CHAPTER 11

Integrated Technology for Biobased Composites

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11.1 Introduction

Forests play a major role in the ecosystem sustainability and general health of our planet. The biomass contained in our forests and other green vegetations affects the carbon cycle, climate change, habitat protection, clean water supplies, and sustainable economy. Exciting new opportunities are emerging for sustainably meeting global energy needs and simultaneously creating high-value biobased products from wood, forest, agricultural residues, and other biobased materials.

Biomass is commonly referred to as lignocellulosics because the two dominant chemical components of plants are cellulose, the structural polymer that represents about 50% of the plant material, and lignin, a crosslinked phenolic polymer that performs the role of adhesive bonding the components of the cell wall together. Globally, the vast lignocellulosic resource provides about half of all major industrial raw materials for renewable energy, chemical feedstock, and biocomposites. Conversion of woody biomass to biofuels is technically feasible, but this conversion process is marginally economical with the current technology and price of crude petroleum. An integrated utilization of biomass

RSC Green Chemistry No. 18
Integrated Forest Biorefineries
Edited by Lew Christopher
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Published by the Royal Society of Chemistry, www.rsc.org

has been proposed as means to overcome economic shortcomings by optimizing biomass use and value for a wider array of products.' Engineered biobased composites provide a tool for resource management because they can add value to low-value fiber resources and thereby promote demand for diverse biofiber feedstocks, including small-diameter timber, fast-growing plantation trees, exotic-invasive species, hazardous forest fuels, and agricultural crop residues. At the same time, engineering biobased composites serve as a means for economic development of rural communities and provide value-added commodity products from recycled or undervalued materials or problematic natural resources.[2]

The term biobased composite is being used to describe any woody material adhesively bonded together. This product mix ranges from fiberboard to laminated beams and components. Composites are used for a number of nonstructural and structural applications in product lines ranging from panels for interior covering purposes, panels for exterior uses, in furniture and support structures (Figure 11.1). This chapter describes the general composition, materials and processes used to manufacture biobased composite materials. This chapter also describes wood–nonwood composites.

Conventional biobased composites are primarily made from wood and other woody materials with only a few per cent resin and other additives. Product types can be subcategorized based on the physical configuration of the woody elements used to make these products. The morphology of the woody elements influences the properties of composite materials, and can be controlled by

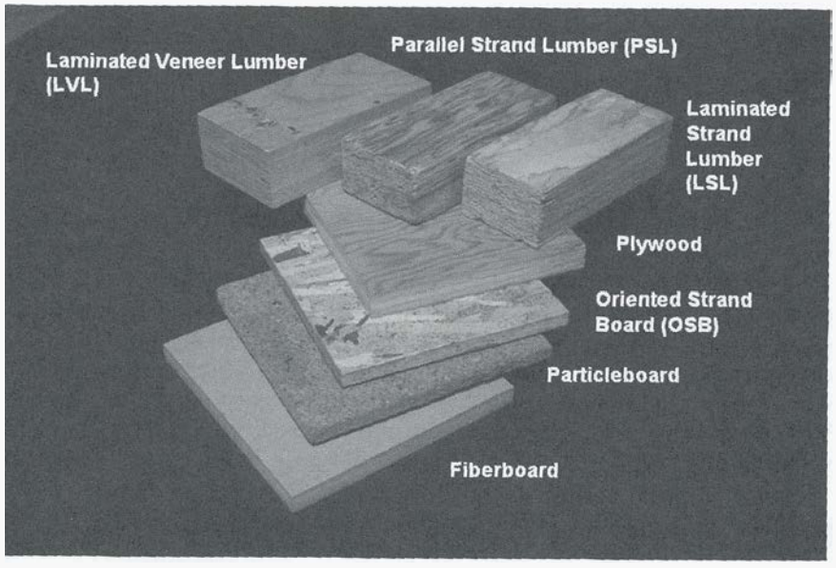

Figure 11.1 Examples of various composite products. From clockwise from top left: laminated veneer lumber, parallel strand lumber, laminated strand lumber, plywood, oriented strand board, particleboard, and fiberboard.

Table 11.1 Static bending properties of different wood and wood-based composites.

		Static Bending Properties			
		Modulus of Elasticity		*Modulus of Rupture*	
Material	*Specific gravity*	*GPa*	*(× 10⁶ psi)*	*MPa*	*(psi)*
Clear wood					
–White Oak	0.68	12.27	(1.78)	104.80	(15200)
– Red Maple	0.54	11.31	(1.64)	92.39	(13400)
– Douglas-fir (Coastal)	0.48	13.44	(1.95)	85.49	(12400)
–Western white pine	0.38	10.07	(1.46)	66.88	(9700)
– Longleaf pine	0.59	13.65	(1.98)	99.97	(14500)
Panel products					
– Hardboard	0.9–1.0	3.10-5.52	(0.45–0.80)	31.02–56.54	(4500–8200)
– Medium densityfiberboard	0.7–0.9	3.59	(0.52)	35.85	(5200)
– Particleboard	0.6–0.8	2.76–4.14	(0.40–0.60)	15.17–24.13	(2200–3500)
– Orientedstrand board	0.5–0.8	4.41–6.28	(0.64–0.91)	21.80–34.70	(3161–5027)
–Plywood	0.4–0.6	6.96–8.55	(1.01–1.24)	33.72–42.61	(4890–6180)
Structural timber Products					
– Glued laminated timber	0.4–0.6	9.00–14.50	(1.30–2.10)	28.61–62.62	(4150–9080)
– Laminated veneer lumber	0.4–0.7	8.96–19.24	(1.30–2.79)	33.78–86.18	(4900–12500)
Wood–nonwood composites					
–Wood plastic	0.8–1.1	1.53–4.23	(0.22–0.61)	25.41–52.32	(3684–7585)

selection of the raw material and by the processing techniques used to generate the wood elements. Composite properties can also be controlled by segregation and stratification of wood elements having different morphologies in different layers of the composite material (Table 11.1). In conventional wood-based composites, properties can also be controlled. The physical configuration of the wood element, adjusting the density of the composite, adjusting adhesive resin, or adding additives are just a few of the many ways to influence properties. Performance standards are in place for many conventional wood-based composite products (Table 11.2).

11.2 Conventional Biobased Composite Materials

11.2.1 Composite Elements

Biobased composites are composed primarily of woody elements (often 90% or more by mass) bound together with a resin and other additives. The vast

Table 11.2 Commercial product or performance standards for wood-based composites.

Product Category	*Applicable standard*	*Name of Standard*	*Source*
Plywood	PS 1-09	Voluntary product standard PS 1-07 construction and industrial plywood	4
	PS 2-04	Voluntary product standard PS 2-04 performance standard for wood-based structural-use panels	11
	HP-1-04	Voluntary product standard HP-1-04 Hardwood and decorative plywood	5
Oriented strandboard (OSB)	PS 2-04	Voluntary product standard PS 2-04 performance standard for wood-based structural-use panels	11
Particleboard	ANSI A208.1-1999	Particleboard standard	12
Fiberboard	ANSI A208.2-2002	MDF standard	7
	ANSI A135.4-2004	Basic Hardboard	13
	ANSI A135.5-2004	Prefinished hardboard paneling	14
	ANSI A135.6-2006	Hardboard siding	15
	ANSI A194.1	Cellulosic fiberboard	16
Glue laminated timber (Glulam)	ANSI/AITC 190.1	American National Standard for Wood Products – Structural Glue-laminated timber	17
Structural composite lumber (including laminated veneer lumber (LVL), laminated strand lumber (LSL), and parallel strand lumber (PSL))	ASTM D 5456-08	Standard specification for evaluation of structural composite lumber products	6

lignocellulosic resource provides the basic element for composite products such as the fiber, as it is in paper, much larger particles varying in size and geometry. Raw materials providing these elements include shavings, straws, hemp, sugarcane, bamboo, sawdust, fiber, particles, wafers, strands, and veneer.

11.2.2 Adhesives

Commonly used resin or binder systems in biobased composites include phenol–formaldehyde, urea–formaldehyde, melamine–formaldehyde, and isocyanate. The selection of the resin system is dependent upon the process, cost, product standards, and applications.

Phenol-formaldehyde (PF) resins, commonly referrel to as phenolic resins, are typically used in the manufacture of construction plywood and oriented

strandboard in structural applications where exposure to weather during construction is a concern. Phenolic resins are relatively slow-curing compared with other thermosetting resins. Cured phenolic resins remain chemically stable at elevated temperatures, even under wet conditions. The PF resin bonds are sometimes referred to as being "boil-proof' because of their ability to maintain structural integrity and adequate bonding after boiling water test. The inherently darker color of PF resin compared with other resins may make them aesthetically unsuitable for product applications such as interior paneling and furniture.

Urea–formaldehyde (UF) resins are typically used in the manufacture of products used in interior applications, for example, particleboard and medium-density fiberboard (MDF). They cure at lower temperatures than PF resins. Urea–formaldehyde resins are the lowest-cost thermosetting adhesive resins. They offer light color, which often is a requirement in the manufacture of decorative products. However, the release of formaldehyde from products bonded with UF is a growing health and environmental concern. Recently enacted EPA regulations (http://www.epa.gov/opptintr/chemtest/formaldehyde/) are forcing changes in UF chemistry, driving some manufacturers to switch away from UF.

MelaminePhenol–formaldehyde (MF) resins are used primarily for decorative laminates, paper treating, and paper coating. They are typically more expensive than PF resins. MF resins may, despite their high cost, be used in bonding conventional wood-based composites. When used in this application, they typically are blended with UF resins. Melamine–UF resins are used to pass formaldehyde emission standards, where an inconspicuous (light color) adhesive is needed, and greater water resistance than can be attained with UF resin is required.

Isocyanate as diphenylmethane di-isocyanate (MDI) resin is commonly used, as an alternative to PF resin, primarily in composite products fabricated from strands. Polymeric MDI (pMDI) resin, which is closely related to MDI resin, is also commonly used in this application. Isocyanate resins are typically more costly than PF resins, but require much lower addition rates, (for example 2% compared to 6–7% w/w UF in particleboard), have higher cure rates, and will tolerate higher moisture contents in the wood source. Facilities that use MDI are required to take special precautionary protective measures, as the uncured resin can result in chemical sensitization of persons exposed to it. Cured isocyanate resin poses no recognized health concerns.

Biobased adhesives, primarily protein glues, were widely used prior to the early 1970s in construction plywood. In the mid 1970s, they were supplanted by PF adhesives, on the basis of the superior bond durability provided by phenolics. Several soy-protein-based resin systems for interior application have recently been developed and commercialized. Durable adhesive systems may also be derived from tannins, lignin, or soy blended with PF.

11.2.3 Additives

A number of additives are used in the production of conventional composite products. One of the most notable additives is wax, which is used to provide

finished products with some resistance to liquid-water absorption. In particle- and fiberboard products, wax emulsions provide limited-term water resistance and dimensional stability when the board is wetted. Even small amounts (0.5% to 1%) act to retard the rate of liquid water pickup for limited time periods. Other additives used for specialty products include preservatives, moldicides, fire retardants, and impregnating resins.

11.2.4 Products

Conventional wood-based composites made from various constituent materials can be subcategorized based on the physical configuration of the wood elements used to make these products: veneer, particle, strand or fiber.

11.2.4.1 Oriented Strandboard

Oriented strandboard (OSB) is an engineered structural-use panel manufactured from thin wood strands bonded together with waterproof resin, typically PF or MDI. Since its debut in 1978, OSB has been rapidly accepted in new residential construction in many areas of North America. It is used extensively for roof, wall, and floor sheathing in residential and commercial construction. The wood strands typically have an aspect ratio (strand length divided by width) of at least 3. OSB panels are usually made with three layers of strands, the outer faces having longer strands aligned in the long direction of the panel and a core layer that is crossaligned or laid randomly using the smaller strands or fines. The orientation of different layers of aligned strands gives OSB its unique characteristics, including greater bending strength and stiffness in the oriented or aligned direction. Control of strand size, orientation, and layered construction allows OSB to be engineered to suit different uses.

In North America, aspen is the predominant wood used for OSB. Other species, such as southern pine, spruce, birch, yellow-poplar, sweetgum, sassafrass, and beech are also suitable raw materials for OSB production. High-density species such as beech and birch are often mixed with low-density species such as aspen to maintain panel properties.[3]

Figure 11.2 shows an OSB manufacturing process. Logs are debarked and then sent to a soaking pond or directly to the stranding process. Long log disk or ring stranders are commonly used to produce wood strands typically measuring 114 to 152 mm (4.5 to 6 in.) long, 12.7 mm (0.5 in.) wide, and 0.6 to 0.7 mm (0.023 to 0.027 in.) thick. Green strands are stored in wet bins and dried prior to panel assembly. Dried strands are blended with adhesive and wax in a highly controlled operation, with separate rotating blenders used for face and core strands.

The strands with adhesive applied are sent to mat formers. Mat formers take on a number of configurations, ranging from electrostatic equipment to mechanical devices containing spinning disks to align strands along the panel's length and star-type crossorienters to position strands across the panel's width. All formers use the long and narrow characteristic of the strands to place it

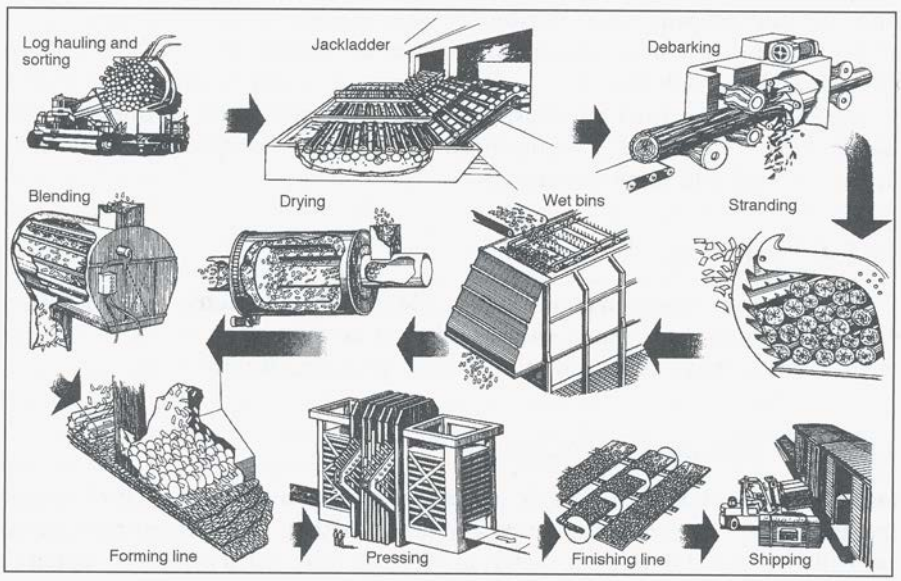

Figure 11.2 Schematic of OSB manufacturing process. (Courtesy of TECO, Sun Prairie, Wisconsin.)

between the spinning disks or troughs before it is ejected onto a moving screen or conveyor belt below the forming heads. Oriented layers of strands within the mat are dropped sequentially onto a moving conveyor. The conveyor carries the mat into the press.

Once the mat is formed, it is hot pressed. In hot pressing, the loose layered mat of oriented strands is compressed under heat and pressure to cure the resin. As many as sixteen 3.7- by 7.3-m (12- by 24-ft) panels may be formed simultaneously in a multiple-opening press. A more recent development is the continuous press for OSB. The press compacts and consolidates the oriented and layered mat of strands and heats it to 177–204°C (350 °F to 400 °F) to cure the resin.

OSB is produced to comply with voluntary industry product performance standards. These inspection or certification programs also generally require that the quality control system of a production plant meet specified criteria. OSB panels conforming to these product performance standards are marked with grade stamps.

11.2.4.2 Plywood

Plywood generally requires larger-diameter, high-value trees and has limited value for many forest management activities. But in integrated utilization, it is a high-value use for large-diameter straight grain trees. Plywood is a flat panel built up wholly or primarily of sheets of veneer called plies. It is constructed

with an odd number of layers with the grain direction of adjacent layers oriented perpendicular to one another. The outside plies are called faces, or face and back plies. Inner plies are plies other than the face or back plies. Inner plies whose grain direction runs parallel to that of the faces are termed "centers", whereas inner plies whose grain direction runs perpendicular to that of the faces are termed "crossbands" or "cores". The outer layers and all odd-numbered layers have their grain direction oriented parallel to the long dimension of the panel. The grain in even-numbered layers is perpendicular to the length of the panel. The center layer may be composed of veneer, lumber, particleboard, or fiberboard; however all-veneer construction is most common in structural plywood.

The properties of plywood depend on the quality of the veneer plies used, the order of layer placement, the adhesive used, and the degree to which bonding conditions are controlled during production. The durability of the adhesive-to-wood bond depends largely on the adhesive used, but also on control of bonding conditions and on veneer quality.

Two classes of plywood are commonly available, covered by separate standards: (a) structural plywood, and (b) hardwood and decorative plywood. The bulk of construction and industrial plywood is used where strength, stiffness, durability, and construction utility are more important than appearance. Structural plywood has traditionally been made from softwoods such as Douglas fir and Southern yellow pine. Construction and industrial plywood is categorized by exposure capability and grade using Voluntary Product Standard PS 1–09.[4]

Hardwood and decorative plywood is made of many different species. Hardwood plywood is normally used in applications including decorative wall panels and furniture and cabinet panels where appearance is more important than strength. Most of the production is intended for interior or protected uses. It is categorized by species and characteristics of face veneer, bond durability, and composition of center layers (veneer, lumber, particleboard, medium-density fiberboard, or hardboard).[5]

11.2.4.3 Structural Composite Lumber and Timber Products

Structural composite lumber (SCL) was developed in response to the increasing demand for high-quality lumber at a time when it was becoming difficult to obtain larger diameter, clear and straight grain trees needed for traditional beams and joists. Structural composite lumber products are characterized by smaller pieces of wood glued together into sizes common for solid-sawn lumber.

One type of SCL product is manufactured by laminating veneer with all plies parallel to the length. This product is called laminated veneer lumber (LVL) and consists of specially graded veneer. Another type of SCL product consists of strands of wood or strips of veneer glued together under high pressures and temperatures. Depending upon the component material, this product is called laminated strand lumber (LSL), parallel strand lumber (PSL), or oriented strand lumber (OSL). Different widths of lumber can be ripped from SCL for

various uses. Compared with similar size solid-sawn lumber, SCL often provides a stronger, more reliable structural member that can often span longer distances and has less dimensional change.

Structural composite lumber is a growing segment of the engineered wood products industry. It is used as a replacement for lumber in various applications, such as prefabricated wood I-joists, which take advantage of engineering design values that can be greater than those commonly assigned to sawn lumber.

Structural glued-laminated timber (glulam) is an engineered, stress-rated product that consists of two or more boards glued together with the grain parallel to the length. The maximum board (lamination) thickness permitted is 50 mm (2 in.), and the laminations are typically made of standard 25- or 50-mm (nominal 1- or 2-in) thick lumber. The boards are joined end to end, edge to edge, and face to face, the size of glulam is limited only by the capabilities of the manufacturing plant and the transportation system. North American standards require that glulam be manufactured in an approved manufacturing plant.

Douglas Fir–Larch, Southern Pine, Hem–Fir, and Spruce–Pine–Fir (SPF) are commonly used for glulam in the United States. Industry standards cover many softwoods and hardwoods, and procedures are in place for including other species.

The ASTM D5456[6] standard provides methods to develop design properties for SCL products as well as requirements for quality assurance during production. Each manufacturer of SCL products is responsible for developing the required information on properties and ensuring that the minimum levels of quality are maintained during production. An independent inspection agency is required to monitor the quality assurance program.

11.2.4.4 Particleboard

Particleboard is produced by mechanically reducing the wood raw material into small particles, applying adhesive to the particles, and consolidating a loose mat of the particles with heat and pressure into a panel product.

Particleboard is typically made in three layers. But unlike OSB, the faces of particleboard usually consist of fine wood particles, while the core is made of coarser material. The result is a smoother surface for laminating, overlaying, painting, or veneering. Particleboard is readily made from virtually any wood material and from a variety of agricultural residues. Low-density insulating or sound-absorbing particleboard can be made from kenaf core or jute stick. Low-, medium-, and high-density panels can be produced with cereal straw, which has begun to be used in North America. Rice husks are commercially manufactured into medium- and high-density products in the Middle East.

All other things being equal, reducing lignocellulosic materials to particles requires less energy than reducing the same material into fibers. However, particleboard is generally not as strong as fiberboard because the fibrous nature of lignocellulosics, *i.e.* their high aspect ratio, is not exploited as well. Particleboard is widely used in furniture and flooring system, where it is typically overlaid with

other materials for decorative purposes. Since most applications are interior, particleboard is usually bonded with a UF resin, although PF and MF resins ai-e sometimes used for applications requiring more moisture resistance.

All particleboard is currently made using a dry process, where air or mechanical formers arc used to distribute the particles prior to pressing. The various steps involved in particleboard manufacturing include particle preparation, particle classification and drying, adhesive application, mat formation, pressing, and finishing.

Alternatively, a few particleboards are made by the extrusion process. In this system, formation and pressing occur in one operation. The particles are forced into a long, heated die (made of two sets of platens) by means of reciprocating pistons. The board is extruded between the platens. The particles are oriented in a plane perpendicular to the plane of the board, resulting in properties that differ from those obtained with flat pressing.

Particleboard that has been grade marked ensures that the product has been periodically tested for compliance with voluntary industry product performance standards. These inspection or certification programs also generally require that the quality control system of a production plant meets strict criteria. Particleboard panels conforming to these product performance standards are marked with grade stamps.

11.2.4.5 Fiberboard

The term fiberboard includes hardboard. medium-density fiberboard (MDF), and insulation board. Several things differentiate fiberboard from particleboard, most notably the physical configuration of the wood element. Because wood is fibrous by nature, fiberboard exploits the inherent strength of wood to a greater extent than does particleboard.

To make fibers for composites, the naturally occurring bonds between the fibers must be broken. Attrition milling, or refining, is the easiest way to accomplish this. During refining process, material is fed between two disks with radial grooves. As the material is forced through the preset gap between the disks, it is sheared, cut, and abraded into fibers and fiber bundles. Grain has been ground in this way for centuries. Refiners are available with single- or double-rotating disks, as well as steam-pressurized and unpressurized configurations.

Refining can be augmented by steaming or chemical treatments. Steaming the lignocellulosic under pressure raises the temperature to the point where the lignin bonds between the cellulosic fibers soften. As a result, fibers are more readily separated and usually are less damaged than fibers processed by lower-temperature processing methods. Chemical treatments, usually alkali, are also used to weaken the lignin bonds. All of these treatments help increase fiber quality and reduce energy requirements, but they may reduce yield and modify the chemistry as well. For MDF, steam-pressurized refining is typical.

Fiberboard is normally classified by density and can be made by either dry or wet forming processes. Dry processes are applicable to boards with high density

(hardboard) and medium density (MDF). Wet processes are applicable to both high-density hardboard and low-density insulation board.

Dry-process fiberboard is made in a similar fashion to particleboard. Resin (UF or melamine-UF) and other additives may be applied to the fibers by spraying in short-retention blenders or introduced as the wet fibers are fed from the refiner into a blow-line dryer. The resinated fibers are then air-laid into a mat for subsequent pressing, much the same as mat formation for particleboard. ANSI A208.2 classifies MDF by physical and mechanical properties, and identifies dimensional tolerances and formaldehyde emission limits.[7]

Wet-process hardboards differ from dry-process fiberboards in several significant ways. First, water is used as the distribution medium for forming the fibers into a mat. The technology is really an extension of paper manufacturing technology. Secondly, some wet-process boards are made without additional binders. If the lignocellulosic contains sufficient lignin and if lignin is retained during the refining operation, lignin can serve as the binder. Under heat and pressure, lignin will flow and act as a thermosetting adhesive, enhancing the naturally occurring hydrogen bonds.

Refining is an important step for developing strength in wet-process hardboards. The refining operation must also yield a fiber of high "freeness;" that is, it must be easy to remove water from the fibrous mat. The mat is typically formed on a Fourdrinier wire, like papermaking, or on cylinder formers. The wet process employs a continuously traveling' mesh screen, onto which the soupy pulp flows rapidly and smoothly. Water is drawn off through the screen and then through a series of press rolls, which compress the fiber mat to remove additional water.

Wet-process hardboards are pressed in multiopening presses heated by steam. The heating press cycle lasts 6 to 15 min. A maximum pressure of about 5 MPa (725 lb/in^2) is used during the press. Heat is essential during pressing to induce fiber-to-fiber bond. A high temperature of up to 210 °C (410 °F) is used to increase production by causing faster evaporation of the water. Lack of sufficient moisture removal during pressing adversely affects strength and may result in "springback" or blistering.

11.2.4.6 Cellulosic Board

Cellulosic boards are low-density, wet-laid panel products used for insulation, sound deadening, carpet underlayment, and similar applications. In the manufacture of cellulosic board, the need for refining and screening is a function of the raw material available, the equipment used, and the desired end-product. Cellulosic boards typically do not use a binder, and they rely on hydrogen bonds to hold the board components together. Sizing agents are usually added to the furnish (about 1%) to provide the finished board with a modest degree of water resistance and dimensional stability.

After drying, some boards are treated for various applications. Boards may be given tongue-and-groove or shiplap edges or can be grooved to produce a plank effect. Other boards are laminated by means of asphalt to produce roof

insulation. A grade-mark stamp will be given for these cellulosic fiberboard products conforming to ASTM C208.[8]

11.3 Wood–Nonwood Composite Materials

Wood may be combined with inorganic materials and with plastics to produce composite products with unique properties to match end-use requirements. Wood–nonwood composites typically contain comminuted wood elements suspended in a matrix material (for example in fiber-reinforced gypsum board, or in thermoplastic material), in which the proportion of wood elements may account for appreciably less than 50% of product mass.

11.3.1 Inorganic-Bonded Composite Materials

Inorganic-bonded wood composites are molded products or boards that contain between 10% and 70% by weight wood particles or fibers and conversely 90% to 30% inorganic binder. Acceptable properties of an inorganic-bonded wood composite can be obtained only when the wood particles are fully encased within the binder to make a coherent material. Because hardened inorganic binders have a higher density than that of most thermosetting resins, the required amount of inorganic binder per unit volume of composite material is much higher than that of resin-bonded wood composites. The properties of inorganic-bonded wood composites are significantly influenced by the amount and nature of the inorganic binder and the woody material as well as the density of the composites.

Inorganic binders fall into two main categories: gypsum-bonded and cement-bonded. Magnesia and Portland cement are the most common cement binders. Gypsum and magnesia cement are sensitive to moisture, and their use is generally restricted to interior applications. Some inorganic-bonded composites are very resistant to deterioration by decay fungi, insects, and vermin. Most have appreciable fire resistance.

Paper-faced gypsum boards, widely used for the interior lining of walls and ceilings, have generically been called drywall because they commonly replace wet-plaster systems. These panels are critical for good fire ratings in walls and ceilings. Paper-faced gypsum boards (and glass fiber-faced gypsum panels), also find use as exterior wall sheathing. Gypsum sheathing panels are primarily used in commercial construction, usually over steel studding and are distinguished from regular gypsum wallboard by their water-repellent additives in the paper facings and gypsum core. The facings of drywall and of gypsum sheathing panels are adhered to the gypsum core, providing the panels with impact resistance, and bending strength and stiffness. The paper facings of gypsum panels are derived from recycled paper fiber.

The properties of cement-bonded composites are influenced by wood element characteristics (species, size, geometry, chemical composition), cement type, wood:water:cement ratio, environmental temperature, and cure time.[9] They are

heavier than conventional wood-based composites, but lighter than concrete. Therefore they can replace concrete in construction, specifically in applications that are not subjected to loads. Wood-cement composites provide an option for using wood residues, or even agricultural residues. However species selection can be important as many species contain sugars and extractives that retard the cure of cement.[3]

In the last few years a new class of inorganic binders, nonsintered ceramic inorganic binders, has been developed. These nonsintered ceramic binders are formed by acid–base aqueous reaction between a divalent or trivalent oxide and an acid phosphate or phosphoric acid. The reaction slurry hardens rapidly, but the rate of setting can be controlled. With suitable selection of oxides and acid phosphates, a range of binders may be produced. Recent research suggests that phosphates may be used as adhesives, cements, or surface augmentation materials to manufacture wood-based composites.

11.3.2 Wood–Thermoplastic Composite Materials

Wood–thermoplastic composites have become a widely recognized commercial product in construction, automotive, furniture, and other consumer applications in the last decade. Commercialization has been primarily due to penetration into the construction industry, first as decking and window profiles, followed by railing, siding, and roofing. The automotive industry has been a leader in using wood–thermoplastic composites for interior panel parts.

The class of materials can include lignocellulosics derived from wood or other natural sources and different thermoplastics including virgin or recycled polypropylene, polystyrene, vinyls, and polyethylenes. Other materials can be added to affect processing and product performance of wood–thermoplastic composites. These additives can improve bonding between the thermoplastic and wood component (for example, coupling agents), product performance (impact modifiers, UV stabilizers, flame retardants), and processability (lubricants).

There are two main types of the wood-thermoplastic composite. In the first, the lignocellulosic component serves as a reinforcing agent or filler in a continuous thermoplastic matrix. In the second, the thermoplastic serves as a binder to the majority lignocellulosic component. The presence or absence of a continuous thermoplastic matrix may also determine the processability of the composite material.

The manufacture of thermoplastic composites is usually a two-step process. The raw materials are first mixed together, and the composite blend is then formed into a product. The combination of these steps is called inline processing, and the result is a single processing step that converts raw materials to end products. Inline processing can be very difficult because of control demands and processing trade-offs. As a result, it is often easier and more economical to separate the processing steps. [10]

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