USFSS (current edition) *Poles and Piles*, *Wood*. Federal specification MM-P-371c-ties, railroad (cross and switch); Federal Specification MM-T-371d-wood preservation: treating practice; Federal Specification TT-W-571. Washington, DC: US Federal Supply Service.

Wood-based Composites and Panel Products

F A Kamke, Virginia Polytechnic Institute and State University, Blacksburg, VA, USA

Introduction

Wood-based composites consist of wood elements, such as veneer, fibers, particles, or strands, which are bonded together to collectively perform some function. These wood elements may be bonded with natural adhesives (such as starch or protein from plant or animal sources) or synthetic adhesives (usually derived from petroleum). The classification of wood-based composites is inexact, but may be grouped as panels or composite lumber. The panels may be further divided into veneer (such as plywood) or particulate (such as particleboard) composites. Another means of categorizing the wood-based composites is by function, i.e., structural (building components) and nonstructural (furniture and cabinet applications). Examples of commercially available wood-based composites are shown in **Figure 1**. While endless combinations of wood elements, and indeed wood and other materials, could be used to produce a vast array of products, this article will focus on the major wood-based composites produced commercially.

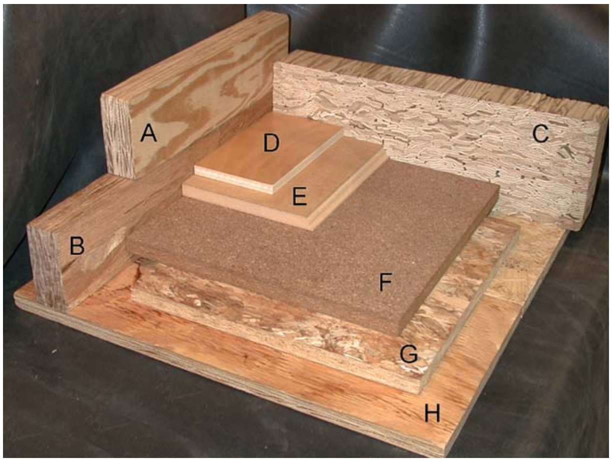

Figure 1 Examples of commercially available wood-based composites. (A) Laminated veneer lumber (LVL); (B) laminated strand lumber (LSL); (C) parallel strand lumber (PSL); (D) nonstructural plywood; (E) medium density fiberboard (MDF); (F) particleboard; (G) oriented strand board (OSB); (H) structural plywood.

History

The event of the first composite produced from wood is probably unknown. The simple act of adhesively bonding together two or more pieces of wood is a composite manufacturing process. Paper is a composite of wood fibers, which utilizes the natural lignocellulosic compounds present in wood to bond the fibers. The Chinese, during the early second century, are believed to have produced the first paper from wood pulp. The ancient Egyptians, prior to 1400 BC, developed the art of bonding wood veneers for decorative articles. A type of wood fiberboard was patented in the USA by Lyman in 1858. This was followed by a high-density version of fiberboard, known today as hardboard, which was called Masonite by its inventor William Mason in 1924. Structural plywood was introduced to the USA in 1905 by the Portland Manufacturing Company in Oregon. Particleboard had its origin in Germany, with early references to Ernst Hubbard in 1887. The first commercial manufacturing facility for particleboard is thought to be one opened in Bremen, Germany in 1941. The growth of the modern wood-based composites industry was made possible with the development of synthetic adhesives during the 1930s. Thermosetting adhesives, such as urea-formaldehyde and phenol-formaldehyde, greatly accelerated the manufacturing process, improved performance, and reduced costs. The latter part of the twentieth century saw the development of structural lumber composites, including laminated veneer lumber, parallel strand lumber, and laminated strand lumber.

Manufacture of wood-based composites is now a worldwide industry. **Table 1** shows the world production of wood composite panels and laminated veneer lumber in 2001. Production has increased each year since the introduction of these products. Structural plywood, oriented strand board, and structural lumber composites are primarily North American products, due to preference for wood for building construction in this region. Europe and Japan are minor but growing producers and consumers of these products. The nonstructural panels are produced throughout the world, and find many applications in furniture, cabinets, and some building construction.

Table 1 World production of wood-based panels and laminated veneer lumber in 2001

Product	*Production (1000 m^3)*
Fiberboard	33,277
Particleboard	60,723
Oriented strand board (OSB)	21,678
Plywood (structural and nonstructural)	55,528
Laminated veneer lumber (LVL)[a]	2,062

[a]Estimated from 2001 North American data and 1999 Europe and Asia data.

Data from FAO (2002) *Forest Products Statistics*. Timber Bulletin no. ECE/TIM/BULL/55/2. Rome: Food and Agricultural Organization. Available online at http://www.fao.org/. UNECE (2002) *Forest Products Annual Market Review 2001–2002*. Timber Bulletin LV ECE/TIM/BULL/2002/3. Rome: Food and Agricultural Organization. Available online at http://www.unece.org/trade/timber/.

Figure 2 Structural wood-based composites used in building construction; OSB floor sheathing, LSL rimboard, I-beams with LVL as flange stock and plywood webs, and LVL floor girder. Photograph courtesy of APA – Engineered Wood Association.

Products and Applications

Panels: Structural Plywood

Structural plywood is produced primarily from softwood species, although some hardwoods are also used. In North America the most commonly used species are southern pine (*Pinus* spp.) and Douglas-fir (*Pseudotsuga menziesii*). These species provide the proper combination of strength, stiffness, and ease of handling. The 2–5-mm thick veneer is produced by peeling logs on a rotary lathe. The veneers are arranged in layers, with the grain perpendicular in adjacent layers, and bonded together using a waterproof adhesive (usually phenol-formaldehyde). The veneer is visually graded, and sometimes machine graded, to eliminate severe defects. The highest-quality veneer is reserved for the highest-quality plywood. Lower-quality veneer can often be used as core plies, or on the backside of the panel.

Structural plywood is used principally in building construction as structural sheathing in floor, wall, and roof systems. Structural plywood has many other uses where strength, stiffness, and dimensional stability are important, such as furniture and cabinet frames, pallet bins, exterior siding, web stock for I-beams (**Figure 2**), and concrete forms. Structural plywood is manufactured in 1.2×2.4 m dimensions. The common thickness range is from 7 to 30 mm depending on the application.

Panels: Nonstructural Plywood

Nonstructural plywood, also called decorative plywood, is produced primarily from hardwood species, although many softwood species are used. In North America, oak (*Quercus* spp.), birch (*Betula* spp.), maple (*Acer* spp.), cherry (*Prunus* spp.), white pine (*Pinus strobus*), and lauan (*Shorea* spp.) are common species used for nonstructural plywood. The face veneer is the highest quality, since its function is decorative. Face veneers are often very thin, generally 0.8 mm and thinner, to provide the most efficient use of the best-quality wood. The back veneer is usually lower quality, although some grades require a good appearance on two sides. The core of nonstructural plywood may be comprised of lower-quality veneer or some other substrate, such as fiberboard, particleboard, or lumber.

Nonstructural plywood has numerous uses in consumer products, where appearance and dimensional stability, and some structural performance is required. Typical uses are furniture, cabinets, store fixtures, decorative paneling, and architectural woodwork. Since the adhesive that is used to manufacture nonstructural plywood is usually urea-formaldehyde, with a low water resistance, these products are limited to interior applications where the potential for moisture exposure is low.

Panels: Particleboard

Particleboard is comprised of wood elements bonded together with an adhesive under heat and pressure. The particles may be generated in a variety of ways starting with logs (rare) or wood residue (typical) from some other wood manufacturing operation. Mechanical devices break down the wood into particles. A clear classification of particleboard is not possible, as modern particleboard manufacturing processes sometimes employ pressure-refined wood fibers in the surface layers. A similar product made from 100% pressure-refined wood fibers is called fiberboard. Virtually any wood species could be used for particleboard, although softwoods and lower-density hardwoods are preferred. Lower-density wood allows for the production of lower-density particleboard without sacrificing strength and stiffness. The most common adhesive used in the manufacture of particleboard is urea-formaldehyde, although some melamine-formaldehyde is sometimes added to improve water resistance. Particleboard is intended for interior applications.

Particleboard is available in a wide variety of dimensions, limited only by the hot-press used in its manufacture. Thickness typically ranges from 12 to 38 mm. The panels are made up to 3.6 m in width and up to 18 m in length. Applications include core stock for furniture and cabinet panels, doors, counter tops, and floor underlayment.

Panels: Fiberboard

Fiberboard may be further classified into insulation board, medium density fiberboard (MDF), and hardboard. The primary difference between these panel types is density and the end-use application. All of these panels are produced from pressure-refined wood fibers. The fibers are individual wood cells or small bundles of cells. Both hardwood and softwood species may be used. Insulation board is a low-density product, less than $30\,\mathrm{lb\,ft^3}$ ($480\,\mathrm{kg\,m^{-3}}$), with very little structural integrity. Its density is less than the density of the wood from which it was produced. MDF is similar to particleboard in its manufacture and end-used applications. MDF offers advantage over particleboard with smoother surfaces, void-free edges, and lower density. Hardboard is a high-density product, over $50\,\mathrm{lb\,ft^3}$ ($800\,\mathrm{kg\,m^{-3}}$). Some hardboard is produced without adhesive, relying instead on lignocellulosic bonding imposed by extreme heat and pressure in the hot-press. Hardboard is typically produced in thickness ranging from 2.5 to 3.2 mm. Individual panels are sometimes bonded together to produce thicker panels. Synthetic or bio-based adhesives are often added to hardboard to improve properties, particularly water resistance.

Insulation board is used for nonstructural wall sheathing where thermal insulation is required. This product has been largely displaced by rigid, synthetic-foam panels. Insulation board is also used for accoustic tiles. MDF is used extensively as core stock in furniture and cabinet panels. It is also used for overlayed and powder-coated millwork. Hardboard is used for exterior siding, cabinets for electrical appliances, flooring, and overlayed decorative paneling.

Panels: Oriented Strand Board

Oriented strand board (OSB) is a structural panel designed for building construction. It is composed of slender wood strands, with the strand length parallel to the grain of the wood. The stranding process requires logs. Many wood species are used. Softwoods, such as the pines, and low-density hardwoods, such as aspen (*Populus* spp.), gum (*Nyssa* spp.), and yellow-poplar (*Liriodendron tulipifera*), are preferred. The strands are oriented and arranged into three layers in the panel. The two outer layers are parallel, and the core layer is either perpendicular to the face layers or not oriented. This cross-lamination concept is similar to plywood. Strength and stiffness is greater in the dimension parallel to the face layer, and the panel has good dimensional stability, with respect to moisture content changes, in both flat-wise directions. Thickness swell has been a problem with some OSB panels. A waterproof adhesive, either phenol-formaldehyde or polymeric methylene diphenyl diisocyanate (pMDI), is used to bond the strands together.

OSB was developed as a direct replacement for the more expensive structural plywood. It is used as structural sheathing for walls, roofs, and floors (**Figure 2**). OSB is also used as web stock in wood composite I-beams, shelving, pallets, and packaging. OSB is manufactured in thickness ranging from 6 to 28 mm. The panels are sold in 1.2×2.4 m dimensions, although the panels are produced in dimensions up to 3.6×18 m.

Structural Composite Lumber: Laminated Veneer Lumber

Laminated veneer lumber (LVL) is produced from veneer and intended for structural framing, where high strength and stiffness are required. Softwoods, such as Douglas-fir and southern pines, are typically used. Some hardwoods are also acceptable. As it is a structural product, only high-quality veneer with high strength and stiffness is acceptable. Unlike plywood, all of the veneer in an LVL billet is aligned in one direction to maximize strength and stiffness in that direction. An advantage of LVL over solid sawn lumber is the dispersion of defects, such as knots and pitch pockets, which greatly reduces the variability of the product. LVL is also more dimensionally stable than solid sawn lumber and it may be produced in large dimensions from small logs.

LVL is used for structural beams (**Figure 2**) and headers in building construction, as well as scaffold planks. Most of today's production is used as flange stock in wood composite I-beams (**Figure 2**). Some LVL is produced specifically for furniture and architectural woodwork, for which some hardwood species are used. LVL is produced in dimensions ranging from 38 to 90 mm thick, up to 1.2 m wide, and 24 m long. The billets are sawn into standard sizes that are compatible with dimension lumber.

Structural Composite Lumber: Parallel Strand Lumber

Parallel strand lumber (PSL) is produced from narrow veneer strips. Currently Douglas-fir, western hemlock (*Tsuga heterophylla*), southern pine, and yellow-poplar are the wood species used for PSL. The process permits veneer with many defects, as these defects will be eliminated or dispersed when the veneer is clipped into the narrow strips. A phenol-formaldehyde adhesive is used to provide excellent water resistance. The mechanical properties are similar to LVL. PSL is produced in large dimensions as a substitute for solid wood timbers.

PSL is intended for structural applications, including beams, columns, and headers. PSL is preferred over LVL for applications that require a large cross-section. When finished properly, PSL has a decorative appearance suitable for exposed timberframe construction.

Structural Composite Lumber: Laminated Strand Lumber

Laminated strand lumber (LSL) is a variation of OSB technology. LSL is produced from long wood strands. The strands are similar to OSB strands in width and thickness, but they are longer. Unlike OSB, all of the strands are oriented in the same direction. This high degree of orientation and long strands produces a structural lumber product with high strength and stiffness. Currently, aspen and yellow-poplar are used to produce LSL, but other low-density species could be used. Unlike OSB, LSL has a uniform density, which better simulates solid wood performance.

LSL is a structural product. It is used for truss cords, rim board in floor systems (**Figure 2**), headers, and columns. Because of its uniform density and good dimensional stability, LSL is also used for furniture and millwork.

Manufacturing Practices

Structural Plywood

All structural plywood is produced from rotary-peeled veneer. The peeler logs are debarked and cut to nominal 1.2 or 2.4 m long peeler blocks. The blocks are conditioned to soften the wood prior to peeling. This is done by soaking the blocks in hot water or spraying them with steam. The blocks are then electronically scanned and positioned in the rotary lathe. Scanning is a rapid and accurate means of maximizing the yield of the highest-quality veneer. The lathe rotates the block against a knife to peel veneer into a continuous sheet, much like paper pulled off a roll (**Figure 3**). The peeling speed is up to 240 m min^{-1}. At the end of peeling, the remaining core, typically 50–100 mm in diameter, is ejected by the lathe operator and saved for other uses.

The continuous sheet of veneer, still wet, is again electronically scanned for defects and then automatically clipped into nominal 1.2×2.4 m sheets, half sheets, or random widths. The veneer is visually

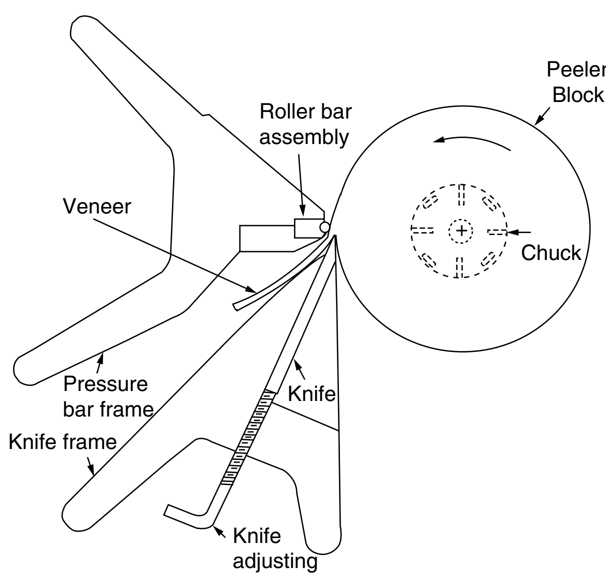

Figure 3 Rotary lathe used to produce veneer for structural plywood and laminated veneer lumber. Detail of peeling veneer from block shown at right. Photograph courtesy of COE Manufacturing.

graded and sorted. All veneer must be dried to the desired moisture content. The target moisture content depends on the adhesive system to be used, but typically is in the range of 5–10%. Electronic moisture detectors are used to identify wet or overdried veneer when it exits the dryer.

State-of-the-art plywood mills assemble full sheets of veneer from the half sheets and random width pieces. A thermoplastic 'string' is used to hold the sheets together loosely so that they may be handled by automated equipment. Adhesive is then applied to the dry veneer in precise amounts at the panel layup station. Roll coaters, curtain coaters, or extrusion coaters are used to apply the adhesive to the veneer. Adjacent veneer layers are arranged with the grain perpendicular to one another. The best grade of veneer is used for the face ply, a lower grade for the back ply, and the lowest grade for the core plies. The selection of the veneer grade depends on the desired finished plywood grade. The adhesive is almost always a phenol-formaldehyde formulation, which has a dark red–brown color. This adhesive has very good moisture resistance. Extenders and fillers are added to the resin to control flow and penetration characteristics. Many plywood mills still employ manual labor to assemble the panels at the layup station.

Prior to hot-pressing, the panels are cold-pressed to flatten the veneer and transfer the adhesive from one side of the bondline to the other. The panels are then loaded into a multi-opening heated press. A typical plywood press may process 20–50 panels simultaneously, with one panel per opening. Hot-press conditions are typically 100–200 psi (690–1380 kPa) pressure at 150°C. The time in the press depends on the thickness of the panel. Thicker panels require more time.

After the panels are removed from the hot-press, they are trimmed to the final dimensions, and visually graded. Some mills use ultrasonic detectors to examine each panel for hidden delaminations in the bondline. Some plywood grades are sanded. Secondary processing may include the addition of a tongue and groove on the edges, patches for aesthetic purpose, or overlays for water resistance. Quality assurance testing is routinely performed, and required, for grade stamp approval.

Nonstructural Plywood

There are many similarities between structural plywood and nonstructural plywood manufacturing processes. One major difference is the preparation of the veneer. Rotary peeled veneer is used for core stock and sometimes for face veneer. The fine face veneer is usually produced by slicing. Thin veneer, often less than 1 mm thick, can be produced with a wide variety of grain patterns using any one of a number of slicing techniques. The log is first sawn into a flitch, which is cut to expose the desired grain pattern. Flat, quarter, or rift slicing are common flitch preparations. Prior to slicing, the flitch is conditioned to soften the wood. The flitch is then mounted on a veneer slicer, which moves the flitch in a linear, back and forth motion against a knife (**Figure 4**). With each stroke, a thin veneer, the length and width of the flitch, is removed. The carriage holding the flitch, or knife assembly, is then indexed a distance equal to the thickness of one veneer, and another veneer is cut. Each veneer is stacked in sequence as it is removed from the flitch, and remains together for further processing. This allows the veneer to be matched in panels to achieve interesting grain patterns.

The face veneer is gently dried to a moisture content of 5–10% in a forced-air dryer with restraints to keep the veneer flat. Core and back veneer may be dried more rigorously. The dry veneer is now precision clipped and edge-joined to create large sheets for further processing into plywood.

Nonstructural plywood is typically bonded with urea-formaldehyde adhesive. This is a near-colorless adhesive that produces a strong bond, but is not suitable for high humidity or water exposure. The decorative face veneer may be laid-up over core veneer, or some other substrate, such as particleboard or fiberboard. As with structural plywood, maintaining a balanced construction is important for preventing warp of the panel with subsequent moisture content changes. The remainder of the manufacturing process is similar to structural plywood processing.

Particleboard

Particleboard manufacture typically begins with some mill residue from some other wood processing

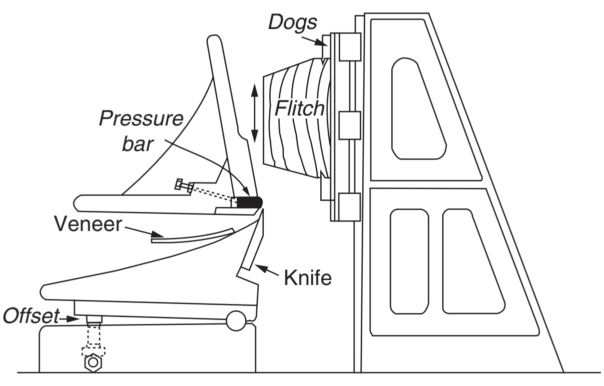

Figure 4 Veneer slicing machine used to produce high-quality face veneer for nonstructural plywood.

operation. Occasionally low-quality logs are used. Some residue, such as sawdust, is so small that no further processing is possible. Larger residue pieces are broken down into more uniform dimensions using various cutting devices, such as chippers, cutter mills, and knife-ring flakers. The desired particle geometry and size depend on the application. Higher strength and stiffness particleboard are achieved using long slender particles. Particleboard with a smooth surface can only be obtained with very small particles. Often fine particles are produced for the face layers of a multilayered particleboard, while the long slender particles are used in the core. Screens are used to separate the particles by size. Oversized particles are processed again, while undersized particles are burned for fuel.

The particles are dried in rotating drum dryers. The particles are tumbled inside the dryer to mix with heated air (200–400°C at the inlet) to achieve the desired particle moisture content, typically 3–6%. Air emissions from wood particle drying systems are a concern. Pollution abatement equipment is used to clean the air stream of particulates, volatile organic compounds, and other potentially hazardous compounds. Wet electrostatic precipitators or thermal oxidizers are commonly used to treat the exhaust air stream.

The dry particles are mixed with adhesive, usually urea-formaldehyde, in an amount of 6–10% based on dry weight. Some phenol-formaldehyde, melamine-formaldehyde, and pMDI are occasionally used. The low-cost urea-formaldehyde is preferred, and is quite suitable for particleboard applications. Wax is also added (1% or less) to impart some temporary resistance to liquid water absorption. Since the particles have a tremendous amount of surface area, and only a small amount of adhesive is added, the adhesive must be atomized and applied as tiny droplets.

The resinated particles are formed into loose mats by a device called a forming machine. Multiple layers are achieved by employing more forming machines. A uniform distribution of particles will provide a uniform density panel. The mats are formed continuously, and either pressed continuously, or the mat is cut and loaded into a multi-opening hot-press.

Continuous hot-presses are becoming more common. In a continuous press two moving metal belts are in direct contact with the mat. These belts run the full length of the press and are synchronized to move the mat slowly through the press. Mechanical pressure in the press creates intimate contact between the particles. Heat is applied to cure the thermosetting adhesive. The pressed panel may be cut to any length. In a multi-opening press the panel size is determined by the press size. Twelve to 16 press openings are typical. Current technology allows mats up to 3.7 m wide to be pressed.

After hot-pressing the raw panels are trimmed, cooled, and cut to size. Sanding is usually performed to achieve accurate thickness and to prepare the surface for bonding of overlay materials.

Fiberboard

The fiberboard manufacturing process begins with wood chips. Occasionally small mill residue may be used. The chips are washed, subjected to pressurized steam, and then fiberized in a device called a disk refiner. The disk refiner uses no knives, but rather two machined disks that rotate in opposing directions to shear the chips into fibers. The wet fibers are then pneumatically transported by steam through a blowline to the next manufacturing step.

Insulation board and wet-process hardboard employ a similar mat forming process to paper manufacture. The wet fiber is diluted to a very low consistency in water and then dispersed on a moving wire screen in a Fourdrinier machine. Water is quickly removed by vacuum suction and the fibers consolidate into a wet mat. Continuous rollers compress the mat and further remove water. Insulation board is then produced by simply drying the mat in an oven. Asphalt is added to insulation board as a binding agent prior to the forming machine. Wet-process hardboard is processed in a heated press. The mat enters the hot-press wet, thus generating a lot of steam when subjected to temperature in excess of 200°C. The mat is pressed on a wire screen to allow the steam to escape, which imparts a screen pattern on the back side of the panel. This hardboard panel is referred to as smooth-one-side (S1S). A variation in hardboard manufacture is to dry the mat prior to hot-pressing. In this case a wire screen is not needed, and the panel is smooth-two-sides (S2S). Hardboard uses little or no adhesive, relying instead on natural lignocellulosic bonding between the fibers. Consequently extreme pressure is needed in the press, resulting in a high-density panel.

Medium density fiberboard (MDF) is a more recent development. The fibers are produced as described above. Adhesive is typically added in the blowline, although separate blenders are sometimes employed. Blowline blending is a simple means of mixing adhesive with the fiber. It consists of a tube into which adhesive is injected and atomized. Turbulence inside the blowline thoroughly mixes the adhesive and fiber. The resinated fiber is then conveyed directly to a tube dryer, where drying to approximately 3–6% moisture content is achieved in a few seconds. This short drying time is not enough to cause the adhesive to cure. Mats are then formed from the dry resinated fibers, hot-pressed, and further processed in a manner similar to particleboard manufacture.

Oriented Strand Board

Oriented strand board (OSB) manufacture is a variation of particleboard manufacture. Certain process steps are modified to account for the long strands and the critical process of orientation. Wood strands are produced from debarked logs on either a disk or ring strander (**Figure 5**). Knives in these devices cut the strands to a precise thickness, width, and length (typically $0.7 \times 19 \times 100$ mm). The strands are dried in rotary dryers. Liquid phenol-formaldehyde or pMDI adhesive is added in a rotating blender using spinning disk atomizers to achieve a fine resin droplet coverage over the surface of the strands. Dry powder phenol-formaldehyde adhesive is sometimes used.

The resinated strands are formed into a three-layer mat. The strands in the face layers are oriented in the same direction, while the core strands are aligned perpendicular to the face, or randomized. Both continuous and multi-opening hot-presses are used by the industry. Secondary processing and testing is similar to that used for structural plywood manufacture.

Laminated Veneer Lumber

Laminated veneer lumber (LVL) manufacture is largely a variation on structural plywood technology. The major differences are in the lay-up of the veneer into billets and the hot-press. LVL has all of the veneer aligned in the same direction. The veneer sheets are overlapped or scarf-jointed to create continuous billets. The billet is then pressed in either a continuous hot-press, or a very long platen press is used. Since LVL is used for long structural members, the platen presses are 20–25 m in length. The pressed billet is then cut to length and ripped to the desired width.

As a critical structural component, LVL uses only the best-quality veneer. To insure adequate strength and stiffness, each sheet of veneer is nondestructively tested, then graded to its apparent modulus of elasticity. The LVL billet is engineered to the desired strength and stiffness by judiciously selecting the proper combination of veneer grades and placing them in the layers best suited for the grade.

Parallel Stand Lumber

The parallel strand lumber manufacturing process requires veneer, so the front end of this process resembles a structural plywood or LVL process. The dry, 3-mm thick veneer is sliced into strands of approximately 19 mm width. Partial sheets of veneer, or veneer with many defects, are well suited for this process because the strands may be random lengths down to a lower limit of about 35 cm. However, since the strands are not substantially compressed in the manufacturing process, the veneer must have acceptable strength and stiffness.

Strands are passed through a double-roll coater to apply a waterproof adhesive (phenol-formaldehyde) to both sides. The strands are then arranged in parallel with a billet-forming machine such that the ends of the strands are randomized in the billet. The unpressed billet is then drawn through a continuous press. The continuous press produces a pressed billet with cross section dimensions of approximately 30×45 cm. Due to the large cross-section, conventional heating is not feasible. Therefore, the continuous press employs a microwave heating section to cure the thermosetting adhesive. The resulting billet is then cross-cut to length and ripped to an appropriate width and thickness.

Figure 5 Long-log knife-ring flaker for producing strands for OSB and laminated strand lumber. Cutting action of the knives is shown at right. Photograph courtesy of Pallmann Pulverizers Co., Inc.

Laminated Strand Lumber

Laminated strand lumber manufacturing is a variation of the OSB process. The strands are longer than those found in OSB, and all of the strands are arranged parallel to each other to simulate solid-sawn lumber. The adhesive blending and mat forming are similar to OSB processes. LSL is produced in billets 5–12 cm thick, 2.4 m wide, and 15 m long. Due to its thickness, conventional heating in the press is not practical. An LSL press employs steam injection through the press platens into the mat of strands. The steam greatly accelerates the rate of heat transfer to the core of the mat, thus reducing the time in the press. The steam injection also serves to reduce the gradient in density through the thickness of LVL. Polymeric MDI adhesive is used for the manufacture of LSL due to the steam injection process. This waterproof, thermosetting adhesive requires water to polymerize, while steam interferes with the bond strength development of phenol-formaldehyde adhesives.

Further Reading

APA (1994) *PRP-108 Performance Standards and Policies for Structural Use Panels*. Tacoma, WA: APA – The Engineered Wood Association.

APA (1995) *PS1-95 Construction and Industrial Plywood*. Tacoma, WA: APA – The Engineered Wood Association.

APA (2000) *PRL-501 Performance Standard for APA EWS Laminated Veneer Lumber*. Tacoma, WA: APA – The Engineered Wood Association.

Baldwin RF (1995) *Plywood and Veneer-Based Products: Manufacturing Processes*. San Francisco, CA: Miller Freeman.

CPA (1996) *Particleboard from Start to Finish*. Gaithersburg, MD: Composite Panel Association.

CPA (1998) *MDF from Start to Finish*. Gaithersburg, MD: Composite Panel Association.

Haygreen JG and Bowyer JL (1996) *Forest Products and Wood Science: An Introduction*, 3rd edn. Ames, IA: Iowa State University Press.

HPVA (2000) *ANSI/HPVA HP-1-2000 American National Standard for Hardwood and Decorative Plywood*. Reston, VA: Hardwood Plywood and Veneer Association.

Maloney TM (1993) *Modern Particleboard and Dry-Process Fiberboard Manufacturing*. San Francisco, CA: Miller Freeman.

Sellers T Jr (1985) *Plywood and Adhesive Technology*. New York: Marcel Dekker.

Smulski S (ed.) (1997) *Engineered Wood Products: A Guide to Specifiers, Designers and Users*. Madison, WI: PFS Research Foundation.

Tichy RJ and Wolcott MP (eds) (published annually) *36th International Particleboard/Composite Materials Symposium Proceedings*. Pullman, WA: Washington State University.

US Department of Agriculture (1999) *Wood Handbook: Wood as an Engineering Material*. Gen. Tech. Rep. no. FPL-GTR-113. Madison, WI: US Department of Agriculture Forest Products Laboratory.

Streamflow *see* **Hydrology**: Hydrological Cycle; Impacts of Forest Conversion on Streamflow; Impacts of Forest Management on Streamflow; Impacts of Forest Management on Water Quality; Impacts of Forest Plantations on Streamflow.

SUSTAINABLE FOREST MANAGEMENT

Contents

Overview

H Schanz, Wageningen University, Wageningen, The Netherlands