may be aligned in layers through the mat thickness as a means of improving mechanical properties.

For panels 1/4 inch or less in thickness, the blended furnish may be deposited directly onto a large heated rotary drum, where the final mat-pressing or consolidation operation occurs.

Post-pressing operations for any of these panels may include cooling, trimming, sanding, and cutting to size.

Process Variable Effect on Particle Panel Properties

Particle Geometry

Board characteristics influenced by particle geometry involve most of the mechanical properties, nailholding and screwholding strength, surface smoothness, dimensional and weathering properties, and machining characteristics. In addition, the particle geometry influences most other process variables. The intricacy of the interactions is compounded by the fact that the furnish does not consist of one particle geometry but is a mix of many varying sizes.

Assessment of properties of homogeneous unaligned boards

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* Revision by Theodore L. Laufenberg, General Engineer.

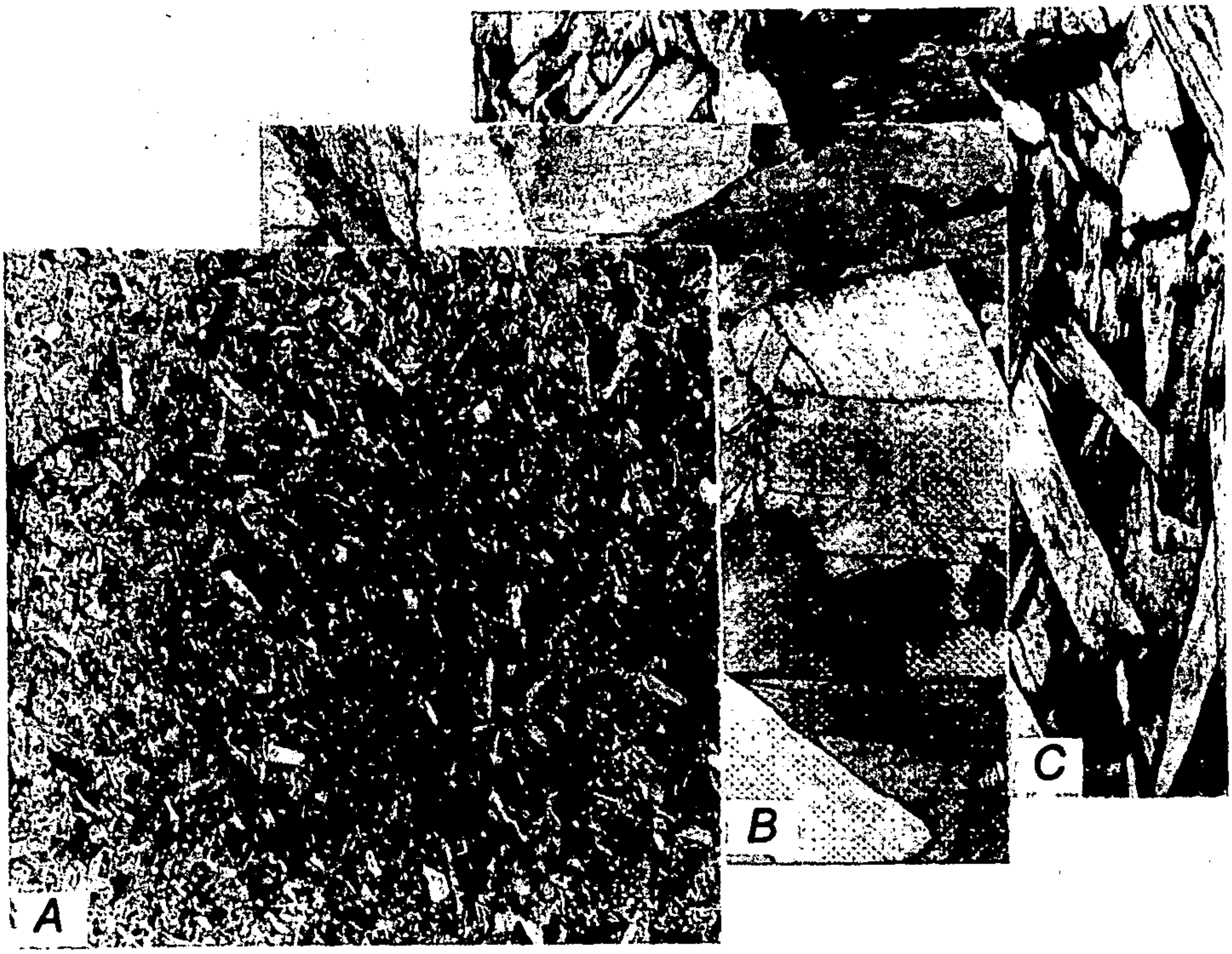

Figure 22–1—Basic particle panel products: *A* particleboard, *B* waferboard, and *C* oriented strand board.

(M84 0285)

made from particles having various geometries has shown that a most important parameter is the ratio of particle length along the fiber to particle thickness. A rule of thumb for obtaining panels with high bending, tensile, and compressive strength and stiffness is to have this ratio higher than 150. Tensile strength perpendicular to the plane of the panel (internal bond strength) is enhanced by thicker particles due to a relative increase in the amount of adhesive per unit surface area of the particles.

Dimensional stability of particle panel products is related to particle geometry in that this property is controlled by the orientations of particles relative to the board surface. Dimensional changes in board thickness due to changes in moisture content are larger for boards made with thick flakes. Dimensional changes in the plane of the board are reduced with longer particles.

Resin Content

If other variables are held constant, increasing resin content produces only a moderate improvement of bending, tensile, and compressive strengths in the plane of the board. The rate of improvement, however, is not the same for all properties and is affected by particle geometry. Internal bond strength and bond durability improve continuously with increased resin levels.

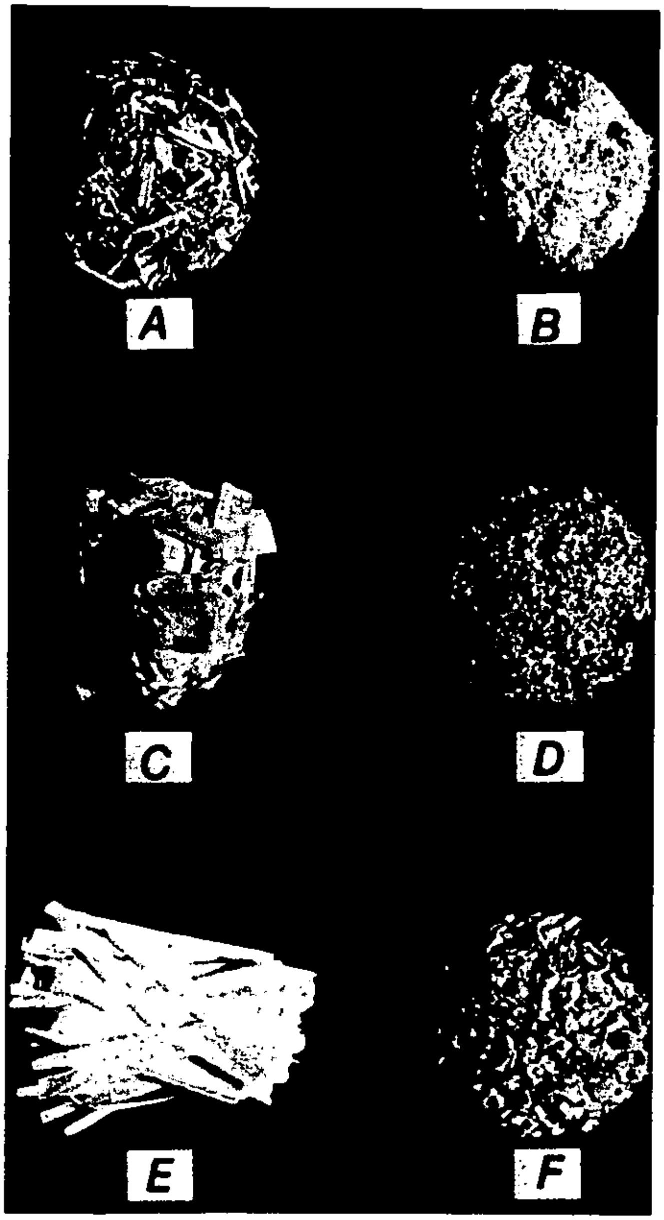

Figure 22-2—Numerous types of furnish suitable for particle panel production: *A* strand-type flakes, *B* fiber bundles, *C* wafer-type flakes, *D* sawdust, *E* long flakes, and *F* planer shaving. (M84 0289)

Although the amount of resin does not significantly affect some properties, the method of application does. The size of the resin droplets and the uniformity of their distribution on the wood particles is critical to the development of particle-to-particle bonds (fig. 22−4). Fine droplets produce a well-dispersed bond area for particles, which increases the mechanical properties of the board.

Resin Type

The bonds produced by different resin systems may be classified in two categories: those sufficiently durable for interior uses and those that are durable enough for protected exterior uses. Urea-formaldehyde resin is typically used to bind particleboard for interior uses. Phenol-formaldehyde or isocyanate resins are typical binders for protected exterior applications.

Density

All physical strength and stiffness properties may be improved by increasing the final density of the board. Bending, tensile and compressive strength, and stiffness increase linearly with density. Internal bond strength, nailholding and screwholding strength, and hardness are very sensitive to board density. Most hot-pressed particleboards possess a gradient of density levels through the thickness of the board, which was created during the pressing sequence. This density gradient is characteristically similar for most particleboards (fig. 22−5), but the differences are significant when assessing thickness swell or linear expansion properties. Board density also affects the rate of water absorption and the equilibrium moisture content (fig. 22−6).

A controlling relationship for the properties of particleboard is the ratio of board density to species density (compaction ratio). The bending strength (MOR) increases with increasing panel density but decreases with increasing species density (fig. 22−7). This relationship appears to be independent of species mix.

Particle Alignment

Alignment of the furnish is a processing variable that has tremendous influence on mechanical and dimensional properties. Typically the type of furnish that lends itself to mechanical alignment has particles longer than 3/4 inch and somewhat narrower in width. These particles may be oriented in either orthogonal direction and may be formed into several distinct layers in the mat. The aligned particles improve the mechanical and dimensional properties in the direction parallel to the orientation, but these improvements are at the expense of those same properties in the opposite direction. The strength and stiffness of panels with aligned particles is capable of exceeding 2.5 times those of panels with random orientation.

Panel shear strength of an aligned panel is less than a similar panel with random orientation. The alignment of flakes produces planes of weakness parallel to the alignment direction. Shear strength perpendicular to the plane of the board (interlaminar shear) is increased significantly due to improved bonding between similarly oriented flakes.

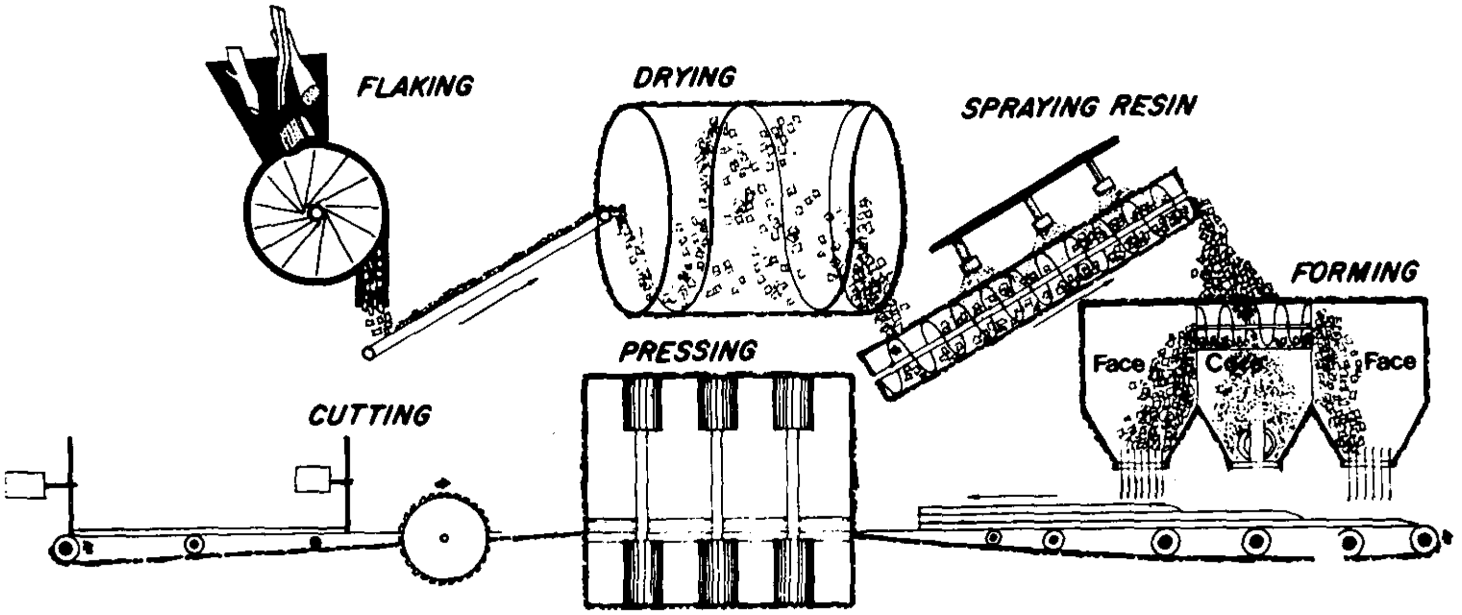

Figure 22-3—Process line schematic for production of mat-pressed particleboards.

(ML83 5387)

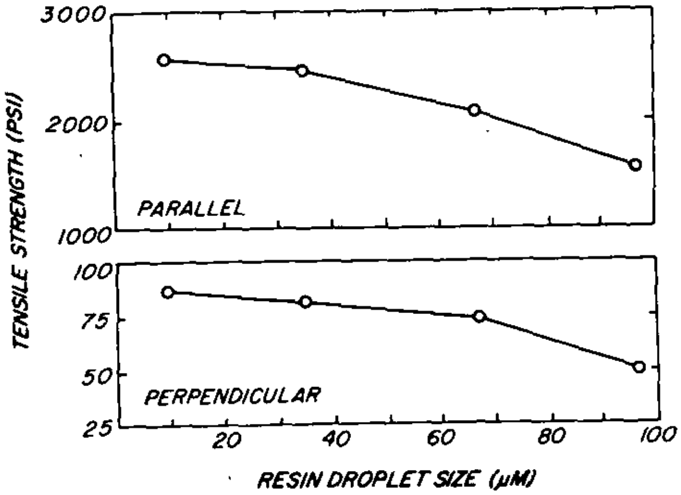

Figure 22-4—Influence of resin droplet size on tensile strength perpendicular and parallel to particleboard surface.

(ML84 5813)

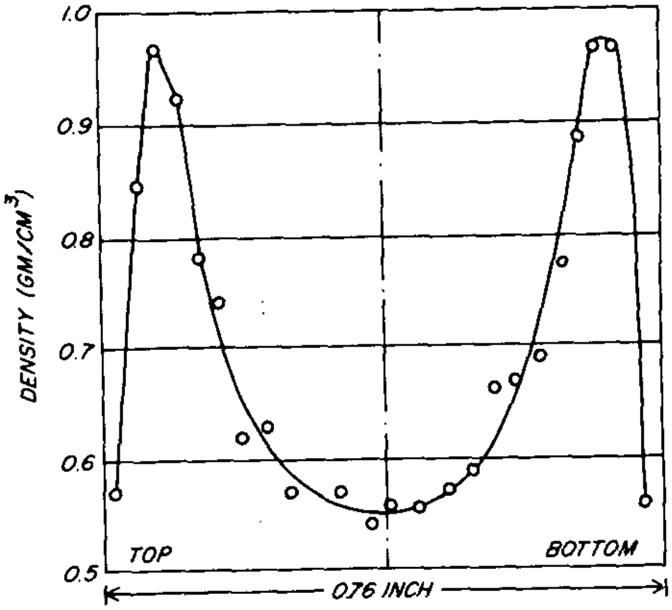

Figure 22-5—Vertical density gradient of a three-layer particleboard.

(ML84 5817)

Hot Pressing

Though limited theoretical analysis has been done on the physics of particleboard pressing, a great deal of information is available from empirical studies. The most obvious "signature" from any particular pressing schedule is the density gradient through the thickness of the panel (fig. 22-5). Press schedule variables for any one furnish type include rate of closing, moisture content distribution in the mat, press temperature and pressure (which is influenced by closing rate), and length of time in the press.

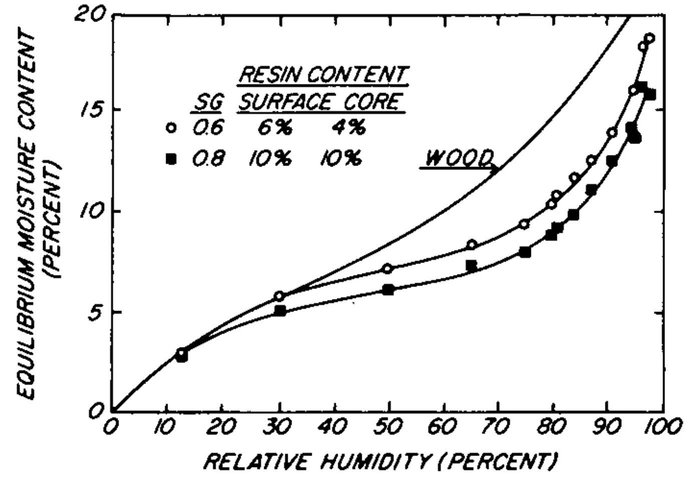

Figure 22–6—Absorption isotherms for two particleboards compared to wood, at 70 °F. (ML84 5819)

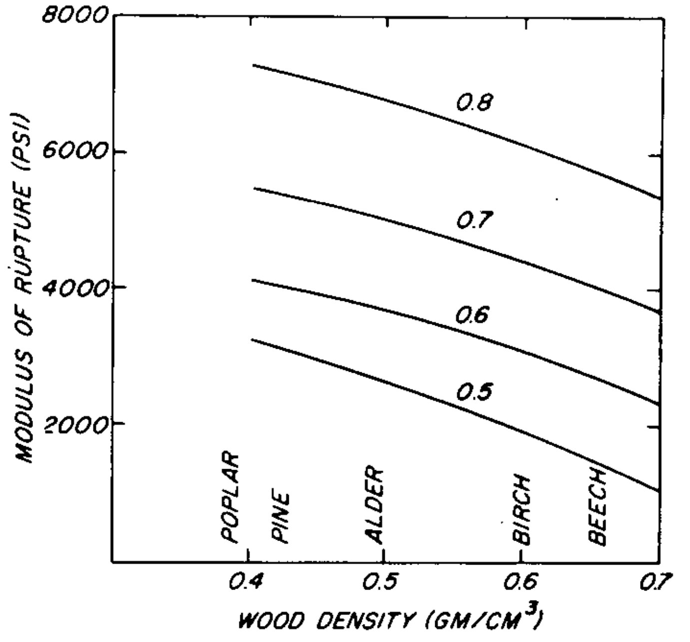

Figure 22–7—Relationship between wood density and modulus of rupture for four particleboard densities. (Use the curves with care, as a board density of 0.5 is not currently possible with wood of 0.6 density.) (ML84 5816)

The most common manipulation of the pressing process utilizes a higher moisture content furnish on the faces of the mat. As the hot platens contact the mat, significantly greater amounts of steam are produced than during pressing of a mat with lower face moisture. This "steam shock" moves through the unpressed mat toward the centerline, heating the mat and effectively shortening the time needed in the press to cure the resin. Another effect of the steam shock method is that the surface layer particles are plasticized and easily densified. In the particle panel product these high-density faces enhance bending properties and surface hardness and smoothness at the expense of internal bond strength and edge integrity.

Specifications for Particle Panel Products

Two approaches have been taken in providing specifications for particle panel products. The traditional approach is to set prescriptive standards for a particular product with minimum mechanical and dimensional properties. An alternate method is to specify what properties a panel must have to perform in a given end use, allowing any number of materials to qualify under the performance standard for that end use.

A majority of the particle panel products commercially available are addressed in the American National Standard, ANSI A 208.1, for mat-formed wood particleboard. This standard specifies minimum mechanical and physical properties as well as dimensional tolerances for the panel. A summary of the properties required by that specification may be found in table 22–1.

Two panel types are recognized: (a) type 1, a particle panel made with urea-formaldehyde (or equivalent) (table 22–1), and (b) type 2, made with phenol-formaldehyde (or equivalent) (table 22–2). Simply stated, type 1 panels are intended for interior use and type 2 panels are for protected exterior and sheathing uses. Three density classes exist within each panel type. High density (H) denotes a density at 5 percent moisture content which exceeds 53 pcf; medium density (M), 38 to 53 pcf; and low density (L), less than 38 pcf. All mechanical property values listed in table 22–1 are used for quality control and grade certification and must not be misconstrued as design allowable values. In-service conditions, material variability, and installation practices preclude the use of these test values for engineering design. Properties of these panels are determined by the test conditions and methods set forth in ASTM D 1037. Within the type 2 grades (table 22–2) are two grades of material that identify a specific particle type to be used in their manufacture.

Phenolic-bonded particleboards, waferboards, and OSB are finding increasing use as sheathing and combination subfloor-underlayment. Many boards are recognized for use based on performance testing rather than on prescriptive standards. These are marketed under a quality control program designed to assure that structural properties do not fall below those of panels successfully passing performance testing. The American Plywood Association has several panel product performance standards that specify the structure of these quality

Table 22 – 1—*Property requirements for Type 1 mat-formed particleboard in ANSI A 208.1 (average values for sample consisting of five panels*[1]*)*

Grade,[2] type 1	Length and width tolerance	Thickness tolerance		Modulus of rupture	Modulus of elasticity	Internal bond	Hardness	Linear expansion, maximum average	Screwholding	
		Panel average[3]	Within panel[4]						Face	Edge
	- - - - - - - - - - *Inch* - - - - - - - - - -			- - - *Pounds per square inch* - - -			Pounds	Percent	Pounds	
1-H-1	±1/16	±0.010	±0.005	2,400	350,000	130	500	NS[5]	400	300
1-H-2	±1/16	±.010	±.005	3,000	350,000	130	1,000	NS	425	350
1-H-3	±1/16	±.010	±.005	3,400	400,000	140	1,500	NS	450	350
1-M-1	±0-1/8	±.015	±.010	1,600	250,000	60	500	0.35	NS	NS
1-M-2	±1/16	±.010	±.005	2,100	325,000	60	500	.35	225	200
1-M-3	±1/16	±.010	±.005	2,400	400,000	80	500	.35	250	225
1-L-1	±1/16	±.005 −.015	±.005	800	150,000	20	NS	.30	125	NS

[1] Except for dimensional tolerances which are individual panel values.

[2] Made with urea-formaldehyde resin binders or equivalent bonding systems.

[3] From nominal.

[4] Individual measurement from panel average.

[5] NS—not specified.

Table 22 – 2—*Property requirements for Type 2 mat-formed particleboard in ANSI A 208.1 (average values for sample consisting of five panels*[1]*)*

Grade,[3] type 2	Length and width tolerance	Thickness tolerance[2]		Modulus of rupture	Modulus of elasticity	Internal bond	Hardness	Linear expansion, maximum average[6]	Screwholding	
		Panel average[4]	Within panel[5]						Face	Edge
	- - - - - - - - - - *Inch*	- - - - - - - - - -		- - - *Pounds per square inch*	- - -		*Pounds*	*Percent*	*Pounds*	
2-H-1	±1/16	±0.015	±0.005	2,400	350,000	125	500	NS	400	300
2-H-2	±1/16	±.015	±.005	3,400	400,000	300	1,800	NS	450	350
2-M-1	+0 −1/8	±.015	±.010	1,800	250,000	60	500	0.35	225	160
2-M-2	+0 −1/8	±.015	±.010	2,500	450,000	60	500	.35	250	200
2-M-3	±0 −1/8	±.015	±.010	3,000	500,000	60	500	.35	NS	NS
2-MW[7]	±0 −1/8	±.015	±.010	2,500	450,000	50	500	.20	NS	NS
2-MF[8]	±0−1/8	±.015	±.010	3,000	500,000	50	500	.20	NS	NS

[1] Except for dimensional tolerances which are individual panel values.

[2] Values shown are for sanded panels as defined by the manufacturer. Values for unsanded panels for all 2-M grades shall be ±0.030 for panel average and ±0.030 within panels.

[3] Made with phenol-formaldehyde resins or equivalent bonding system.

[4] From nominal.

[5] Individual measurement from panel average.

[6] NS—not specified.

[7] Product is made from wafers.

[8] Product is made from flakes.

control programs. This program also establishes minimum criteria for physical properties and durability.

Some standards on specific uses of particleboard are issued by trade associations such as the National Particleboard Association (NPA), building code organizations, and government agencies. A summary of these standards and the uses to which they apply is in table 22−3.

Particleboard Properties and Uses

The particle panel product that is typically made from small wood particles of mill residue is designated particleboard. While particleboards are difficult to characterize because of the infinite variations in the process variables discussed previously, the properties given in table 22−4 should pro-

Table 22−3—*Particleboard application reference table*[1]

Applications	Grade	Product reference[2]
	INTERIOR	
Floor underlayment	1−M−1	ICBO, SBCC, BOCA, HUD/FHA MPS, One and Two Family Dwelling Code
Mobile home decking	Class D−2 Class D−3	NPA 1−73 HUD-Mobile Home Construction and Safety Standards
Shelving	1−M−1 1−M−2 1−M−3	
Countertops	1−M−2 1−M−3	ANSI A 161.2
Kitchen cabinets	1−M−1 1−M−2	ANSI A 161.1
Door core	1−L−1	NWMA Industry Standard Series I.S. 1−78 (wood flush doors)
Stair treads	1−M−3	HUD/FHA UM 70, ICBO RR 3390
Moldings	1−M−3	WMMP Standard WM 2−73
	EXTERIOR	
Roof sheathing	2−M−W	ICBO, SBCC, BOCA, One and Two Family Dwelling Code
Wall sheathing	2−M−1	ICBO, SBCC, BOCA, One and Two Family Dwelling Code
Wall sheathing	2−M−W	ICBO, SBCC, BOCA, One and Two Family Dwelling Code
Combined subfloor underlayment	2−M−3 2−M−W	ICBO, SBCC, BOCA, One and Two Family Dwelling Code
Factory built decking	NPA 2−72	HUD/FHA UM−57a
Siding	2−M−1	ICBO, SBCC, BOCA, One and Two Family Dwelling Code
Siding	2−M−W	SBCC, BOCA

[1] Grades shown refer to ANSI A 208.1 except for mobile home decking which refers to NPA 1−73 and factory-built decking which refers to NPA 2−72.

ICBO — International Conference of Building Officials, Whittier, CA.

SBCC — Southern Building Code Congress International, Birmingham, AL.

BOCA — Building Officials and Code Administrators International, Chicago, IL.

HUD/FHA — Housing and Urban Development/Federal Housing Authority, Washington, DC.

NWMA — National Woodwork Manufacturers Association, Park Ridge, IL.

WMMP — Wood Moulding and Millwork Producers, Portland, OR.

le an idea of the ranges possible for the mat-formed product. ;ain, the primary distinction between flakeboards and parti- :boards is in the size of the particle or flake. The properties ted do not reflect the properties attainable when using a ıke furnish.

Mat-Formed Particleboard

Approximately 85 percent of interior-type mat-formed par- leboard produced has traditionally been used as core stock : a wide variety of furniture and cabinet applications and ›or underlayment in light-frame construction. The majority production is between 1/2 and 2 inches thick for mat- :med boards. Low-density panels are produced in thick- sses to 1-1/2 inches for the solid core door market.

As corestock, particleboard has moved into the market :merly held by lumber-core panels and, to a limited extent, /wood. Certain grades of hardwood plywood now permit : use of particleboard as the core ply, where formerly lum- r core was specified. The type of facing or finishing system plied commonly controls the construction of the particle- ard produced. A panel to be overlaid with 0.0015-inch :raviolet-cured vinyl overlay requires fine particles, or pos- ›ly fibers, on the surfaces to reduce showthrough. An over- / of veneer or high-density plastic can accommodate a arser face particle. Balanced construction in layups using rticleboard is important to minimize warping, cupping, or isting in service.

Edges of particleboard exposed in furniture or cabinetry : frequently covered as there are coarse particles in the ›ver density core. Edge banding with plastic extrusions or a gh-density plastic are common treatments. Filling of edge ›ids and subsequent finishing, or bonding solid wood to :posed edges are other options.

As floor underlayment, particleboard provides a smooth, iff, and hard surface for coverings of carpet, resilient tile, ›d seamless floor coverings. Particleboard for this use is ›duced in 4- by 8-foot panels 1/4 to 3/4 inch thick. Specifi- :ions for these numerous uses have been written to cover rticleboard floor underlayments, and manufacturers pro- le individual application instructions to ensure proper con- uction techniques. Particleboard underlayment is sold under :ertified quality program where established grademarks ›arly identify the use, quality, grade, and originating mill. Other uses for particleboard require a more durable type 2 NSI A 208.1) adhesive in the board. Siding, combined :ing-sheathing, soffit linings, ceilings for carports, porches, d other protected exterior applications are examples of uses proved by some of the model building codes. Satisfactory rformance of particleboard in protected exterior environ- :nts depends not only on the manufacturing process and kind of adhesive used, but on the protection afforded by a finish. This may be a plastic film, paper overlay, or paint which is factory applied.

Manufacturers of mobile homes and factory-built conventional housing also use particleboard. Because these uses may require larger sized panels than those used for conventional construction particleboard is manufactured in sizes as great as 8 by 60 feet. With mechanical handling available in factories, large-sized panels can be positioned and attached to structural members effectively and economically. Two particleboard products have been developed to satisfy these uses. Mobile home decking is used for combined subfloor and underlayment. It is a board with a type 1 bond, but is intended to be protected from moisture when in use by a subfloor which is exposed to the exterior environment. Thus, the board is generally regarded as giving satisfactory service for mobile home use. Particleboard decking for factory-built housing is similar to mobile home decking, but it has a type 2 bond for longer life. The National Particleboard Association has established separate standards for these products. They are marketed under a certified product quality program with each product adequately identified.

Extruded Particleboard

Extruded products are typically "fluted" in that the product is not of uniform thickness over its width. This configuration is used in flush doors or overlaid with a structural panel product such as a hardboard, flakeboard, or plywood for sandwich constructions. The extruded products have distinct zones of weakness across the width of the panel as extruded; thus they are rarely used without facings of some kind glued to them. These facings control the physical and mechanical properties of the sandwich construction. This type of particleboard also has a strong tendency to swell in the lengthwise direction due to particle orientation and subsequent compression as particles are rammed through the heated die during manufacture.

Flakeboard Properties and Uses

Flakeboard is a generic subset of products included under particle panel products. Flakeboards are structural panels made from specially produced flakes, typically from relatively low-density species, such as aspen or pine, and bonded with an exterior-type water-resistant adhesive. The industry began production in the 1950's with a small plant in Sandpoint, Idaho. Subsequent plants built in the 1960's in Hudson Bay, Saskatchewan, proved to be the major developing ground for the flakeboard industry. Producing mills are now located in

Table 22 – 4—*Physical and mechanical properties of mat-formed (platen-pressed) wood particleboard*¹

Table 22-4—*Physical and mechanical properties of mat-formed (platen-pressed) wood particleboard*[1]

Type of particleboard	Property											
					Tensile strength		Shear strength					
	Density	Specific gravity	Modulus of elasticity (bending)	Modulus of rupture	Parallel	Perpendicular	In board plane	Across board plane	24-hour water adsorption	Thickness swelling, 24-hour soaking	Linear expansion[2]	Thermal conductivity[3]
	Pcf		1,000 psi	Psi	---- Psi ----		--- Psi ---		Pct by wt	Pct	Pct	Btu·in/hr·ft²·°F
Low density	[4]25–37	[4]0.40–0.59	[5]150–250	[5]800–1,400	—	[5]20–30	—	—	—	—	[6]0.30	0.55–0.75
Medium density	37–50	.59–.80	250–700	1,600–3,000	500–2,000	30–200	100–450	200–1,000	10–50	5–50	.2–.6	.75–1.00
High density	50–70	.80–1.12	350–1,000	2,400–7,500	1,000–5,000	125–450	200–800	—	15–40	15–40	.2–.85	1.00–1.25

[1] General round-figure values, accumulated from numerous sources; for more exact figures on a specific product, individual manufacturers should be consulted or tests made. Values are for general laboratory conditions of temperature and humidity.

[2] From measurements made on material at equilibrium from 50 to 90 percent relative humidity at room temperature.

[3] At a mean temperature of 75 °F.

[4] Lower of values is for boards as generally manufactured; lower density products with lower properties may be made.

[5] Only limited production of low-density particleboard so values presented are specification limits.

[6] Maximum permitted by specification.

Table 22-5—*Ranges of physical and mechanical properties for commercially available flakeboard*

Type of flakeboard	Property[1]								
	Density[2]	Water absorption	Thickness swell	Linear expansion	Modulus of rupture	Modulus of elasticity	In-plane shear strength	Hardness	Internal bond
	Pcf	---------- Percent ----------			Psi	1,000 psi	Psi	Lb	Psi
Waferboard	38–45	10–30	10–16	0.08–0.15	2,000–3,500	450–650	1,200–1,800	700–1,000	50–100
Oriented strand board									
Parallel to alignment	38–50	10–30	10–20	.05–.10	4,000–7,000	750–1,300	1,000–1,500	700–1,000	70–100
Perpendicular to alignment	—	—	—	.12–.30	1,500–3,500	300–500	—	—	—

[1] Not design allowables.

[2] Limited by specification (ANSI A 208.1) to 38–53 pcf.

the Great Lakes region, New England, and most Canadian provinces.

The youth of the flakeboard industry has not prevented it from making major inroads into the light-frame construction industry. Beginning in the early 1970's, interest in flakeboards increased for a variety of reasons including a strong demand for structural board products and an increase in softwood plywood prices. Utilization of the lower priced aspen stumpage in the Great Lakes and Hudson Bay regions, coupled with closer proximity to the large eastern markets than western or southern plywood mills, gave builders a low-cost alternative to plywood for sheathing uses.

Two major types of flakeboard are recognized, waferboard and OSB. Waferboard, the product produced almost exclusively from aspen wafers (wide flakes), traditionally possesses no intentional orientation of these flakes, and is bonded with an exterior-type resin. OSB is a flakeboard product that emerged in the market place during the early 1980's. Exterior-type resin is applied to wood strands (long and narrow flakes) that are formed into a mat of three to five layers. The strands in each layer are aligned in a direction 90° from the adjacent layer. Flake alignment gives the OSB bending properties (in the aligned direction) that are generally superior to those of a randomly oriented flake waferboard. Some important physical and mechanical properties for flakeboards are summarized in table 22–5. As with any particle panel product, the properties are highly dependent upon the process used to manufacture the panel; the values in tables 22–5 and 22–6 were generated from typical commercially available flakeboards.

The properties of flakeboards indicate that products are suitable for many applications now dominated by softwood plywood. Primary markets for flakeboards are wall and roof sheathing, single-layer flooring, and underlayment in light-frame construction. Several building codes have approved flakeboards for siding materials either over sheathing or nailed directly to the studs. Exterior ceilings, soffits, and interior walls or ceilings are other uses in light residential construction that have received building code approval. In nonresidential applications, flakeboard is used as sheathing/siding of farm structures, industrial packaging, crating, and pallet decks.

Other Wood-Based Particle Products

Veneer/Particle Composite Panels

Structural composite panels marketed since the mid-70's are made with face veneers bonded to a core layer made from oriented strands or random particles. This product (sometimes referred to as COM-PLY) is marketed as a plywood product and is considered to be interchangeable with construction grades of plywood (see ch. 11). Thicknesses of 3/8 to 1/2 inch are common for sheathing uses of this panel, and thicknesses up to 1-1/8 inches have been produced for single-layer flooring applications. The performance standard for structural-use panels sponsored by the American Plywood Association embodies procedures for grademarking this type of panel.

Mende-Process Particleboard

A unique process for producing thin particleboard, the Mende process, involves continuous pressing of the mat by application of heat and pressure through a large rotating cylinder. The board thickness ranges up to 1/4 inch, which permits it to be formed on this cylindrical platen and subsequently flattened. Furnish for the process may range from fibers to flakes. The panels produced in this process may be

Table 22–6—*Effect of waferboard thickness on thermal conductivity and lateral and direct nail withdrawal*

Board thickness	Property		
	Thermal conductivity	Lateral nail loads[1,2]	Withdrawal nail loads[1]
In	*Btu·in/h·ft²·°F*	*Lb*	*Lb*
5/16	2.4	200+	20+
7/16	1.8	400+	40+
5/8	1.2	550+	65+

[1] For 6d common nails.

[2] Edge distance 1/2 inch.

used as wall paneling (with printed overlay or other surface finish), furniture backing, drawer bottoms, and case goods.

Molded Particle Products

Moldings from wood particles can be defined as parts that are formed from furnish blended with less than 25 percent binder resin and cured in dies under heat and pressure. Limited flow of the furnish during pressing restricts the kind of items that may be profitably molded. Exterior siding, door jambs, window sills, table tops, pallets, casket tops, and many other items may be molded using conventional particles. By using finer particles which approach wood flour in size, items with large relief such as toilet seats and croquet balls may be compression molded.

Cement-Bonded Particle Products

Portland cement is commercially used as a binder for a special class of wood particle panels. The wood particles typically used are called excelsior, or wood-wool, as they are long (up to 10 in) and stringy. Medium- to low-density species are reduced to excelsior, blended with cement, formed into mats, and pressed to a density of 30 to 40 pcf. A common use for this product is as roof decking due to its sound-absorbing and fire-resistive properties. Other cement-bonded particle products include building blocks and a panel made with flakes that can be used in doors, floors, load-bearing walls, partitions, concrete forms, and exterior siding.

Selected References

American National Standards Institute. Mat-formed wood particleboard. ANSI A 208.1. New York; 1979.

American Plywood Association. Performance standards and policies for structural-use panels. Tacoma, WA: APA; 1982.

American Society for Testing and Materials. Standard definitions of terms relating to wood-base fiber and particle panel materials. ASTM D 1554. Philadelphia, PA: ASTM; (see current edition).

American Society for Testing and Materials. Standard methods of evaluating the properties of wood-base fiber and particle panel materials. ASTM D 1037. Philadelphia, PA: ASTM; (see current edition).

Canadian Waferboard Association. Waferboard in residential construction. Don Mills, ON, Canada; 1982.

Geimer, R. L.; Hoover, W. L.; Hunt, M. O. Design and construction of large-scale reconstituted wood roof decking. RB 973. West Lafayette, IN: Purdue University, Agricultural Experiment Station; 1982.

Geimer, R. L. Data basic to the engineering design of a reconstituted flakeboard. In: Proceedings, 13th Washington State University International Symposium on Particleboard. Pullman, WA: Washington State University;, 1979. 105–125.

Jessome, A. P. Canadian waferboard properties. Tech. Rep. 523E. Vancouver, BC, Canada: FORINTEK Canada Corporation; 1979.

Kelly, M. W. Critical literature review of relationships between processing parameters and physical properties of particleboard. Gen. Tech. Rep. FPL–10. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1977.

Kieser, J.; Steck, E. F. The influence of flake orientation on the MOR and MOE of strandboards. In: Proceedings, 12th Washington State University Symposium on Particleboard. Pullman, WA: Washington State University; 1978: 99–122.

National Particleboard Association. Standard for particleboard for mobile home decking. NPA 1–73. Silver Springs, MD: NPA; 1973.

National Particleboard Association. Standard for particleboard floor underlayment coated with wax-polymer type hot melt coatings. NPA 3–73. Silver Springs, MD: NPA; 1973.

National Particleboard Association. Filling particleboard. Tech. Bull. 9. Silver Springs, MD: NPA; 1972.

National Particleboard Association. Standard for particleboard decking for factory-built housing. NPA 2–72. Silver Springs, MD: NPA; 1972.

National Particleboard Association. Edge banding and veneering of particleboard. Tech. Bull. 7. Silver Springs, MD: NPA; 1971.

National Research Board. APA structural-use panels. Rep. NRB-108. Whittier, CA: Council of American Building Officials; 1982.

Nestler, F. H. M. The formaldehyde problem in wood-based products - an annotated bibliography. Gen. Tech. Rep. FPL–8. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1977.

Snodgrass J. D. Manufacture of oriented-strand core for composite plywood. In: Proceedings, 11th Washington State University Symposium on Particleboard. Pullman, WA: Washington State University; 1977: 453–470.

Stillinger, J. R.; Wentworth, Irv W. Product, process and economics of producing structural wood-cement panels by the Bison-Werke system. In: Proceedings 11th Washington State University Symposium on Particleboard. Pullman, WA: Washington State University; 1977: 383–410.

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Chapter 23

Modified Woods and Paper-Base Laminates

Materials with properties substantially different than the base material are obtained by chemically treating a wood or wood-base material, compressing it under specially controlled conditions, or by combining the processes of chemical treatment and compression. Sheets of paper treated with chemicals are laminated and hot-pressed into thicker panels that have the appearance of plastic rather than paper, and they are used in special applications because of their structural properties and in items requiring hard, impervious, and decorative surfaces.

Modified woods, modified wood-base materials, and paper-base laminates are normally more expensive than wood because of the cost of the chemicals and the special processing required to produce them. Thus, their use is generally limited to special applications where the increased cost is justified by the special properties needed.

Modified Woods

Wood is treated with chemicals to increase hardness and other mechanical properties, as well as its resistance to decay, fire, and moisture. Application of water-resistant chemicals to the surface of wood, impregnation of the wood with such chemicals dissolved in volatile solvents, or bonding chemicals to the cell wall polymer reduces the rate of swelling and shrinking of the wood when in contact with water. Such treatments may also reduce the rate at which wood changes dimension because of humidity changes, even though they do not affect the final dimension changes caused by long-duration exposures. Paints, varnishes, lacquers, wood-penetrating water repellents, and plastic and metallic films retard the rate of moisture absorption, but have little effect on total dimension change if exposures are long enough.

Resin-Treated Wood (Impreg)

Permanent stabilization of the dimensions of wood is needed for certain specialty uses. This can be accomplished by depositing a bulking agent within the swollen structure of the wood fibers. The most successful bulking agents that have been commercially applied are highly water-soluble, thermosetting, phenol-formaldehyde resin-forming systems, with initially low molecular weights. No thermoplastic resins have been found that effectively stabilize the dimensions of wood.

Wood treated with a thermosetting fiber-penetrating resin and cured without compression is known as impreg. The wood (preferably green veneer to facilitate resin pickup) is soaked in the aqueous resin-forming solution or, if air dry, is impregnated with the solution under pressure until the resin content equals 25 to 35 percent of the weight of dry wood. The treated wood is allowed to stand under nondrying conditions for a day or two to permit uniform distribution of the solution throughout the wood. The resin-containing wood is dried at moderate temperatures to remove the water and then heated to higher temperatures to set the resin.

Uniform distribution of the resin has been effectively accomplished with thick wood specimens only in sapwood of readily penetrated species. Although thicker material can be treated, the process is usually applied to veneers up to 1/3 inch thick, since treating time increases rapidly with increases in thickness. Drying thick resin-treated wood may result in checking and honeycombing. For these reasons, treatments should be confined to veneer and the treated-cured veneer used to build up the desired products. Any species can be used for the veneer except the resinous pines. The stronger the original wood, the stronger will be the product.

Impreg has a number of properties differing from those of normal wood and ordinary plywood. These are given in table 23−1, together with similar generalized findings for other modified woods. Data for the strength properties of birch impreg are given in table 23−2. Information on thermal expansion properties of ovendry impreg is given in table 23−3.

The good dimensional stability of impreg has been the basis of one use where its cost was no deterrent to its acceptability. Wood dies of automobile body parts serve as the master from which the metal-forming dies are made for actual manufacture of parts. Small changes in moisture content, even with the most dimensionally stable wood, produce changes in dimension and curvature of an unmodified wood die; such changes create major problems in making the metal-forming dies where close final tolerances are required. The substitution of impreg, with its high antishrink efficiency (ASE) (table 23−4), almost entirely eliminated the problem of dimensional change during the entire period that the wood master dies were needed. Despite the tendency of the resins to dull cutting tools, patternmakers accepted the impreg readily because it machines without splitting more easily than unmodified wood.

Patterns made from impreg also are superior to unmodified wood in resisting heat when used with shell-molding techniques where temperatures as high as 400 °F were required to cure the resin in the molding sand.

Resin-Treated Compressed Wood (Compreg)

Compreg is similar to impreg except that it is compressed before the resin is cured ~~within the~~ wood. The resin-forming chemicals (usually phenol-formaldehyde) act as plasticizers for the wood so that it can be compressed under modest

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*Revision by Donald S. Fahey, Forest Products Technologist; Roger M. Rowell, Chemist; and Theodore H. Wegner, Chemical Engineer.

Table 23 – 1—*Properties of modified woods*

Property	Impreg	Compreg	Staypak
Specific gravity	15 to 20 pct greater than normal wood	Usually 1.0 to 1.4	1.25 to 1.40
Equilibrium swelling and shrinking	1/4 to 1/3 that of normal wood	1/4 to 1/3 that of normal wood at right angle to direction of compression, greater in direction of compression but very slow to attain	Same as normal wood at right angle to compression, greater in direction of compression but very slow to attain
Springback	None	Very small when properly made	Moderate when properly made
Face checking	Practically eliminated	Practically eliminated for specific gravities below 1.3	About the same as in normal wood
Grain raising	Greatly reduced	Greatly reduced for uniform-texture woods, considerable for contrasting-grain woods	About the same as in normal wood
Surface finish	Similar to normal wood	Varnished-like appearance for specific gravities above about 1.0. Cut surfaces can be given this surface by sanding and buffing	Varnished-like appearance. Cut surfaces can be given this surface by sanding and buffing
Permeability to water vapor	About 1/10 that of normal wood	No data, but presumably much lower than impreg	No data, but presumably lower than impreg
Decay and termite resistance	Considerably better than normal wood	Considerably better than normal wood	Normal, but decay occurs somewhat more slowly
Acid resistance	Considerably better than normal wood	Better than impreg because of impermeability	Better than normal wood because of impermeability but not as good as compreg
Alkali resistance	Same as normal wood	Somewhat better than normal wood because of impermeability	Somewhat better than normal wood because of impermeability
Fire resistance	Same as normal wood	Same as normal wood for long exposures, somewhat better for short exposures	Same as normal wood for long exposures, somewhat better for short exposures
Heat resistance	Greatly increased	Greatly increased	No data
Electrical conductivity	1/10 that of normal wood at 30 pct RH; 1/1,000 that of normal wood at 90 pct RH	Slightly more than impreg at low relative humidity values due to entrapped water	No data

Table 23 – 1—*Properties of modified woods*—Continued

Property	Impreg	Compreg	Staypak
Heat conductivity	Slightly increased	Increased about in proportion to specific gravity increase	No data, but should increase about in proportion to specific gravity increase
Compressive strength	Increased more than proportional to specific gravity increase	Increased considerably more than proportional to specific gravity increase	Increased about in proportion to specific gravity increase parallel to grain, increased more perpendicular to grain
Tensile strength	Decreased significantly	Increased less than proportional to specific gravity increase	Increased about in proportion to specific gravity increase
Flexural strength	Increased less than proportional to specific gravity increase	Increased less than proportional to specific gravity increase parallel to grain, increased more perpendicular to grain	Increased proportional to specific gravity increase parallel to grain, increased more perpendicular to grain
Hardness	Increased considerably more than proportional to specific gravity increase	10 to 20 times that of normal wood	10 to 18 times that of normal wood
Impact strength:			
Toughness	About 1/2 of value for normal wood but very susceptible to the variables of manufacture	1/2 to 3/4 of value for normal wood but very susceptible to the variables of manufacture	Same to somewhat greater than normal wood
Izod	About 1/5 of value for normal wood	1/3 to 3/4 of value for normal wood	Same to somewhat greater than normal wood
Abrasion resistance (tangential)	About 1/2 of value for normal wood	Increased about in proportion to specific gravity increase	Increased about in proportion to specific gravity increase
Machinability	Cuts cleaner than normal wood, but dulls tools more	Requires metalworking tools and metalworking tool speeds	Requires metalworking tools and metalworking tool speeds
Moldability	Cannot be molded, but can be formed to single curvatures at time of assembly	Can be molded by compression and expansion molding methods	Cannot be molded
Gluability	Same as normal wood	Same as normal wood after light sanding, or, in the case of thick stock, machining surfaces plane	Same as normal wood after light sanding, or, in the case of thick stock, machining surfaces plane

Table 23 – 2—*Strength properties of normal and modified laminates*[1] *of yellow birch and a laminated paper plastic*

Property	Normal laminated wood[2]	Impreg (impregnated, uncompressed)[3]	Compreg (impregnated, highly compressed)[3]	Staypak (unimpregnated, highly compressed)[2]	Paper laminate (impregnated, highly compressed)[4]
Thickness (t) of laminate (in)	0.94	1.03	0.63	0.48	0.126 0.512
Moisture content at time of test (pct)	9.2	5.0	5.0	4.0	—
Specific gravity (based on weight and volume at test)	0.7	0.8	1.3	1.4	1.4
	PARALLEL LAMINATES				
Flexure—grain parallel to span (flatwise):[5]					
Proportional limit stress (psi)	11,500	15,900	26,700	20,100	15,900
Modulus of rupture (psi)	20,400	18,800	36,300	39,400	36,600
Modulus of elasticity (1,000 psi)	2,320	2,380	3,690	4,450	3,010
Flexure—grain perpendicular to span (flatwise):[5]					
Proportional limit stress (psi)	1,000	1,300	4,200	3,200	10,500
Modulus of rupture (psi)	1,900	1,700	4,600	5,000	24,300
Modulus of elasticity (1,000 psi)	153	220	626	602	1,480
Compression parallel to grain (edgewise):[6]					
Proportional limit stress (psi)	6,400	10,200	16,400	9,700	7,200
Ultimate strength (psi)	9,500	15,400	26,100	19,100	20,900
Modulus of elasticity (1,000 psi)	2,300	2,470	3,790	4,670	3,120
Compression perpendicular to grain (edgewise):[6]					
Proportional limit stress (psi)	670	1,000	4,800	2,600	4,200
Ultimate strength (psi)	2,100	3,600	14,000	9,400	18,200
Modulus of elasticity (1,000 psi)	162	243	571	583	1,600
Compression perpendicular to grain (flatwise):[5]					
Maximum crushing strength (psi)	—	4,280	16,700	13,200	42,200
Tension parallel to grain (lengthwise):					
Ultimate strength (psi)	22,200	15,800	37,000	45,000	35,600
Modulus of elasticity (1,000 psi)	2,300	2,510	3,950	4,610	3,640

Table 23 – 2—*Strength properties of normal and modified laminates*[1] *of yellow birch and a laminated paper plastic*—**Continued**

Property	Normal laminated wood[2]	Impreg (impregnated, uncompressed)[3]	Compreg (impregnated, highly compressed)[3]	Staypak (unimpregnated, highly compressed)[2]	Paper laminate (impregnated, highly compressed)[4]
Tension perpendicular to grain (edgewise):					
Ultimate strength (psi)	1,400	1,400	3,200	3,300	20,000
Modulus of elasticity (1,000 psi)	166	227	622	575	1,710
Shear strength parallel to grain (edgewise):[6]					
Johnson, double shear across laminations (psi)	2,980	3,460	7,370	6,370	17,800
Cylindrical, double shear parallel to laminations (psi)	3,020	3,560	5,690	3,080	3,000
Shear modulus:					
Tension method (1,000 psi)	182	255	454	—	—
Plate shear method (FPL test) (1,000 psi)	—	—	—	385	909
Toughness (FPL test, edgewise)[6] (in–lb)	235	125	145	250	—
Do (in-lb per in of width)	250	120	230	515	—
Impact strength (Izod)—grain lengthwise:					
Flatwise (notch in face) (ft–lb per in of notch)	14.0	2.3	4.3	12.7	4.7
Edgewise (notch in face) (ft–lb per in of notch)	11.3	1.9	[7]3.2	—	0.67
Hardness:					
Rockwell, flatwise[5] (M–numbers)	—	–22	84	—	110
Load to embed 0.444-inch steel ball to 1/2 its diameter (lb)	1,600	2,400	—	—	—
Hardness modulus (H_M)[8] (psi)	5,400	9,200	41,300	43,800	35,600
Abrasion-Navy wear-test machine (flatwise),[5] wear per 1,000 revolutions (in)	0.030	0.057	0.018	0.015	0.018
Water absorption (24-hr immersion), increase in weight (pct)	43.6	13.7	2.7	4.3	2.2
Dimensional stability in thickness direction:					
Equilibrium swelling (pct)	9.9	2.8	8.0	29	—
Recovery from compression (pct)	—	0	0	4	—

Table 23 – 2—*Strength properties of normal and modified laminates*[1] *of yellow birch and a laminated paper plastic*—Continued

Property	Normal laminated wood[2]	Impreg (impregnated, uncompressed)[3]	Compreg (impregnated, highly compressed)[3]	Staypak (unimpregnated, highly compressed)[2]	Paper laminate (impregnated, highly compressed)[4]
CROSSBAND LAMINATES					
Flexure—face grain parallel to span (flatwise):[5]					
Proportional limit stress (psi)	6,900	8,100	14,400	11,400	12,600
Modulus of rupture (psi)	13,100	11,400	22,800	25,100	31,300
Modulus of elasticity (1,000 psi)	1,310	1,670	2,480	2,900	2,240
Compression parallel to face grain (edgewise):[6]					
Proportional limit stress (psi)	3,300	5,200	8,700	5,200	5,000
Ultimate strength (psi)	5,800	11,400	23,900	14,000	18,900
Modulus of elasticity (1,000 psi)	1,360	1,500	2,300	2,700	2,370
Tension parallel to face grain (lengthwise):					
Ultimate strength (psi)	12,300	7,900	16,500	24,500	27,200
Modulus of elasticity (1,000 psi)	1,290	1,460	2,190	2,570	2,700
Toughness (FPL test edgewise)[6] (in-lb per in of width)	105	40	115	320	—

[1] Laminates made from 17 plies of 1/16-in rotary-cut yellow birch veneer.

[2] Veneer conditioned at 80 °F and 65 percent relative humidity before assembly with phenol resin film glue.

[3] Impregnation, 25 to 30 percent of water-soluble phenol-formaldehyde resin based on the dry weight of untreated veneer.

[4] High-strength paper (0.003-in thickness) made from commercial unbleached black spruce pulp (Mitscherlich sulfite), phenol resin content 36.3 percent, based on weight of treated paper. Izod impact, abrasion, flatwise compression, and shear specimens, all on 1/2-in-thick laminate.

[5] Load applied to the surface of the original material (parallel to laminating pressure direction).

[6] Load applied to the edge of the laminations (perpendicular to laminating pressure direction).

[7] Values as high as 10.0 ft–lb per in of notch have been reported for compreg made with alcohol-soluble resins and 7.0 ft–lb with water-soluble resins.

[8] Values based on the average slope of load-penetration plots, where H_M is an expression for load per unit of spherical area of penetration of the 0.444-in steel ball expressed in pounds per square inch:

$$H_M = \frac{P}{2\pi rh} \text{ or } 0.717\frac{P}{h}$$

pressures (1,000 psi) to a specific gravity of 1.35. Some of its properties are similar to those of impreg, and others vary considerably (tables 23−1 and 23−2). Its advantages over impreg are its natural lustrous finish that can be developed on any cut surface by sanding with fine-grit paper and buffing, its greater strength properties, and the fact that it can be molded (tables 23−1 and 23−2). Thermal expansion coefficients of ovendry compreg, however, are also increased (table 23−3).

Compreg can be molded by: (1) Gluing blocks of resin-treated (but still uncured) wood with a phenolic glue so that the gluelines and resin within the plies are only partially set; (2) cutting to the desired length and width but two to three times the desired thickness; and (3) compressing in a split mold at about 300 °F. Only a small flash squeezeout at the parting line between the two halves of the mold need be machined off. This technique was used for molding motor-test propellers and airplane antenna masts during World War II.

A more generally satisfactory molding technique, known as expansion molding, has been developed. The method consists of rapidly precompressing dry but uncured single sheets of resin-treated veneer in a cold press after preheating the sheets to 200 to 240 °F. The heat-plasticized wood responds to compression before cooling. The heat is insufficient to cure the resin, but the subsequent cooling sets the resin temporarily. These compressed sheets are cut to the desired size, and the assembly of plies is placed in a split mold of the final desired dimensions. Because the wood was precompressed, the filled mold can be closed and locked. When the mold is heated, the wood is again plasticized and tends to recover its uncompressed dimensions. This exerts an internal pressure in all directions against the mold equal to about half of the original compressing pressure. On continued heating, the resin is set. After cooling, the object may be removed from the mold in finished form. Metal inserts or metal surfaces can be molded to compreg or compreg handles molded onto tools by this means. Compreg bands have been molded to the outside of turned wood cylinders without compressing the core. Compreg tubes and small airplane propellers have been molded in this way.

Past uses for compreg once related largely to aircraft; however, it is a suitable material where bolt-bearing strength

Table 23−3—*Coefficients of linear thermal expansion per degree Celsius of wood, hydrolyzed wood, and paper products*[1]

Material[2]	Specific gravity of product	Glue plus resin content[3]	Linear expansion per °C by 10⁶			Cubical expansion per °C by 10⁶
			Fiber or machine direction	Perpendicular to fiber or machine direction in plane of laminations	Pressing direction	
		Pct				
Yellow birch laminate	0.72	3.1	3.254	40.29	36.64	80.18
Yellow birch staypak laminate	1.30	4.7	3.406	37.88	65.34	106.63
Yellow birch impreg laminate	.86	33.2	4.648	35.11	37.05	76.81
Yellow birch compreg laminate	1.30	24.8	4.251	39.47	59.14	102.86
Do.	1.31	34.3	4.931	39.32	54.83	99.08
Sitka spruce laminate	.53	[4] 6.0	3.887	37.14	27.67	68.65
Parallel-laminated paper laminate	1.40	36.5	5.73	15.14	65.10	85.97
Crossbanded paper laminate	1.40	36.5	10.89	[5] 11.00	62.20	84.09
Molded hydrolyzed-wood plastic	1.33	25	42.69	42.69	42.69	128.07
Hydrolyzed-wood sheet laminate	1.39	18	13.49	24.68	77.41	115.58

[1] These coefficients refer to bone-dry material. Generally, air-dry material has a negative thermal coefficient of expansion, because the shrinkage resulting from the loss in moisture is greater than the normal thermal expansion.

[2] All wood laminates made from rotary-cut veneer, annual rings in plane of sheet.

[3] On basis of dry weight of product.

[4] Approximate.

[5] Calculated value.

is required, as in connector plates, because of its good specific strength (strength per unit of weight). Layers of veneer making up the compreg for such uses are often cross laminated (alternate plies at right angles to each other, as in plywood) to give nearly equal properties in all directions. It is extremely useful for aluminum drawing and forming dies, drilling jigs, and jigs for holding parts in place while welding, because of its excellent strength properties, dimensional stability, low thermal conductivity, and ease of fabrication.

Compreg has also been used in silent gears, pulleys, water-lubricated bearings, fan blades, shuttles, bobbins and picker sticks for looms, nuts and bolts, instrument bases and cases, musical instruments, electrical insulators, tool handles, and various novelties. Compreg at present finds considerable use in handles for knives and other cutlery. Both the expansion-molding techniques of forming and curing the compreg around the metal parts of the handle and attaching previously made compreg with rivets are used.

Veneer of any nonresinous species can be used for making compreg. Most properties depend upon the specific gravity to which the wood is compressed rather than the species used. Up to the present, however, compreg has been made almost exclusively from yellow birch or sugar maple.

Untreated Compressed Wood (Staypak)

Resin-treated wood in both the uncompressed (impreg) and compressed (compreg) forms is more brittle than the original wood. To meet the demand for a tougher compressed product than compreg, a compressed wood containing no resin (staypak) was developed. It will not lose its compression under swelling conditions as will ordinary compressed untreated wood. In making staypak, the compressing conditions are modified so that the lignin-cementing material between the cellulose fibers flows sufficiently to eliminate internal stresses.

Staypak is not as water resistant as compreg, but it is about twice as tough and has higher tensile and flexural strength properties, as shown in tables 23−1 and 23−2. The natural finish of staypak is almost equal to that of compreg. Under weathering conditions, however, it is definitely inferior to compreg. For outdoor use, a good synthetic resin varnish or paint finish should be applied to staypak.

Staypak can be used in the same way as compreg where extremely high water resistance is not needed. It shows promise in tool handles, forming dies, connector plates, propellers, and picker sticks and shuttles for weaving, where high impact strength is needed. As staypak is not impregnated, it can be made from solid wood as well as from veneer. Its cost is less than compreg.

A material similar to staypak was produced in Germany prior to World War II. It was a compressed solid wood with much less dimensional stability than staypak and was known as lignostone. Another similar German product was a laminated compressed wood known as lignofol.

Untreated Heated Wood (Staybwood)

Heating wood under drying conditions at higher temperatures (200 to 600° F) than those normally used in kiln drying produces a product known as staybwood that reduces the hygroscopicity and subsequent swelling and shrinking of the

Table 23−4—*Comparison of wood treatments and the degree of dimensional stability achieved*

Treatment	Antishrink efficiency[1]
	Pct
Simple wax dip	2−5
Wood-plastic combination	10−15
Staypak/staybwood	30−40
Impreg	65−70
Chemical modification	65−75
Polyethylene glycol	80−85
Formaldehyde	82−87
Compreg	90−95

[1] Calculated from:

$$S = \frac{V_2 - V_1}{V_1} \times 100$$

where

S = volumetric swelling coefficient,
V_2 = wood volume after humidity conditioning or wetting with water, and
V_1 = wood volume of ovendried sample before conditioning or wetting,

then

$$ASE = \frac{S_2 - S_1}{S_1} \times 100$$

where

ASE = reduction in swelling or antishrink efficiency resulting from a treatment,
S_2 = treated volumetric swelling coefficient,
S_1 = untreated volumetric swelling coefficient.

wood appreciably. The stabilization, however, is always accompanied by loss of mechanical properties. Toughness and resistance to abrasion are most seriously affected.

Under conditions that cause a reduction of 40 percent in shrinking and swelling, the toughness is reduced to less than half that of the original wood. Extensive research to minimize this loss was not successful. Because of the reduction in strength properties from heating at such high temperatures, wood that is dimensionally stabilized in this manner is not used commercially.

Polyethylene Glycol-Treated Wood (PEG)

The dimensional stabilization of wood with polyethylene glycol-1000 (PEG), also known as Carbowax, is accomplished by bulking the fibers to keep the wood in a partially swollen condition. PEG acts in the same manner as does the previously described phenolic resin. It cannot be further cured. The only reason for heating the wood after treatment is to drive off water. PEG remains water soluble. Above 60 percent relative humidity it is a strong humectant and, unless used with care and properly protected, PEG-treated wood can become sticky at high relative humidities. Because of this, PEG-treated wood is usually finished with polyurethane varnish.

Treatment with PEG is facilitated by using green wood. Here, pressure is not applied since the treatment is based on diffusion. Treating times are such that uniform uptakes of 25 to 30 percent of chemical are achieved (based on dry weight of wood). The time necessary for this uptake depends on the thickness of the wood and may require weeks. This treatment is being effectively used for walnut gunstocks for high-quality rifles. The dimensional stability of such gunstocks greatly enhances the continued accuracy of the rifles. Tabletops of high-quality furniture stay remarkably flat and dimensionally stable when made from PEG-treated wood.

Another application of this chemical is to reduce the checking of green wood during drying. For this application a high degree of polyethylene glycol penetration is not required. This method of treatment has been used to reduce checking during drying of small wood blanks or turnings.

Cracking and distortion that old, waterlogged wood undergoes when it is dried can be substantially reduced by treating the wood with polyethylene glycol. The process was used to dry 200-year-old waterlogged wood boats raised from Lake George, NY. The "Vasa," a Swedish ship that sank on its initial trial voyage in 1628, has also been treated after it was raised. There have been many applications of PEG treatment for the restoration of waterlogged wood from archeological sites.

Wood-Plastic Combination

In the modified wood products previously discussed, most of the chemical resides in cell walls; the lumens are essentially empty. If wood is vacuum impregnated with certain liquid vinyl monomers that do not swell wood, and which are later polymerized by gamma radiation or chemical catalyst-heat systems, the resulting polymer resides almost exclusively in the lumens. Methyl methacrylate is a common monomer used for a wood-plastic combination. It is converted to polymethyl methacrylate. Such wood-plastic combinations with polymer contents of 75 to 100 percent (based on the dry weight of wood) resist moisture movement through them. Moisture movement is extremely slow so that normal equilibrium swelling is reached very slowly. Wood-plastic combination materials are much stronger than untreated wood (table 23–5) and commercial application of these products is largely based on increased strength properties.

The main commercial use of this modified wood at present is as parquet flooring where it is produced in squares about 5-1/2 inches on a side from strips about 7/8 inch wide and 5/16 inch thick. It has a specific gravity of 1.0. Comparative tests with conventional wood flooring indicate wood-plastic materials resisted indentation from rolling, concentrated, and impact loads better than white oak. This is largely attributed to improved hardness, which was increased 40 percent in regular wood-plastic combination and 20 percent in the same material treated with a fire retardant. Abrasion resistance was no better than white oak; but because the finish is built in, buffing is all that is required to provide the luster. The finish is maintained even under severe traffic conditions.

Wood-plastic combinations are also being used in sporting goods, musical instruments, and novelty items.

Chemical Modification

Through chemical reactions it is possible to add an organic chemical to the hydroxyl groups on wood cell wall components. This type of treatment bulks the cell wall with a permanently bonded chemical. Many reactive chemicals have been used experimentally to chemically modify wood. For best results, chemicals used should be capable of reacting with wood hydroxyls under neutral or mildly alkaline conditions at temperatures below 248 °F. The chemical system should be simple and must be capable of swelling the wood structure to facilitate penetration. The complete molecule must react quickly with wood components to yield stable chemical bonds while the treated wood retains the desirable properties of untreated wood. Chemicals such as anhydrides, epoxides, isocyanates, acid chlorides, carboxylic acids, lactones, alkyl chlorides, and nitriles all have antishrink efficiency values of

65 to 75 percent at chemical weight gains of 20 to 30 percent.

Reaction of these chemicals with wood yields a modified wood with increased dimensional stability and improved resistance to termites, decay, and marine organisms. Mechanical properties of chemically modified wood are somewhat reduced (10 to 15 percent) as compared to untreated wood.

The reaction of formaldehyde with wood hydroxyl groups is an interesting variation of chemical modification. At weight gains as low as 2 percent, formaldehyde-treated wood is not attacked by wood-destroying fungi. An antishrink efficiency of 47 percent is achieved at a weight gain of 3.1 percent, 55 percent at 4.1, 60 percent at 5.5, and 90 percent at 7.

The mechanical properties of formaldehyde-treated wood are all reduced from those of untreated wood. A definite embrittlement is observed, toughness and abrasion resistance are greatly reduced, crushing strength and bending strengths are reduced about 20 percent, and impact bending strength is reduced up to 50 percent.

Paper-Base Plastic Laminates

Commercially, paper-base plastic laminates are of two types—industrial and decorative. The total annual production is equally divided between the two types. They are made by superimposing layers of paper that have been impregnated with a resinous binder and curing the assembly under heat and pressure.

Industrial Laminates

Industrial laminates are produced to perform specific functions requiring materials with predetermined balances of mechanical, electrical, and chemical properties. The most common use of such laminates is for electrical insulation. The paper reinforcements used in the laminates are of kraft pulp, alpha pulp, cotton linters, or blends of these. Kraft paper emphasizes mechanical strength and dielectric strength perpendicular to laminations. Alpha paper is used for its electric and electronic properties, machinability, and dimensional stability. The cotton linter paper combines greater strength than alpha paper with excellent moisture resistance.

Phenolic resins are the most suitable resins for impregnating the paper from the standpoint of high water resistance, low swelling and shrinking, and high strength properties (except for impact). Phenolics are also lower in cost than other resins that give comparable properties. Water-soluble resins of the type used for impreg impart the highest water resistance and compressive strength properties to the product, but they make the product brittle (low impact strength). Alcohol-soluble phenolic resins produce a considerably

Table 23–5—*Strength properties of wood-plastic combination*[1]

Strength property	Unit	Untreated[2]	Treated[2]
	STATIC BENDING		
Modulus of elasticity	10^6 psi	1.356	1.691
Fiber stress at proportional limit	psi	6,387	11,582
Modulus of rupture	psi	10,649	18,944
Work to proportional limit	in–lb/in^3	1.66	4.22
Work to maximum load	in–lb/in^3	10.06	17.81
	COMPRESSION PARALLEL TO GRAIN		
Modulus of elasticity	10^6 psi	1.113	1.650
Fiber stress at proportional limit	psi	4,295	7,543
Maximum crushing strength	psi	6,505	9,864
Work to proportional limit	in–lb/in^3	11.28	21.41
Toughness	in–lb/in^3	41.8	62.6

[1] Methyl methacrylate impregnated basswood.

[2] Moisture content—7.2 percent.

tougher product, but the resins fail to penetrate the fibers as well as water-soluble resins and thus impart less water resistance and dimensional stability to the product. In practice, alcohol-soluble phenolic resins are generally used.

Paper-base plastic laminates inherit their final properties from the paper from which they are made. High-strength papers yield higher strength plastic laminates than do low-strength papers. Papers with definite directional properties result in plastic laminates with definite directional properties unless they are cross-laminated (alternate sheets oriented with the machine direction at 90° to each other).

Improving the paper used has helped develop paper-base laminates suitable for structural use. Pulping under milder conditions and operating the paper machines to give optimum orientation of the fibers in one direction, together with the desired absorbency, contribute markedly to improvements in strength.

Strength and some other properties of a paper plastic laminate are shown in table 23–2. The National Electric Manufacturers Association L1–1 specification has further information on industrial laminates. As paper is considerably less expensive than glass fabric or other woven fabric mats and can be molded at considerably lower pressures, the paper-base laminates generally have an appreciable price advantage over fabric laminates. Some fabric laminates, however, give superior electrical properties and the highest impact properties. Glass fabric laminates can be molded to greater double curvatures than paper laminates.

During World War II, a high-strength paper plastic known as papreg was used for molding nonstructural and semi-structural airplane parts, such as gunner's seats and turrets, ammunition boxes, wing tabs, and the surfaces of cargo aircraft flooring and catwalks. Papreg was tried to a limited extent for the skin surface of airplane structural parts, such as wing tips. One major objection to its use for such parts is that it is more brittle than aluminum and requires special fittings. Papreg has been used to some extent for heavy-duty truck floors and industrial processing trays for nonedible materials. Because it can be molded at low pressures and is made from thin papers, it is advantageous for use where accurate control of panel thickness is required.

Decorative Laminates

Although decorative laminates are made by the same process as industrial laminates, they are used for very different purposes and bear little outward resemblance to each other. They are used as facings for doors and walls, and for tops of counters, tables, desks, and other furniture.

These decorative laminates are usually composed of a combination of phenolic- and melamine-impregnated sheets of paper. The phenolic-impregnated sheets are brown because of the impregnating resins and comprise most of the built-up thickness of the laminate. The phenolic sheets are overlaid with paper impregnated with melamine resin. One sheet of the overlay is usually a relatively thick one of high opacity and has the color or design printed on it. Then one or more tissue-thin sheets, which become transparent after the resin is cured, are overlaid on the printed sheet to protect it in service. The thin sheets generally contain more melamine resin than the printed sheet, providing stain and abrasion resistance as well as resistance to cigarette burns, boiling water, and common household solvents.

The resin-impregnated sheets of paper are hot-pressed, cured, and then bonded to a wood-base core, usually plywood, hardboard, or particleboard. The thin transparent (when cured) papers impregnated with melamine resin can be used alone as a covering for decorative veneers in furniture to provide a permanent finish. In this use the impregnated sheet is bonded to the wood surface in hot presses at the same time the resin is cured. The heat and stain resistance and the strength of this kind of film make it a superior finish.

The overall thickness of a laminate may obviously be varied by the number of sheets of kraft-phenolic used in the core assembly. Some years ago the 1/16-inch thickness was used with little exception because of its very high impact strength and resistance to substrate showthrough. More recently the 1/32-inch thickness has been popular on vertical surfaces such as walls, cabinet doors, and vertical furniture faces. This results in better economy, since the greater strength of the heavier laminate is not necessary. As applications have proliferated, a whole series of thicknesses have been offered from about 20 to 62 mils, or even up to 150 mils when self-supporting types are needed. The laminate may have decorative faces on both sides if desired, especially in the heavier thicknesses.

The phenolic sheets may also contain special postforming-type phenolic resins or extensible papers that make it possible to postform the laminate. By heating to 325 °F for a short time, the structure can undergo simple bending to a radius of 1/2 inch readily and of 3/16 to 1/4 inch with careful control. Rolled furniture edges, decorative moldings, curved counter tops, shower enclosures, and many other applications are served by this technique. Finally, the core composition may be modified to yield fire-retardant, low-smoking laminates to comply with fire codes. These high-pressure decorative laminates are covered by the National Electrical Manufacturers Association Specification LD3.

Paper will absorb or give off moisture, depending upon conditions of exposure. This moisture change causes paper to shrink and swell, usually more across the machine direction than along it. Likewise, the laminated paper plastics shrink and swell, although at a much slower rate. Cross-laminating minimizes the amount of this shrinking and swelling. In many uses in furniture where laminates are bonded to cores, these changes in dimension due to moisture changes with the change of seasons are different than those of the core material. To balance the construction, a paper plastic with similar properties may be glued to the opposite face of the core to prevent bowing or cupping from the moisture changes.

Lignin-Filled Laminates

The cost of phenolic resins at one time resulted in considerable effort to find impregnating and bonding agents that were less expensive and yet readily available. Lignin-filled laminates made with lignin recovered from the spent liquor of the soda pulping process have been produced as a result of this search. Lignin is precipitated from solution within the pulp or added in a pre-precipitated form before the paper is made. The lignin-filled sheets of paper can be laminated without the addition of other resins, but their water resistance is considerably enhanced when some phenolic resin is applied to the paper in a second operation. The water resistance can also be improved by impregnating only the surface sheet with phenolic resin. It is also possible to introduce lignin, together with phenolic resin, into untreated paper sheets.

The lignin-filled laminates are always dark brown or black. They have better toughness than phenolic laminates. In most other strength properties they are comparable or lower. In spite of the fact that lignin is somewhat thermoplastic, the loss in strength on heating to 200 °F is proportionately no more than for phenolic laminates.

Reduction in costs of phenolic resins has virtually eliminated the lignin-filled laminates from American commerce. They have a number of potential applications, however, where a cheaper laminate with less critical properties than phenolic laminates can be used.

Paper-Face Overlays

Paper has found considerable use as an overlay material for veneer or plywood. Overlays can be classified into three different types according to their use—masking, structural, and decorative. Masking overlays are used to cover minor defects in plywood, such as face checks and patches, minimize grain raising, and provide a more uniform paintable surface, thus making possible the use of lower grade veneer. Paper for this purpose need not be of high strength, as the overlays need not add strength to the product. For adequate masking a single surface sheet with a thickness of 0.012 to 0.030 inch is desirable. Paper impregnated with phenolic resins at 17 to 25 percent of the weight of the paper gives the best all-around product. Higher resin contents make the product too costly and tend to make the overlay more transparent. Appreciably lower resin contents give a product with low scratch and abrasion resistance, especially when the panels are wet or exposed to high relative humidities.

The paper faces can be applied at the same time that the veneer is assembled into plywood in a hot press. Thermal stresses that might result in checking are not set up if the machine direction of the paper overlays is at right angles to the grain direction of the face plies of the plywood.

The masking paper-base overlays or vulcanized fiber sheets have been used for such applications as wood house siding that is to be painted. These overlays mask defects in the wood, prevent bleedthrough of resins and extractives in the wood, and provide a better substrate for paint. The paper-base overlays improve the across-the-board stability from changes in dimension due to changes in moisture content.

The structural overlay, also known as the high-density overlay, contains no less than 45 percent thermosetting resin, generally phenolic. It consists of one or more plies of paper similar to that used in the industrial laminates described previously. The resin-impregnated papers can be bonded directly to the surface of a wood substrate during cure of the sheet, thus requiring only a single pressing operation.

The decorative-type overlay has been described in the section on decorative laminates.

Selected References

Erickson, E.C.O. Mechanical properties of laminated modified woods. FPL Rep. 1639. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1947.

Forest Products Laboratory. Physical and mechanical properties of lignin-filled laminated paper plastic. FPL Rep. 1579. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; rev. 1962.

Heebink, B. G. Importance of balanced construction in plastic-faced wood panels. Res. Note FPL−021. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1963.

Heebink, B. G.; Haskell, H. H. Effect of heat and humidity on the properties of high-pressure laminates. Madison, WI: Forest Products Journal. 12(11): 542−548; 1962.

Langwig, J. E.; Meyer, J. A.; Davidson, R. W. Influence of polymer impregnation on mechanical properties of basswood. Madison, WI: Forest Products Journal. 18(7): 33−36; 1968.

Meyer, J. A. Treatment of wood-polymer systems using catalyst-heat techniques. Madison, WI: Forest Products Journal. 15(9): 362−364; 1965.

Meyer, J. A.; Loos, W. E. Treating southern pine wood for modification of properties. Madison, WI: Forest Products journal. 19(12): 32−38; 1969.

Mitchell, H. L. How PEG helps the hobbyist who works with wood. FPL Unnumbered publication. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. n.d.

National Electrical Manufacturers Association. Standard specification for industrial laminated thermosetting products. Designation L1−1. Washington, DC: NEMA; (see current edition).

National Electrical Manufacturers Association. Standard specification for high-pressure decorative laminates. Designation LD−3. Washington, DC: NEMA; (see current edition).

Rowell, R. M. Chemical modification of wood: advantages and disadvantages. American Wood-Preservers Association Proceedings. 71: 41−51; 1975.

Rowell, R. M., ed. The chemistry of solid wood. American Chemical Society, Advances in Chemistry Series No. 207; 1984.

Seborg, R. M.; Inverarity, R. B. Preservation of old, waterlogged wood by treatment with polyethylene glycol. Science. 136(3516): 649−650; 1962.

Seborg, R. M.; Millett, M. A.; Stamm, A. J. Heat-stabilized compressed wood (staypak). Mechanical Engineering. 67(1): 25−31; 1945.

Seborg, R. M.; Vallier, A. E. Application of impreg for patterns and die models. Madison, WI: Forest Products Journal 4(5): 305−312; 1954.

Seidl, R. J. Paper and plastic overlays for veneer and plywood. Madison, WI: Forest Products Research Society Proceedings. 1: 23−32; 1947.

Stamm, A. J. Effect of polyethylene glycol on dimensional stability of wood. Madison, WI: Forest Products Journal. 9(10): 375−381; 1959.

Stamm, A. J. Wood and cellulose science. New York: Ronald Press; 1964.

Stamm, A. J.; Seborg, R. M. Forest Products Laboratory resin-treated laminated, compressed wood (compreg). FPL Rep. 1381. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1951.

Stamm A. J.; Seborg, R. M. Forest Products Laboratory resin-treated wood (impreg). FPL Rep. 1380. Madison WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; rev. 1962.

Weatherwax, R. C.; Stamm, A. J. Electrical resistivity of resin-treated wood (impreg and compreg), hydrolyzed-wood sheet (hydroxylin), and laminated resin-treated paper (papreg). FPL Rep. 1385. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory; 1945.

Weatherwax, R. C.; Stamm, A. J. The coefficients of thermal expansion of wood and wood products. Transactions of American Society of Mechanical Engineering 69(44): 421−432; 1946.

Structure of Wood*

Forest Products Lab.
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The fibrous nature of wood strongly influences how it is used. Specifically, wood is composed mostly of hollow, elongate, spindle-shaped cells that are arranged parallel to each other along the trunk of a tree. When lumber and other products are cut from the tree, the characteristics of these fibrous cells and their arrangement affect such properties as strength and shrinkage, as well as grain pattern of the wood.

A brief description of some elements of wood structure is given in this chapter.

Bark, Wood, and Pith

A cross section of a tree (fig. 2−1) shows the following well-defined features in succession from the outside to the center: (1) Bark, which may be divided into the outer, corky, dead part that varies greatly in thickness with different species and with age of trees, and the thin, inner living part; (2) wood, which in merchantable trees of most species is clearly differentiated into sapwood and heartwood; and (3) the pith, the small core of tissue located at the center of tree stems, branches, and twigs.

As the tree grows in height, branching is initiated by lateral bud development. The lateral branches are intergrown with the wood of the trunk as long as they are alive. These living branches constitute intergrown knots. After the branch dies, the trunk continues to increase in diameter and surrounds the portion of the branch which was projecting from the trunk at the time the branch died. Such enclosed portions of dead branches constitute the loose or encased knots. After the dead branches drop off, the dead stubs become overgrown and, subsequently, clear wood is formed.

Most growth in thickness of bark and wood arises by cell division at a layer of thin-walled living cells called the cambium. This layer of cells is located between the bark and wood and is invisible without a microscope. No growth in either diameter or length takes place in wood already formed; new growth is purely the addition of new cells, not the further development of old ones. New wood cells are formed on the inside of the cambium and new bark cells on the outside. Thus, new wood is laid down to the outside of old wood and the diameter of the woody trunk increases. The existing bark is pushed outward by the formation of new bark, and the outer bark layers become stretched, cracked, and ridged and are finally sloughed off.

Sapwood and Heartwood

Sapwood is located between the bark and the heartwood. The sapwood contains both living and dead cells and functions primarily in the storage of food and the mechanical transport of water or sap.

The sapwood layer may vary in thickness and in the number of growth rings contained in it. Sapwood commonly ranges from 1-1/2 to 2 inches in radial thickness. In certain species, such as catalpa and black locust, the sapwood contains few growth rings and sometimes does not exceed 1/2 inch in thickness. The maples, hickories, ashes, some of the southern pines, ponderosa pine, and cativo (*Prioria copaifera*), ehie (*Guibourtia ehie*), and courbaril (*Hymenaea courbaril*) of tropical origin may have sapwood 3 to 6 inches or more in thickness, especially in second-growth trees. As a rule, the more vigorously growing trees have wider sapwood layers. Many second-growth trees of merchantable size consist mostly of sapwood.

In general, heartwood consists of inactive cells that do not function in either water conduction or food storage. The transition from sapwood to heartwood, however, is accompanied by an increase in the extractive content. Frequently these extractives darken the heartwood and give species such as black walnut and cherry their characteristic color. Species in which heartwood does not darken to a great extent include the spruces (except Sitka spruce), hemlock, the true firs, basswood, cottonwood, buckeye, ceiba, obeche, and ramin. Heartwood extractives in some species such as black locust, western redcedar, and redwood make the wood resistant to fungi or insect attack. All dark-colored heartwood is not resistant to decay and some nearly colorless heartwood provides decay resistance, as in northern white-cedar. Sapwood of all species, however, is not resistant to decay. Heartwood extractives may also affect wood in the following ways: (1) Reduce the permeability making the heartwood slower to dry and more difficult to impregnate with chemical preservatives, (2) increase the stability to changing moisture conditions, (3) increase the weight slightly, and (4) dull cutting tools. However, as sapwood becomes heartwood, no cells are added or taken away, nor do any cells change shape. The basic strength of the wood is essentially not affected by sapwood cells becoming heartwood cells.

In some species such as the ashes, hickories, and certain oaks, the pores (vessels) become plugged to a greater or lesser degree with ingrowths known as tyloses. Heartwood having pores tightly plugged by tyloses, as in white oak, is suitable for tight cooperage, since this prevents the passage of liquid through the pores. Tyloses also make impregnation with liquid preservatives difficult.

Growth Rings

With most species in temperate climates, there is sufficient difference between the wood formed early and that formed late in a growing season to produce well-marked annual growth

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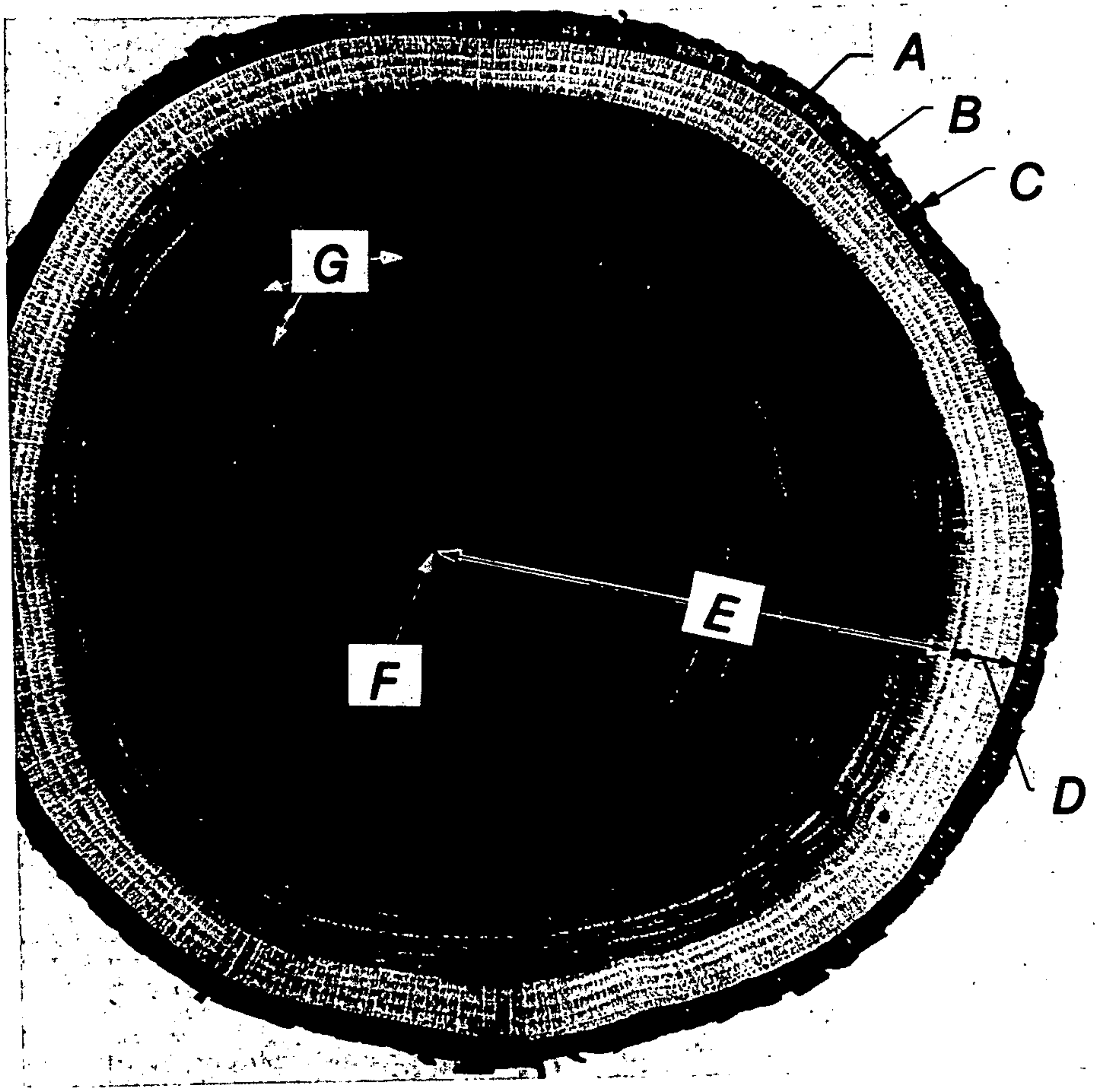
* Revision by Regis B. Miller, Botanist.



(M88 620)

Figure 2–1—Cross section of a white oak tree trunk: *A*, Cambium layer (microscopic) is inside inner bark and forms wood and bark cells. *B*, Inner bark is moist, soft, and contains living tissue; carries prepared food from leaves to all growing parts of tree. *C*, Outer bark containing corky layers is composed of dry dead tissue. Gives general protection against external injuries. Inner and outer bark are separated by a bark (cork) cambium. *D*, Sapwood, which contains both living and dead tissues, is the light-colored wood beneath the bark. Carries sap from roots to leaves. *E*, Heartwood (inactive) is formed by a gradual change in the sapwood. *F*, Pith is the soft tissue about which the first wood growth takes place in the newly formed twigs. *G*, Wood rays connect the various layers from pith to bark for storage and transfer of food.

rings. The age of a tree at the stump or the age at any cross section of the trunk may be determined by counting these rings (fig. 2–2). However, if the growth in diameter is interrupted by drought or defoliation by insects, more than one ring may be formed in the same season. In such an event, the inner rings usually do not have sharply defined boundaries and are termed false rings. Trees that have only very small crowns or that have accidentally lost most of their foliage may form only an incomplete growth layer, sometimes called a discontinuous ring.

The inner part of the growth ring formed first in the growing season is called earlywood and the outer part formed later in the growing season, latewood. Actual time of formation of these two parts of a ring may vary with environmental and weather conditions. Earlywood is characterized by cells having relatively large cavities and thin walls. Latewood cells have smaller cavities and thicker walls. The transition from earlywood to latewood may be gradual or abrupt, depending on the kind of wood and the growing conditions at the time it was formed.

Growth rings are most readily seen in species with sharp contrast between earlywood, last year's latewood and next year's earlywood, such as in the native ring-porous hardwoods ash and oak, and softwoods such as southern pine. In some other species, such as water tupelo, aspen, and sweetgum, differentiation of early and late growth is slight, and the annual growth rings are difficult to recognize. In many tropical regions, growth may be practically continuous throughout the year, and no well-defined annual rings are formed.

When growth rings are prominent, as in most softwoods and ring-porous hardwoods, earlywood differs markedly from latewood in physical properties. Earlywood is lighter in weight, softer, and weaker than latewood. Because of the greater density of latewood, the proportion of latewood is sometimes used to judge the strength of wood. This method is useful with such species as the southern pines, Douglas-fir, and the ring-porous hardwoods—ash, hickory, and oak.

Wood Cells

Wood cells that make up the structural elements of wood are of various sizes and shapes and are quite firmly cemented together. Dry wood cells may be empty or partly filled with deposits, such as gums and resins, or with tyloses. The majority of wood cells are considerably elongated and pointed at the ends; they are customarily called fibers or tracheids. The length of wood fibers is highly variable within a tree and among species. Hardwood fibers average about one twenty-fifth of an inch (1 mm) in length; softwood fibers (called tracheids) range from one-eighth to one-third of an inch (3 to 8 mm) in length.

In addition to their fibers, hardwoods have cells of relatively large diameter known as vessels (or pores). These form the main arteries in the movement of sap. Softwoods do not contain vessels for conducting sap longitudinally in the tree; this function is performed by the tracheids.

Both hardwoods and softwoods have cells (usually grouped into structures or tissues) that are oriented horizontally in the direction from the pith toward the bark. These groups of cells conduct sap radially across the grain and are called rays or wood rays. The rays are most easily seen on edge-grained or quartersawed surfaces. They vary greatly in size in different species. In oaks and sycamores, the rays are conspicuous and add to the decorative features of the wood.

Wood also has other cells, known as longitudinal or axial parenchyma cells, that function mainly for the storage of food.

Chemical Composition of Wood

Dry wood is made up chiefly of cellulose, lignin, hemicelluloses, and minor amounts (5-10 percent) of extraneous materials.

Cellulose, the major constituent, comprises approximately 50 percent of wood substance by weight. It is a high-molecular-weight linear polymer consisting of chains of bonded glucose monomers. During growth of the tree, the cellulose molecules are arranged into ordered strands called fibrils, which in turn are organized into the larger structural elements comprising the cell wall of wood fibers. Delignified wood fibers which are mostly cellulose have great commercial value when formed into paper. Moreover, they may be chemically altered to form synthetic textiles, films, lacquers, and explosives.

Lignin comprises 23 to 33 percent of softwoods, and 16 to 25 percent of hardwoods. It occurs in the wood throughout the cell wall, but is concentrated toward the outside of the cells and between cells. Lignin is a three-dimensional phenylpropane polymer. Lignin structure and distribution in wood are still not fully understood. To remove lignin from wood on a commercial scale may require vigorous reagents or high temperatures or high pressures.

Theoretically, lignin might be converted to a variety of chemical products but, practically, a large percentage of the lignin removed from wood during pulping operations is a troublesome byproduct. It is often burned for heat and recovery of pulping chemicals. One sizable commercial use for lignin is in the formulation of oil-well drilling muds. It is also used in rubber compounding and in concrete mixes. Lesser amounts are processed to yield vanillin for flavoring purposes and to produce solvents.

The hemicelluloses are associated with cellulose and are polymers built from several different kinds of sugar monomers.

Figure 2-2—Cross section of a ponderosa pine log showing growth rings: Light bands are earlywood, dark bands are latewood. An annual (growth) ring is composed of the earlywood ring and the latewood ring outside it. (M60 729)

The relative amounts of these sugars vary markedly with species. The hemicelluloses play an important role in fiber-to-fiber bonding in the papermaking process. The component sugars of hemicellulose are of potential interest for conversion into chemical products.

Unlike the major constituents just discussed, the extraneous materials are not structural components of wood. They are both organic and inorganic. The organic component contributes to such properties of wood as color, odor, taste, decay resistance, density, hygroscopicity, and flammability. Extractives include tannins and other polyphenolics, coloring matters, essential oils, fats, resins, waxes, gums, starch, and simple metabolic intermediates. This component is termed extractive because it can be removed from wood by extraction with such solvents as water, alcohol, acetone, benzene, and ether. In quantity, the extractives may range from roughly 5 to 30 percent, depending on such factors as species, growth conditions, and time of year the tree is cut.

The inorganic component of the extraneous material generally comprises 0.2 to 1.0 percent of the wood substance, although higher values are occasionally reported. Calcium, potassium, and magnesium are the more abundant elemental constituents. Trace amounts (<100 p/m) of phosphorus, sodium, iron, silicon, manganese, copper, zinc, and perhaps a few others are also usually present.

A significant dollar value of nonfibrous products is produced from wood including naval stores, pulp byproducts, vanillin, ethyl alcohol, charcoal, extractives, and bark products.

Identification

Many species of wood have unique physical, mechanical, or chemical properties. Efficient utilization dictates that species should be matched to use requirements through an understanding of properties. This requires identification of the species in wood form, independent of bark, foliage, and other characteristics of the tree.

Field identification can often be made on the basis of readily visible characteristics such as color, odor, density, presence of pitch, or grain pattern. Where more positive identification is required, a laboratory investigation of the microscopic anatomy of the wood can be made. Detailed descriptions of identifying characteristics are given in texts such as "Textbook of Wood Technology" by Panshin and de Zeeuw and "Understanding Wood: A Craftsman's Guide to Wood Technology" by B. R. Hoadley.

Selected References

Bratt, L. C. Trends in the production of silvichemicals in the United States and abroad. Atlanta, GA: Tappi 48(7): 46A–49A; 1965.

Core, H. A.; Côté, W. A.; Day, A. C. Wood structure and identification. Syracuse, NY: Syracuse University Press; 1979.

Hamilton, J. K., Thompson, N. C. A comparison of the carbohydrates of hardwoods and softwoods. Atlanta, GA: Tappi 42: 752–760; 1959.

Hoadley, B. R. Understanding wood: a craftsmen's guide to wood technology. Newtown, CT: Taunton Press; 1980.

Kribs, D. A. Commercial woods on the American market. New York: Dover Publications; 1968.

Ott, E.; Spurlin, H. M.; Grafflin, M. W. Cellulose and cellulose derivatives. Volume V. Parts I, II, and III (1955) of High Polymers. New York: Interscience Publishers; 1954.

Panshin, A. J.; de Zeeuw, C. Textbook of wood technology. 4th ed. New York: McGraw-Hill; 1980.

Sarkanen, K. V.; Ludwig, C. H. (editors). Lignins: occurrence, formation, structure and reactions. New York: Wiley-Interscience; 1971.

Sjöström, E. Wood chemistry: fundamentals and applications. New York: Academic Press; 1981.

Wise, L. E.; Jahn, E. C. Wood chemistry, Volumes I and II. New York: Reinhold; 1952.

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(citation is in References for Section 4)

tent of the veneer should be as low as practical. Very dry veneer, however, is difficult to handle without damage, so the minimum practical moisture content is about 4 percent. Freshly glued plywood intended for interior service should be dried to the moisture content values given in table 14−1.

Hot-pressed plywood and other board products, such as particleboard and hardboard, often do not arrive at the same equilibrium moisture content values as those given for lumber. The high temperatures used in hot presses cause these products to assume a lower moisture content for a given relative humidity. Because this lower equilibrium moisture content varies widely, depending on the specific type of hot-pressed product, it is recommended that such products be conditioned at 40 to 50 percent relative humidity for interior use and 65 percent for exterior use.

Lumber used in the manufacture of large laminated members should be dried to a moisture content slightly below the moisture content expected in service so that moisture absorbed from the glue will not cause the moisture content of the product to exceed the service value. The range of moisture content between laminations assembled into a single member should not exceed 5 percentage points. Although laminated members are often massive and respond rather slowly to changes in environmental conditions, it is desirable to follow the recommendations in table 14−1 for moisture content at time of installation.

Drying of Wood

Well-developed techniques have been established for removing the large amounts of moisture normally present in green wood (ch. 3). In addition to drying, some end uses require equalizing and conditioning treatments to improve moisture uniformity within and between pieces, and to relieve residual stresses and sets. Careful techniques are necessary, especially during the drying phase, to protect the wood from stain and decay and from excessive drying stresses that cause defects and degrade. The established drying methods are air drying, accelerated air drying, and kiln drying. Other methods, such as high-frequency dielectric heating, vapor drying, and solvent drying, have been developed for special uses.

Drying reduces the weight of wood, with a resulting decrease in shipping costs; reduces or eliminates shrinkage, checking, and warping in service; increases strength and nail-holding power; decreases susceptibility to infection by blue stain and other fungi; reduces chance of attack by insects; and improves the capacity of wood to take preservative and fire-retardant treatment and to hold paint.

Sawmill Practice

It is common practice at most softwood sawmills to kiln dry all upper grade lumber intended for finish, flooring, and cut stock. Lower grade boards are often air dried. Dimension lumber is air dried or kiln dried, although some mills ship certain species without drying. Timbers are generally not held long enough to be considered dry, but some drying may take place between sawing and shipment or while they are held at a wholesale or distributing yard. Sawmills cutting hardwoods commonly classify the lumber for size and grade at the time of sawing. Some mills send all freshly sawed stock to the air-drying yard or an accelerated air-drying operation. Others kiln dry directly from the green condition. Air-dried stock may be kiln dried at the sawmill, at a custom drying operation during transit, or at the remanufacturing plant before being made up into such finished products as furniture, cabinet work, interior finish, and flooring.

Air Drying

Air drying is not a complete drying process, except as preparation for uses for which the recommended moisture content is not more than 5 percent below that of the air-dry stock. Even when air-drying conditions are mild, air-dry stock used without kiln drying may have some residual stress and set that can cause distortions after nonuniform surfacing or machining. On the other hand, rapid air drying accomplished by low relative humidities produces a large amount of set that will assist in reducing warp during the final kiln drying. Rapid surface drying also greatly decreases the incidence of chemical and sticker stain, blue stain, and decay.

Air drying is an economical method when carried out (1) in a well-designed yard or shed, (2) with proper piling practices, and (3) in favorable drying weather. In cold or humid weather, air drying is slow and cannot readily reduce wood moisture to levels suitable for rapid kiln drying or for use.

Accelerated air drying involves the use of fans to force the air through the lumber piles in a shed or under other protection from the weather. Sometimes small amounts of heat are used to reduce relative humidity and slightly increase temperature. Accelerated air drying to moisture content levels between 20 and 30 percent may take only one-half to one-fourth as long as ordinary air drying. Moisture content in the stock dried with such acceleration may vary somewhat more than that of stock air dried under natural conditions to the same average moisture level.

Kiln Drying

In kiln drying, higher temperatures and fast air circulation are used to increase the drying rate considerably. Average moisture content can be reduced to any desired value. Specific schedules are used to control the temperature and humid-