CHAPTER 11

WOOD-BASED COMPOSITES: PLYWOOD AND VENEER-BASED PRODUCTS

SHELDON SHI[1] AND JOHN WALKER

[1]*Department of Forest Products, Mississippi State University, Mississippi, USA*

1. INTRODUCTION

A wood-based composite can be defined as a composite material mainly composed of wood elements. These wood elements are usually bonded together by a thermosetting adhesive (wood truss products could also be regarded as wood-based composites, but connected by metal connectors). The commonly used adhesives include urea-based adhesive (such as urea formaldehyde resin), phenolic-based adhesive (including phenol resorcinol adhesives), isocyanate-based adhesive, and adhesives from renewable resources (like soybean, lignin *etc*). The wood elements in wood composites can be in many different forms such as:

- Dimension lumber – for laminated glued timber (Glulam) and wood trusses;
- Veneers – for plywood, laminated veneer lumber (LVL), and parallel strand lumber (PSL);
- Fibres – for medium density fibreboard (MDF), high density fibreboard (hardboard), and other fibre-based products;
- Particles – for particleboard;
- Flakes or strands – for flakeboard, oriented strand board (OSB), oriented strand lumber (OSL), and laminated strand lumber (LSL); and
- Scrims – for scrim-based products, as in Scrimber.

Traditional composite panels are made from veneers and from mat-formed composites bonded by adhesive. More recently wood has also been combined (compression moulded or extruded) with synthetic polymers, e.g. thermoplastic polymers, to make wood-polymer composites (WPC). WPC products have been growing very rapidly in the recent years, especially in the decking market, where Wolcott (2004) observed that their market share has grown from 2% in 1997 to 14% in 2003. Further, much research work has explored the use of fibre-reinforced polymers (FRP) to enhance the structural performance of engineered wood composites, called FRP-wood hybrid composites (Dagher *et al.*, 1998; Shi, 2002).

Some engineered wood composite products are made from combinations of other wood composites, such as wooden I-joists that can have flanges of sawn lumber, LVL, or other structural composite lumbers together with webs of OSB or plywood.

Table 11.1. Market demand (in Mm^3) of lumber and some major wood-based composites in the United States in 2004 (Adair and Camp, 2003; Adair, 2004).

	Residential [b]	Non-residential	Industrial [c]	Total
Lumber	99.58	5.57	29.99	135.14
Plywood	7.36	1.35	4.81	13.52
OSB	18.13	1.33	0.82	20.28
Glulam	0.51	0.21	0.04	0.76
LVL	1.93	NA	NA	1.93
I-joist [a]	269.93	22.88	NA	292.80

a) I-joist volume in million lineal feet. b) Includes remodelling. c) Furniture, pallets, transportation.

Wood-based composites fall into two categories from the end application standpoint: panel applications, such as plywood, OSB, particleboard and fibreboard; and beam or header applications, such as glulam, LVL, OSL, PSL and scrim-based lumber. Panel applications are mainly for sheathing and flooring in residential housing and other industrial applications. Beam and header applications are mainly for load-carrying members in the residential and commercial buildings, such as garage door headers, floor joists *etc*.

2. TRENDS

The long-term trend in wood use reflects social and economic development and the changes in resources. The diameters of the trees are getting smaller while the cost of labour has increased steadily, forcing industry to use it efficiently so that labour productivity keeps ahead of labour costs. Those production processes that break wood down into small pieces or fibres are most adaptable to continuous flow, to automation, to standardization of product and to large-scale operations. Such products are technologically progressive and can be manufactured while showing respect for the growing costliness of human effort. On the other hand, those products in which wood is kept more nearly in its original state and in which pieces are handled individually tend to be technologically backward and will decline in importance. Thus there is a natural progression from solid wood, through plywood to strand-based-based composites, particleboard, fibreboard and paper.

Wood-based composites are widely used in industrial applications (furniture, pallets, packaging materials and concrete formwork), and other outdoor applications, such as bridges. However, the biggest market for wood-based composites is with residential and commercial building applications. In the United States, about 95% of the residential housing is built with wood-based materials. As trees got smaller and new technologies developed for wood-based composites, so sawn lumber beams or joists in housing construction have been replaced gradually by engineered wood products (EWPs), such as glulam, LVL, I-joists, PSL *etc*. Solid wood floors, wall diaphragms, panelling and ceiling lining have instead being sheathed with structural composite panels such as plywood and OSB. Table 11.1 summarizes the demand for some major wood-based composites and lumber in the United States in 2004.

In North America, all plywood manufactures used to follow the prescriptive standard PS1 (APA, 1995). However, since the introduction of performance-based standards such as PS2 (NIST, 2004) and PRP-108 (APA, 2001) in 1990s other structural panel products, such as OSB, can and have been used interchangeably in structural panel applications.

Figure 11.1 shows structural panel production (plywood and OSB) from 1970 to 2004, and some major engineered wood products (glulam, I-joists, and LVL) from 1980 to 2004 in North America. Structural panel production was under 15 million m^3 in 1970, but has increased to 37 million m^3 by 2004. Although OSB only became significant in the structural panel market in the 1980s, it overtook plywood by the late 1990s because of its lower production costs. In turn plywood has sought more diversified industrial applications, such as the furniture and transportation markets. Veneer-based composites have penetrated other areas, such as in LVL applications where production has grown strongly in the past ten years.

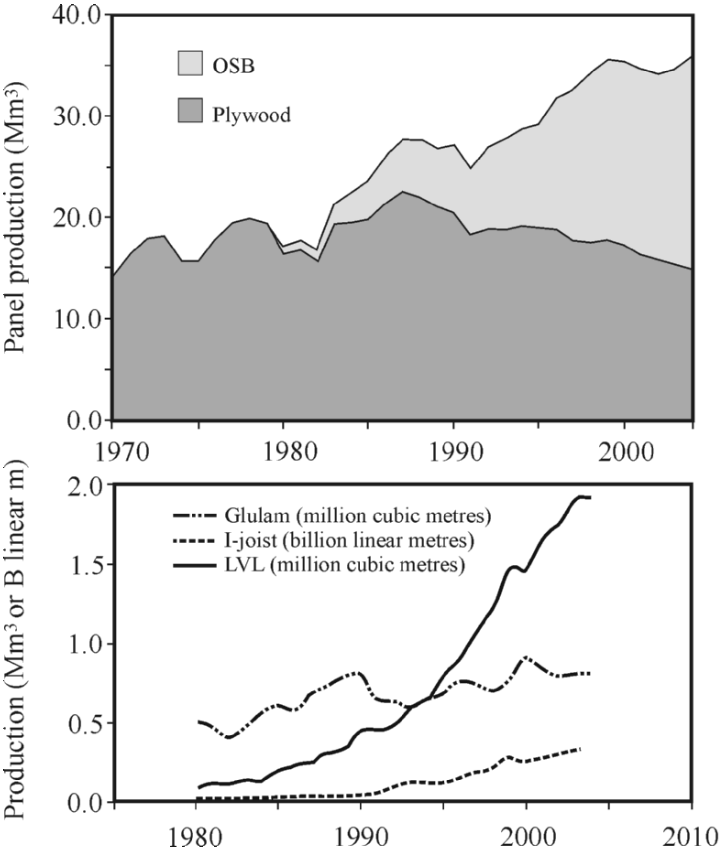

Figure 11.1. Production of structural panels and major engineered wood products in North America (Adair and Camp, 2003; Adair, 2004).

Table 11.2. Production (in Mm^3) of selected wood-based composites data in 2003 (FAO yearbook: forest products, 2005).

	Sawn wood[a]	Veneer sheets	Plywood[b]	Particleboard[c]	Fibre-based board[d]
Africa	7.7	0.88	0.69	0.47	0.23
N. & C. America	152.1	1.66	17.4	30.9	8.7
S. America	34.0	0.83	3.7	2.9	2.3
Asia	67.6	5.44	39.7	11.7	16.4
Europe	132.1	1.78	6.3	42.6	14.9
Oceania	8.6	0.72	0.58	1.2	1.7
World	402.0	11.31	68.4	89.7	44.1

a) All softwood and hardwood. b) Structural and decorative plywoods. c) Includes OSB but not those with inorganic binders. d) Insulation board, medium density fiberboard and hardboard.

Table 11.2 shows 2003 production of both sawn timber and wood panels for various regions of the world. Structural panel production is dominated by North America, mainly because structural panel products have enjoyed a dominant position in residential construction. The United States is a substantial manufacturer of softwood plywood for domestic production but only 10% is exported; whereas half that volume is imported as tropical hardwood plywood. Europe manufactures and uses comparatively little plywood and OSB. Instead the region relies on its own lower quality domestic wood resources for the manufacture of other wood-based panels, e.g. particleboard and fibre-based board. Amazingly, panel production in Asia equals that of lumber, reflecting the inter-regional China-centric supply chain.

Traditionally plywood has required a much higher grade of log than was necessary for the manufacture of other wood panels, so those nations with an unsuitable wood supply have had to import plywood although now there are manufacturing construction grades that use a poorer and smaller log type.

Manufacturers of other wood panels seek the cheapest possible wood. They are able to utilize lower quality logs and wood residues from other wood processing industries and still produce homogeneous boards with adequate mechanical and physical properties. Typically, the delivered cost of sawlogs, peeler logs and chipwood account for around 80-60%, 60-40% and 40-15% respectively of the production costs of lumber, plywood and boards made from comminuted wood.

3. PLYWOOD

Thousands of years ago Chinese and Egyptians shaved wood and glued it together to achieve special effects with veneered surfaces. In the 17th and 18th centuries, the English and French progressed the general principle of plywood, to where one or two veneers were overlaid on a plain, stable plank – or on narrow alternate wood strips jointed side-by-side to counteract wood's natural tendency to warp: the finest items would be counter-veneered and might be steam bent. However, Czarist Russia is credited for first making a form of plywood prior to the 20th century.

Typically early modern-era plywood was made from decorative hardwoods and was most commonly used in the manufacture of household items such as cabinets, chests, desktops and doors. Construction plywood made from softwood species did not appear in the market until the 20th century, although the first patent for plywood was issued in 1865, to John K. Mayo of New York City. The plywood industry really started in 1905 in the city of Portland, Oregon, USA.

Plywood is manufactured from sheets of cross-laminated veneers or plies, arranged in layers, and bonded with adhesives. Usually, the structure must be symmetric about the mid-point. Therefore, plywood has an odd number of layers, in which each layer may consist of one or more plies. Plywood construction is described by the number of plies and layers (i.e. 3-ply/3-layer). In the particular case of 4-ply/3-layer, this is manufactured using 4 plies of veneer sheets with the two inner veneers both orientated perpendicular to the face and back veneers (to maintain symmetry about the mid-point or neutral axis). Because of the way plywood is laid up, movement within the plane of the board is minimal because the wood grain lies at right angles to each other in alternate plies: the axial alignment of the grain in one sheet of veneer restrains the tangential movement in adjacent veneers. The resulting panel has similar shrinkage and strength properties in these two directions and thus the large dimensional changes and low strength values that occur across the grain in solid wood are eliminated. However, restraining the wood in the plane of the board results in greater than normal movement in the thickness of board. Further desirable features of plywood are its resistance to splitting, its availability in sheet form, and its ability to withstand large racking forces imposed on structures, for example by an earthquake.

Softwood plywood production in North America had grown to 345 000 m^3 by 1933 with major applications in industrial markets such as door panels, cabinets, trunks, and drawer bottoms. Later, in the 1940s and 1950s, plywood was promoted for residential construction and by 1960 softwood plywood production had reached 8 million m^3 of which nearly 50% was used as sheathing for residential construction. Plywood was also used for sub-flooring, siding, soffits, and stair treads and risers. The repair and remodelling and the non-residential building markets were also growing. By 1980, North America plywood production had reached 16 Mm^3. Then, OSB technology was introduced, and OSB has largely displaced plywood as structural sheathing in housing construction. Subsequently, plywood production has been static: in 1999, the production of OSB at 18 Mm^3 overtook plywood production at 17 Mm^3. Currently in 2005, the residential construction market accounts for only one-third of plywood market demand in the U.S. Instead plywood has gradually secured additional industrial markets, such as furniture, pallets, and others.

Over 70 wood species are used to manufacture plywood (APA, 1995). These species are divided into five groups on the basis of strength and stiffness. Strongest species are in Group 1, while weakest species are in Group 5. Veneer grades (A, B, C, $C_{plugged}$ or C_p, D) define veneer appearance in terms of natural features and the allowable number and size of repairs that may be made during manufacture (Table 11.3). A represents the highest grade and D the lowest. The grades of the face and back veneers in a sheet of plywood define the grade of the plywood (such as A-A, A-B, A-D, B-B, B-D, C-C_p, C-D, *etc*.). Grade A face veneer is necessary if a paintable surface is required, while B grade offers a solid face suitable for overlaying. The minimum grade of veneer for exterior applications is C-grade, while

D-grade veneer is used in plywood intended for interior applications. Lower grades may be permitted on the reverse face of a panel, e.g. C-D. The plywood will indicate whether it has been manufactured with an exterior or interior rated adhesive. Plywood can be used as rough sawn, unsanded, touch sanded, sanded, and overlaid. Plywood panels with rough sawn surfaces are used only for decorative purpose such as siding applications. Panels are unsanded if a smooth surface is not required, for subfloor, roof, and wall applications. Single floor and underlayment may require only touch sanded board for sizing to make the panel thickness more uniform. Plywood panels with B-grade or better veneer faces are always sanded smooth in manufacture since the intended end application is for cabinets, shelving, and furniture. There are two types of overlays: high density overlay (HDO) and medium density overlay (MDO). The overlays can be applied to the plywood at the same time as the panel is pressed, in one-step, or after the panel is pressed, in two-steps. The two-step process usually requires the panels to be sanded before overlaying.

Table 11.3. Veneer grades for plywood (APA, 1995).

A	Smooth, paintable. Not more than 18 neatly made repairs, boat, sled, or router type, and parallel to grain, permitted. Wood or synthetic repairs permitted. May be used for natural finish in less demanding applications.
B	Solid surface. Shims, sled or router repairs, and tight knots to 25.4 mm across grain permitted. Wood or synthetic repairs permitted. Some minor splits permitted.
C Plugged	Improved C veneer with splits limited to 3.2 mm width and knotholes or other open defects limited to 6.4 x 12.7 mm. Wood or synthetic repairs permitted. Admits some broken grain.
C	Tight knots to 38.1 mm. Knotholes to 25.4 mm across grain and some to 38.1 mm if total width of knots and knotholes is within specified limits. Wood or synthetic repairs permitted. Discoloration and sanding defects that do not impair strength permitted. Limited splits allowed. Stitching permitted.
D	Knots and knotholes to 63.5 mm width across grain and 12.7 mm larger within specified limits. Limited splits are permitted. Stitching permitted. Limited to Exposure 1 or Interior panels.

4. RAW MATERIAL REQUIREMENTS

The desired characteristics of the species for plywood include density, colour, ease of peeling or slicing, drying without wrinkling, bondability *etc*. However, only a few species have gained general acceptance as a sufficient volume of logs must be available on the international market on a continuing basis and these must be of sufficient size and adequate form.

Early mills in the Pacific Northwest of the United States made plywood from virtually flawless, old-growth, large diameter logs (>1.5 m) of Douglas fir. In the mid-1960s Douglas fir accounted for 90% of North American plywood production, falling to 55% ten years later. The declining availability of large, high quality

Douglas fir veneer logs has brought about a profound change in the United States plywood market. The main development has been in the construction and industrial (C and I) market, for sheathing, floor underlayment (with carpet, vinyl, or hardwood floor laid on top) and for containers. A key feature is the emphasis on physical and mechanical properties rather than on visual characteristics. Thus in the southern United States a new industry emerged in the 1960s producing relatively cheap 5- and 9-ply boards from the southern pines with C and C_p face veneers. These panels differ from those produced earlier in that knots as large as 75 mm in diameter and splits 25 mm wide are permitted and raw material requirements have shifted from traditional peeler grade logs to first and second grade sawlogs (Lutz, 1971). Such trends forced foresters to reassess their ideas on softwood plantation management. The largest, high quality logs used to be considered potential veneer logs and in a managed plantation these could only come from the final clearfell and even then only at the end of long rotations. Today, in the southern United States some of the first pine thinnings at age 12 are used for veneer. Log size is no longer of overwhelming importance. Here the better logs may go to the sawmill rather than the plywood plant. By the mid-1970s 30% of United States plywood was southern pine, rising to 50% by 1983. Elsewhere in North America the main plywood species are mostly Douglas fir and larch in Inland United States, mainly hemlock and Douglas fir on the West Coast, and in Canada mainly Douglas fir and spruce.

Commodity southern pine plywood requires three hours/m^3 and waferboard/OSB only one hr/m^3 (Spelter, 1988). By contrast in Finland the emphasis is on adding value to a basic commodity. Slow growing birch logs averaging only 200-250 mm in diameter are peeled down to a core diameter of 60-65 mm. Only efficient operations can hope to be profitable when peeling such small logs. The increased costs due to the lower yield (36%) and modest log quality are compounded by the fact that the lower yield also reduces output. The predominant use of a single species (pure birch or birch-faced plywood) and veneer thickness (1.5 mm) helps automation – although 35% of the raw material is 2.5-3.2 mm spruce veneer (Höglund, 1980). The veneer made from small diameter logs necessitates much repair work, e.g. patching and jointing represents about a third of the work input (Höglund, 1980). To add value two-thirds of plywood is processed: by scarf-jointing (with a 10-30% local loss of strength depending on board thickness 24-6.4 mm) into giant panels (up to 2.75 x 12.5 m); by preservative treatment; by overlying (for appearance or multi-pour concrete formwork – reused 10-80 times) or by adding a thick textured phenol-resin coat (2 mm; 200 g/m^2) providing a non-slip pattern for flooring, for use in van/trailer floors, warehouses, scaffolding and staging; or grooved ready-to-install wall panels.

Europe has over 40% of the 10 billion m^2 global market for panel surfacing materials, with market share for low pressure melamine (51%), veneer (18%), paper foils (13%), high pressure laminates and paint (7% each) *etc.* (O'Carroll, 2001). The prime substrate is particleboard and MDF, except for the uses discussed above, e.g. formwork and floating floors where plywood excels. The laminating paper is typically an absorbent kraft sheet that is saturated with resin.

Plywood is not a homogeneous commodity product (Todd, 1982). North America manufactures predominantly softwood plywood. Asian production is tropical hardwood plywood, while European production is a mix of softwood and temperate and tropical hardwood plywood. Currently, a ‘combi’ panel that combines both hardwood and softwood species is common. For example, many manufacturers in Europe use birch faces and spruce inners, while those in China are likely to use Russian larch faces and poplar inners. Some plywood mills in the United States are using radiata pine (from Australia) face and Douglas fir or hemlock back veneer: however, radiata pine veneer tends to show more linear expansion than the Douglas fir veneer because the wood’s higher microfibril angle and grain irregularity and so within-plane warping is more problematic. Other mills use high density eucalypts for face veneer.

Hardwood plywood is sold in both decorative (thin boards, <6 mm) and construction (thick panels, >6mm) markets. Temperate hardwoods are used primarily for decorative purposes, although Finnish birch is an exception being used in specialized high value construction applications. Thin boards are manufactured from tropical hardwoods and are used for decorative or platform uses. Decorative uses include wall panelling and door faces. As a platform the thin board receives a decorative surface that is either printed or overlaid on the panel surface, at which point it is known as prefinished (ready to use), and these are the major items traded internationally. Thin tropical boards are manufactured with water resistant, interior grade adhesives, whereas the majority of other boards use phenolic-based resin that can be used in exterior situations.

5. PLYWOOD MANUFACTURE (BALDWIN, 1981; SELLERS, 1985)

Plywood production can typically be divided into three manufacturing stages (Figure 11.2): veneer manufacture; clipping, drying and up-grading; and panel layup, pressing and finishing.

Construction plywood panels (1.2 x 2.4 m) are made from rotary peeled softwood veneers of 2-6 mm thicknesses in grades generally admitting large defects. A typical mill would process 100 000 m^3 per year.

5.1. Veneer manufacture

5.1.1. Principles of rotary veneer cutting (Koch, 1964; Lutz, 1974)

The process of rotary veneer cutting is essentially to cut perpendicular to the grain with the knife lying parallel to the grain. The bolt is centred between two chucks on a lathe and then turned against the knife that extends the full length of the bolt. As the bolt turns, a thin sheet of veneer is peeled off through the gap between the nosebar and the face of the knife as a long continuous ribbon. The quality of the veneer is determined to a considerable extent by the precise set up of the lathe (Figure 11.3). It is important that the veneer does not break and that it should have a smooth finish. Uniform thickness is a sign of good control at the lathe.

As the knife cuts the wood, the veneer is bent or rotated like a cantilevered beam and is liable to break (Figure 11.3a). An obvious way to reduce the bending moment

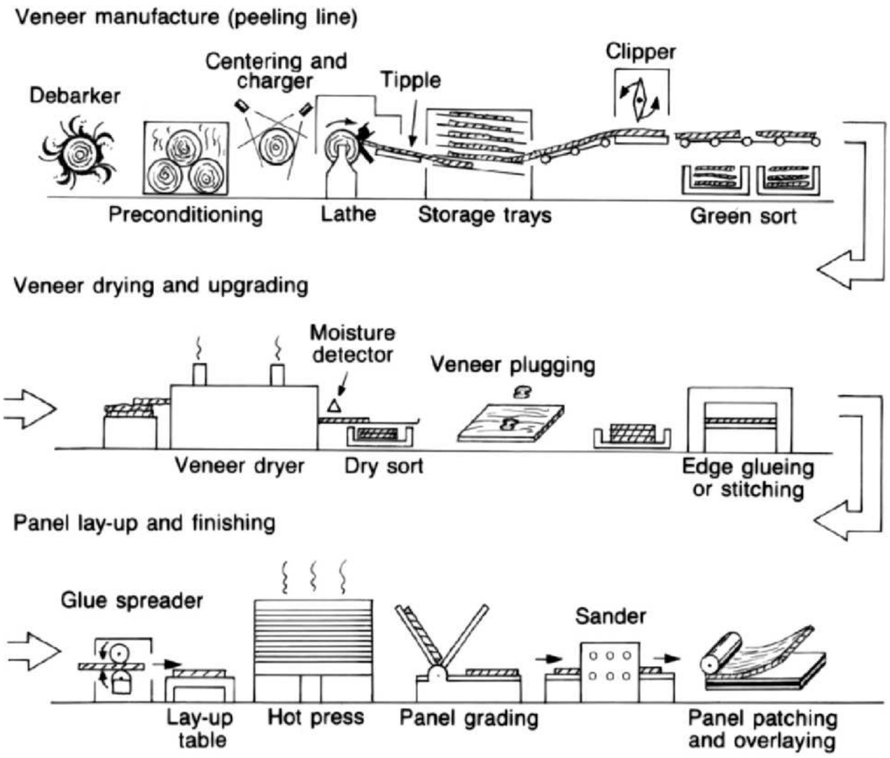

Figure 11.2. An outline of the principal features of plywood production.

is to increase the rake angle, α, and to keep to a minimum both the sharpness angle of the knife, β, and the clearance angle, γ (Figure 11.3b). Unfortunately it is not practical to use a knife with too fine an edge as this dulls rapidly. A microbevel (Figure 11.3d) on the knife gives a more durable cutting edge. Provided the joint or heel is not too large (<2.5 mm), a negative clearance angle is possible as only the small heel of the knife will press into the bolt. A nosebar is essential. Without a nosebar the veneer can split away from the bolt ahead of the knife and the surface of the veneer would be very rough. The nosebar compresses the wood perpendicular to the grain so that the veneer is cut at the knife and the knife edge itself defines the surface of the veneer. The nosebar pressure is achieved by reducing the gap between the nosebar and the knife so that it is less than the thickness of the veneer being cut. Adjusting the position of the nosebar does not affect the nominal thickness of the veneer but it does influence its quality. The nominal thickness of the veneer is determined by the rate of advance of the knife per revolution of the bolt, e.g. if 3 mm veneer is being cut the knife advances 3 mm per revolution. Typically the nosebar compression is between 10 and 20% so that the gap through which the veneer must escape is 90-80% of the nominal thickness of the veneer. If the nosebar opening is too large the veneer will be compressed insufficiently and will be loose and of uneven thickness. If the nosebar opening is too small the veneer will be compressed beyond the elastic limit for the wood and it will be very tight and over compressed: it will not recover to its nominal thickness. Further, the power required to peel a bolt increases steeply as the nosebar pressure is increased.

Veneer is characterized by the presence of small checks, called lathe checks, on the side of the veneer that was originally nearest the centre of the bolt. Lathe checks form as the veneer is bent sharply as it passes between the knife and the nosebar (Figure 11.3a inset). Checks on the knife side of the veneer are opened up as the sheet of veneer is unrolled from the bolt and flattened out for use. The knife side of the veneer is the loose side and the nosebar side is the tight side. Veneer that has many deep lathe checks is 'loose-cut' veneer while one having shallow checks is 'tight-cut'. Deep lathe checks will greatly affect the veneer quality.

A dull knife causes other problems. The fibres may bow and wrap themselves around the advancing knife rather than separating cleanly. This means that cutting at the knife edge can become intermittent as a plug builds up before being severed. At the same time that these fibres are being compressed the resistance to severance ahead of the knife will generate tensile stresses behind the cutting edge. These stresses may be sufficient to form checks in the veneer, resulting in groups of cells being torn from the veneer surfaces. Finally friction between the knife and the veneer may generate high shear stresses in the fibres adjacent to the knife resulting in a poor surface finish. Injecting superheated steam (up to 200°C) at the back of the knife and the introduction of a ‘hot knife’ has improved the cutting action by softening the wood fibres at the instant of contact with the knife and by reducing friction between the veneer and the back of the knife (Walser, 1978).

The nosebar performs a number of functions in maintaining veneer quality:

- It compresses the wood ahead of the cutting edge which reduces the chance of the wood splitting ahead of the knife. Cleavage ahead of the knife results in a very rough surface.
- Compressing the veneer permits it to bend more readily and with less risk of failure as the veneer escapes between the nosebar and the knife.
- By applying a steady pressure against the bolt the nosebar takes up any slack in the mechanical system due to wear, and guides the knife in relation to the outer surface of the bolt. This helps to ensure a veneer of constant thickness.
- A powered roller nosebar (Figure 11.3c) reduces frictional drag and clears slivers that stick in the gap. These spoil good veneer and interrupt peeling.

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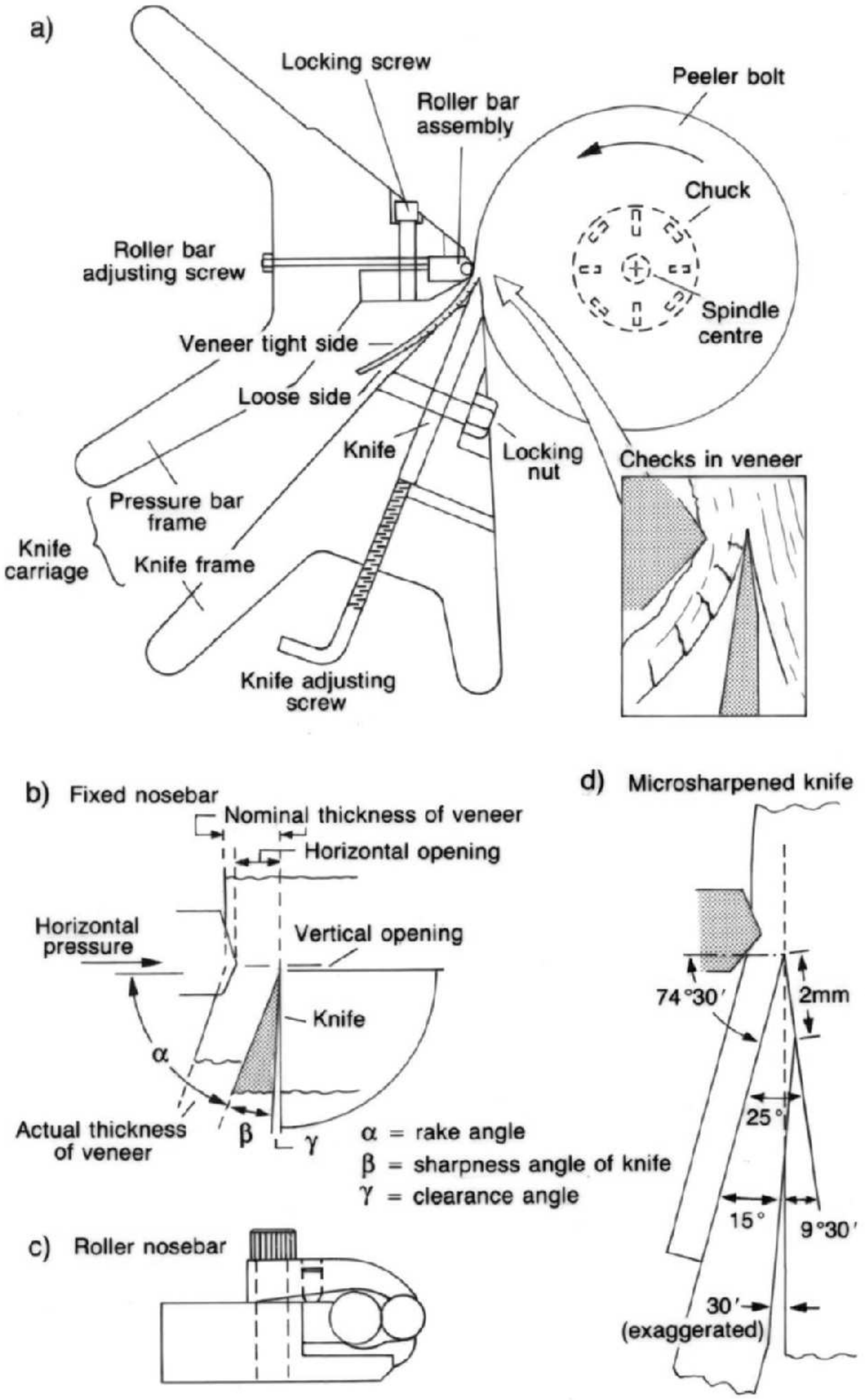
Figure 11.3. Rotary veneer lathe (Feihl and Godin, 1967). (a) Knife and roller nosebar mounted on a single carriage advance towards the chucks as the log rotates. The insert shows tension failures that are liable to form as the veneer is bent to pass between the nosebar and knife: the worst of the lathe checks are inhibited by slightly compressing the veneer. (b) Close-up of a fixed nosebar and knife. The gap between the two determines the degree of compression of the veneer, while the nominal thickness of the veneer is a function of the rate of advance of the knife carriage and the speed of rotation of the bolt. (c) Close-up of roller nosebar. (d) Microsharpening of the knife increases its resistance to damage from hard knots.


a)
Locking screw
Roller bar assembly
Peeler bolt
Chuck
Roller bar adjusting screw
Spindle centre
Veneer tight side
Loose side
Knife
Locking nut
Checks in veneer
Pressure bar frame
Knife carriage
Knife frame
Knife adjusting screw
b) Fixed nosebar
Nominal thickness of veneer
Horizontal opening
Horizontal pressure
Vertical opening
Knife
α
Actual thickness of veneer
β
γ
α = rake angle
β = sharpness angle of knife
γ = clearance angle
c) Roller nosebar
d) Microsharpened knife
74°30′
2mm
25°
15°
9°30′
30′
(exaggerated)

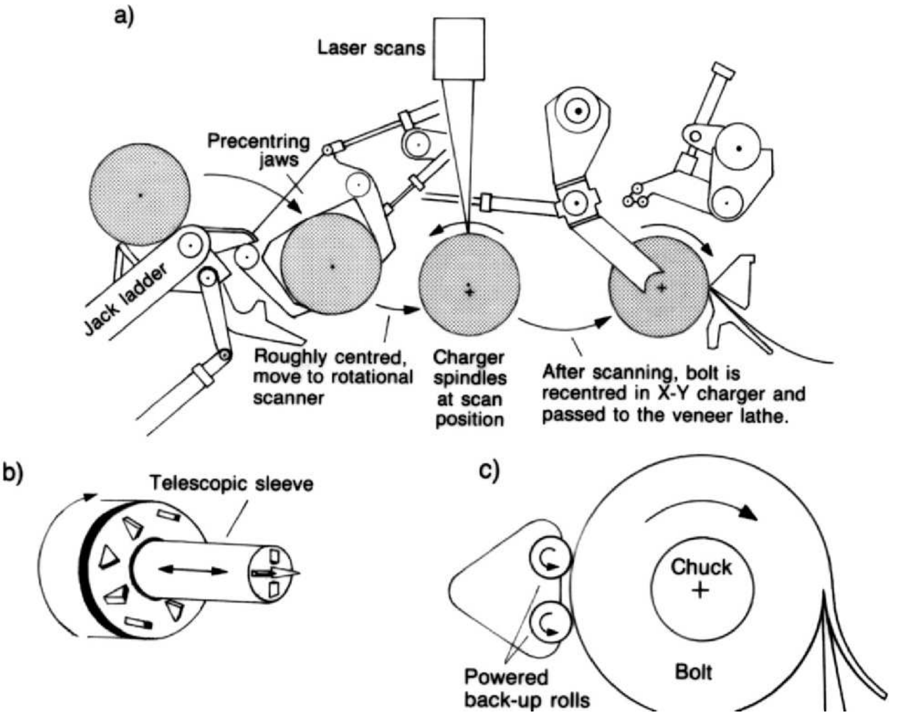


Figure 11.4. Some features of modern lathes (courtesy of Coe Manufacturing Co., Painsville, Ohio). (a) An automatic centring and lathe charging device. (b) telescopic, retractable chucks for peeling large logs. (c) powered backup rolls.

Walser (1978) examined the benefits of heating a contoured nosebar and of introducing hot water to the nip between the nosebar and the bolt. Only the most superficial fibres can be heated and softened, but this effect and reduced friction are sufficient to reduce power consumption and yield a smoother veneer of more uniform thickness. Since 1980, the small 16 mm diameter roller bar has been replaced by a larger roller bar ranging from 64–95 mm in diameter. The bigger roller bar allows for higher veneer productivity and recovery.

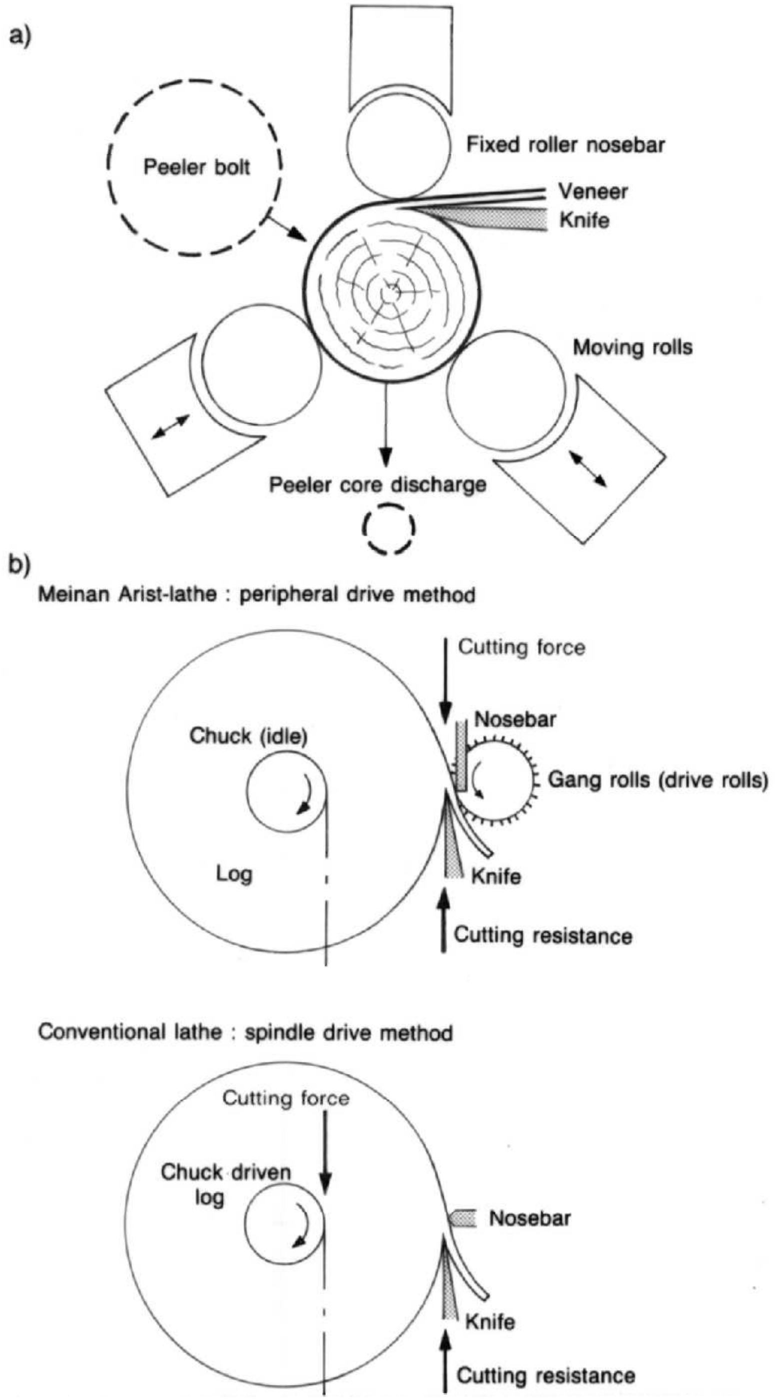
Other technical developments to conventional veneer lathes have made the peeling of small logs (<200 mm) economically viable. They include:

- Scanning bolts along their length to obtain a three-dimensional profile. The optimal spindle centre that would give the largest possible true cylinder of wood is computed. The bolt is then repositioned by displacing the ends both horizontally and vertically so that it can be passed to the lathe in that optimal position (Figure 11.4a). Traditional positioning devices only got within 25 mm of the optimal position. Precentring the bolts before loading the lathe has resulted in chucking rates in excess of five bolts a minute.

- The use of telescopic, retractable chucks allows the transfer of a large torque to the bolt when it is large, while the outer sleeve can be withdrawn to permit peeling down to a small diameter (Figure 11.4b). Spin out from the chucks sets a lower limit to the diameter that a bolt can be peeled to.
- Powered backup rolls augment the torque transmitted by the chucks and prevent the bolt bowing away from the knife (Figure 11.4c). The additional torque provided by coated, high friction backup rolls means that the torque transmitted by the chucks can be reduced. Backup rolls enable logs to be turned down to 130 mm cores without wood failure at the ends of the bolt that occurs where the chucks spin free. Smaller chucks are possible and the lathe can peel to a smaller core diameter.
- Fast peeling speeds, up to 6 m s^{-1}, allow large quantities of veneer to be peeled.
- Hydraulic control devices on the knife carriage have replaced gears and mechanical drives which can suffer from slack and wear. The use of hydraulics reduces the variability in veneer thickness and allows the thickness of the veneer to be adjusted very rapidly, for example peeling thick veneer during rounding up and then thin veneer when producing a continuous sheet.
- 1.2 m mini-lathes can be used to produce core veneer from large peeler cores coming from full-width veneer lathes or from smaller than average logs. Halving the length of the knife halves the torque needed to peel the shortened bolt while the torque that can be applied through the chucks remains unchanged. The short core lathe is a conventional response that has been superseded conceptually by the spindleless lathe.

The Durand-Raute spindleless lathe (Baldwin, 1987; Bland, 1990; Sorenson, 1985a) has transformed the economics and increased the productivity of small-log plywood mills. At the front end a round-up lathe peels the bolt until about 50% of its surface is dressed and the waste trim drops into the trash. The trimmed bolt is passed to the spindleless lathe (Figure 11.5a). The bolt is gravity fed onto the bottom rolls and then hydraulically lifted back up against the top fixed roll/nosebar and the adjacent knife that immediately peels a continuous ribbon of veneer. With a lineal output of 2.5 m s^{-1} a 165 mm diameter bolt can be peeled down to a 50 mm core in about one and a half seconds. Such machines are capable of peeling 15-20 bolts per minute, and 5,600 bolts per shift. The increase in efficiency is considerable as the time spent charging and rounding up a small diameter bolt in a conventional lathe can be half as long as the time to peel it.

The optimal clearance angle of the knife varies with bolt diameter and has to be adjusted continuously especially when peeling very small logs. If the clearance angle is too large, the knife tends to chatter while cutting, giving a short ripple (corrugation) in the veneer. If the clearance angle is too small the heel of the knife rubs on the bolt, and can force the knife out of the ideal spiral cutting line, giving a long, undulating wave in the veneer. They result in veneer of variable thickness.


a)
Peeler bolt
Fixed roller nosebar
Veneer
Knife
Moving rolls
Peeler core discharge
b)
Meinan Arist-lathe : peripheral drive method
Cutting force
Nosebar
Chuck (idle)
Gang rolls (drive rolls)
Log
Knife
Cutting resistance
Conventional lathe : spindle drive method
Cutting force
Chuck driven log
Nosebar
Knife
Cutting resistance

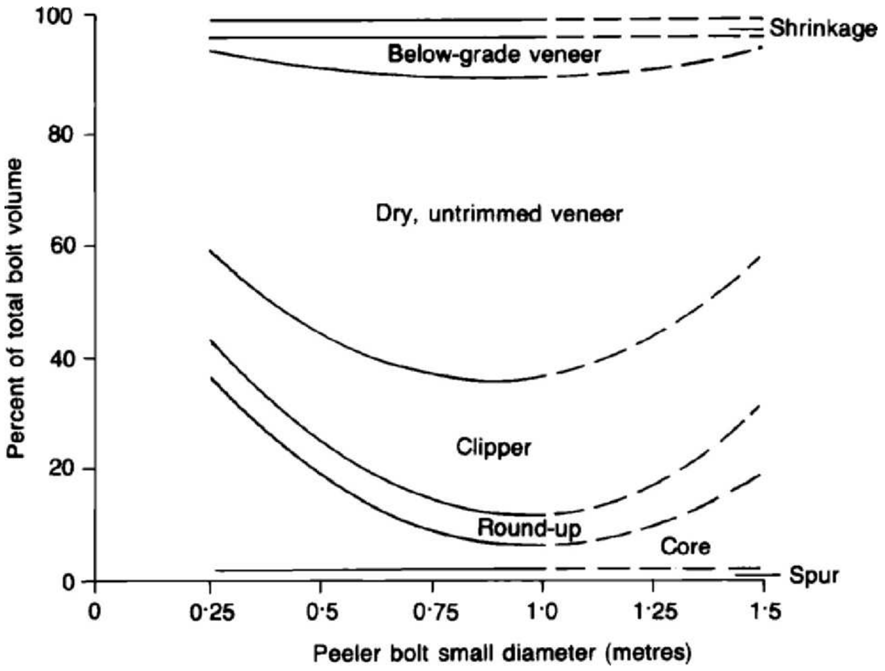


Figure 11.6. Veneer recovery from Douglas fir peeler logs (Woodfin, 1973).

Another unconventional approach is offered by the Meinan Arist-lathe (Figure 11.5b). The log is held in a modified lathe and a peripheral force is applied by a drive roll with a gang of spiked discs spaced at 50 mm intervals along its length to feed the bolt into the knife (Sakamoto, 1987). The spiked roller with its spacers functions as a peripheral drive unit and sectional nosebar. The cutting force is applied directly toward the knife eliminating the torque applied by a conventional chuck. There is far less tendency for badly split logs to break up and such material can now be peeled successfully. Further the spikes introduce small microchecks on the tight side of the veneer that becomes 'tenderized' so there is less likelihood of the veneer curling and breaking up. The veneer lies flat and dries more quickly.

In summary, Figure 11.6 demonstrates the high core losses with small logs and emphasizes the incentives to reduce these during veneer manufacture (Woodfin, 1973). Table 11.5 shows the efficiencies achieved by veneer manufacturers despite using much smaller softwood logs. Target core sizes and actual core sizes are far smaller than hitherto – and the recovery is actually improved.

←

Figure 11.5. Unconventional veneer lathes. (a) The spindleless lathe (courtesy Durand-Raute, Nastola, Finland). The lower rolls move up and in as the veneer is peeled, retracting again to release the peeler core and receive another bolt. Torque is provided by driving all three rolls. (b) Characteristics of the Arist-lathe compared to a conventional lathe (courtesy Meinan Machinery, Aichi-ken, Japan).

Table 11.5. The decline in both log quality and log supply on softwood plywood output has been mitigated by changes in technology (Spelter, 1988).

Technology of	Log size (mm)	Target size of core (mm)	Spin outs of bolts (%)	Core size after peeling (mm)	Recovery of green veneer (%)	Recovery of plywood (%)
Mid 1970s	350	135	8	240	65	51
Late 1980s	230	50	1	150	73	57

5.1.2. Log specifications

The poplar concept of the ideal, cylindrical log for veneer production relates more particularly to rotary peeled veneer (Lutz, 1971). Sliced veneer can be cut from logs having a degree of irregularity unacceptable in peelers. With sliced veneer irregular grain of various kinds is highly prized: burl walnut is a classic example. While large diameter logs are preferred, scarcity and rising log costs have forced mills to utilize smaller logs.

Sweep, taper and eccentricity all lower veneer recovery. The effect of sweep may be minimized by judicious cross-cutting of stems into individually straight logs. Taper produces short lengths of veneer during initial rounding up, and much of this material is unusable. Further the fibres in a tapered log do not lie parallel to the veneer knife so that the veneer is weak in bending, and can bleed from the glue line.

Eccentricity results in the production of narrow sheets during rounding up, which can be utilized but are not particularly valuable. More critically, eccentric or swept logs are indicative of the presence of reaction wood. Compression wood with its large longitudinal shrinkage (>1%) can result in imbalance and warping of softwood plywood, and board stability is one of the prized characteristics of plywood. Tension wood, on the other hand, can give a fuzzy surface after sanding because the fibres tend to pull out and bend rather than being severed cleanly. This is critical for decorative hardwood veneer.

Wood density is logically linked with hardness, machining characteristics and end use. Veneer species tend to have densities between 380 and 700 kg m^{-3} with a preference for those having a density near 500 kg m^{-3}. Lower density timbers are preferred for cores and crossbands because of ease of cutting, because they generally dry more easily with less tendency to warp and because they give lighter panels. However, low density species can be difficult to peel. They are liable to give a fuzzy surface though this can be counteracted to some extent by peeling when the wood is very wet and the cells are full of water: this gives some support to the cell walls during cutting. However with too high a moisture content there is no room for compression to occur until some water is forced out: if the bolt is peeled too fast the water is forced out at such a rate that the cells are ruptured. For this reason 'sinker' logs of species like redwood are not peeled. Species with uniform moisture content of about 50-60% cut best.

High density species are not necessary for structural grades of plywood, even though high density and strength are closely related. There are problems associated with peeling dense woods in that:

- They require more power to cut, and knives and machinery wear more.
- They tend to develop deep checks as they pass over the knife.
- They are not always easy to dry.
- They require an excellent glue bond as denser woods move more in service.

Knots are acceptable in structural plywood, and in core and in cross-plies of many other types of plywood. However, the knots should be sound and satisfy grade requirements. Steaming prior to peeling helps to soften knots and permits the bolts to be processed more easily.

Spiral grain can result in buckling or cracking during veneer drying. Even where such material is dried successfully thin plywood, in particular, can warp if the plies are not properly balanced.

Fast growth can result in peeling alternate strips of earlywood and latewood veneer. A 3-ply sheet manufactured from this material is liable to be unbalanced. Panels with seven or more plies are more stable.

5.1.3. Practical aspects concerning veneer manufacture

The primary objective is to maximize the recovery of veneer, in long ribbons with the minimum amount of veneer breakage, and with the veneer having a smooth surface and being of uniform thickness.

Veneer should be cut from logs as soon as possible after felling. If logs are stored they are best kept fully submerged or in a sprinkler system to prevent decay and seasoning checks.

Preconditioning. Veneer logs are first debarked and preconditioned (heated through) before peeling. Apart from the obvious need to heat frozen logs, conditioning is desirable as it improves veneer quality and recovery. Young, freshly felled, low density pine which is soft and pliable and Douglas fir are partial exceptions in that acceptable veneer can be obtained even if they are peeled cold. The object of preconditioning is to soften the bolts so that they peel more easily, with less sheet breakage and produce smooth veneer of uniform thickness. Power consumption at the lathe is reduced and the bolt can be peeled to a smaller core. Veneer quality is improved because hot wood is more plastic and will bend over the knife with minimum checking. Even large knots in lower grade logs are softened and can be cut more cleanly with less torn grain. Warm veneer can be handled with less chance of subsequent breakage: breakage results in more clipping to waste and fewer full width sheets of veneer are produced.

Efficient, uniform heat transfer is achieved when logs are heated in steam-water mixtures or immersed in hot water. Some form of segregation is desirable as the conditioning period ranges from a few hours to three or more days, depending on the log diameter and species characteristics. Logs can be conditioned in batches and in continuous-flow vats or tunnels: with tunnels the speed of the conveyor determines the conditioning period and individual sections in the tunnel allow batches of bolts to be treated separately. The most prominent characteristic of insufficient temperature is hard knots, which result in knife nicks, a reduction in knife life and rougher, looser veneer. In general dense hardwoods are heated to higher temperatures (80-100°C) than are softwoods. Excessive temperature causes earlywood/latewood delamination in softwoods that results in excessive roughness at low compression levels and fuzzy grain at high compression levels. Generally the centre of a softwood log needs to be heated to no more than 50°C: the lower the basic density of the timber the lower the necessary core temperature.

The round-up lathe. There are advantages in partially rounding up the log prior to passing it to the main lathe. In the round-up lathe the eccentricity, sweep and taper of the log are largely removed until recovery of short lengths or widths of veneer appears viable, at which point the bolt is prepared and ready for the main lathe. The round-up lathe reduces significantly the amount of unproductive time at the main lathe. Furthermore, any dirt or stones clinging to the log mark the round-up knife rather than the main veneer knife which must be kept in perfect condition if it is to cut quality veneer.

Lathe outfeed. Veneer is peeled at speeds between 2.5 and 6.0 m s^{-1}. Increased peeling speeds have put pressure on the clipper to enable the whole line to run faster. The traditional approach has been to separate the processes of peeling and clipping because they can rarely be synchronized: indeed the lathe may operate two shifts and the clipper(s) three shifts. Storage without damage and undue handling is needed. Veneer can be stored in reels (generally thin hardwood veneer) or most commonly directed automatically by a hinged tipple to multiple-deck storage trays (numbering 2 to 5 and up to 70 m long, enough to take the full length of veneer peeled from a single bolt). However, in a number of recent small-log mills the lathe has been directly coupled with a fast acting, computer-controlled rotary veneer clipper.

Clipper. One objective is to maximize veneer recovery, especially in full width sheets which minimize further handling. At the same time there is a call for the more valuable A and B grade veneers for faces or backs, which means cutting out defects such as decay, knot holes and splits. Management must determine the most profitable balance. Preference may be given to the production of A and B grade half widths or even random width (called strip), over full width C and D grade. The value added must exceed the cost of extra handling and jointing of narrow widths. Clipped veneer is sorted according to full sheet/random-width/fishtails, by sapwood and heartwood, and by grade before being fed into the dryer.

There are alternative mill configurations. Some modern mills direct the veneer from the lathe to the dryer and only then to the clipper. The advantage of clipping after drying is that veneer can be cut to size much more accurately than when green. The yield can be increased by some 3-5%.

Computerized clippers use scanners to detect breaks and defects in the veneer and then automatically clip these out. Typically 15-35% of veneer is in narrow strips and a clipper might spend 40% of its time trimming round-up and 60% of its time

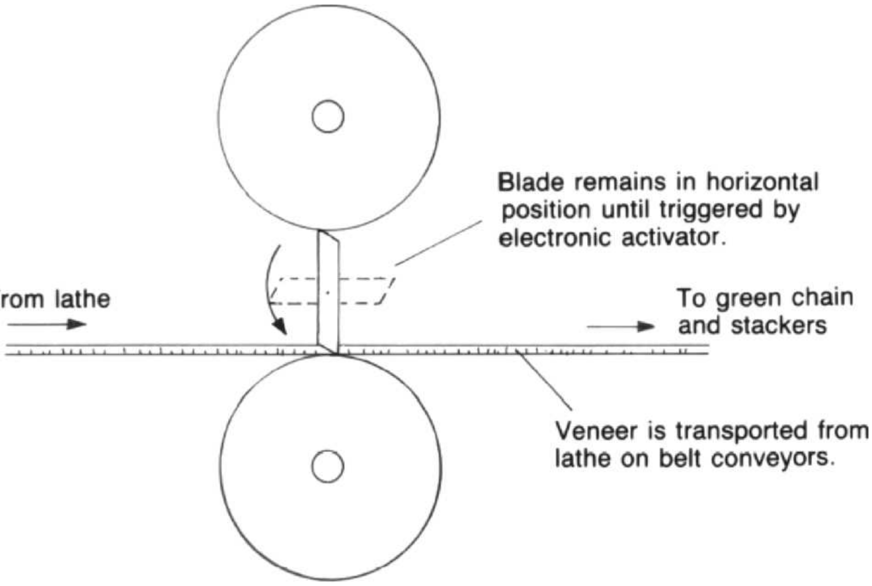


Figure 11.7. Principles of rotary veneer clipping (courtesy Durand-Raute, Nastola, Finland).

cutting full sheets from a continuous ribbon of veneer. Once the veneer is continuous, full sized sheets are clipped at a faster set rate. The up and down action of the old guillotine knife interrupted the steady flow of veneer, could cause the leading edge of the veneer to fold under, and cause pile ups and loss of veneer.

Today very fast clipping is achieved with a rotary clipper (Sorenson, 1985b). This device operates with the knife placed between two vertical rotating rollers (Figure 11.7). The bottom roll acts as an anvil and the top roll as a brace for the blade. The knife is electronically controlled and flips/spins between the rolls pressing and cutting the veneer against the bottom roller. The cut is very fast and does not cause any buckling of the veneer as both rolls and blade rotate with the flow of veneer. These clippers run at speeds of 1.8-3.0 m s^{-1} cutting with an accuracy of ±2.5 mm. They are quieter, more reliable, and require less maintenance than conventional clippers.

Veneer incising. Veneer can be incised when green before entering the veneer dryer (Dai *et al.*, 2003). The veneer sheets travel between incising rollers where a pattern of fine incisions are made on the tight side of the veneer in the grain direction. The incising rollers contain numerous chisel-shaped teeth. There are many benefits from veneer incising. It has been shown that the veneer drying time can be reduced by up to 10% and a less wrinkled, dry veneer obtained. Also the incised veneers can pick up 24% more preservative. Mill trials show that the incised veneer has a better bond quality and incising veneer can substantially reduce the panel blow (delamination), due to the greater permeability of the incised veneer.

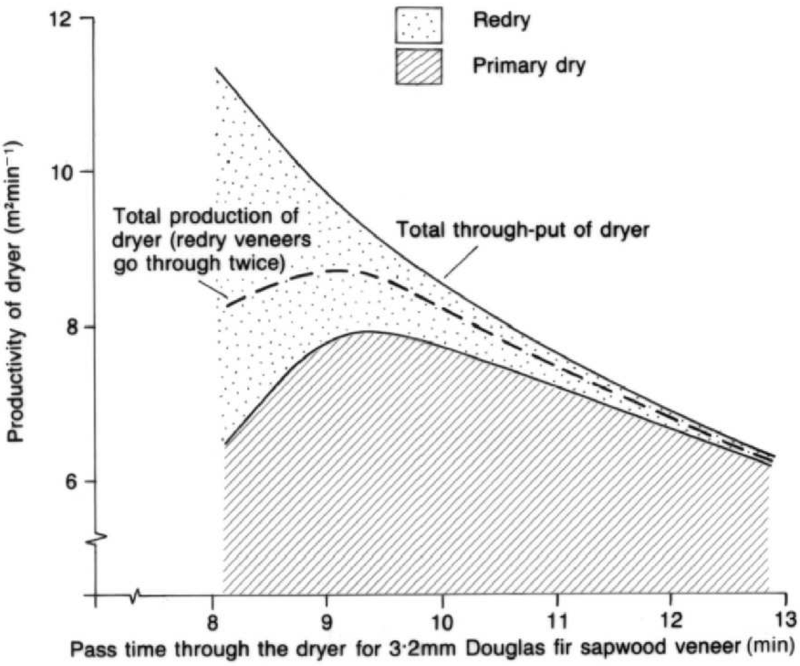
5.2. Drying and upgrading veneer

Over half the mill's energy requirement is used in drying veneer. However, burning wood residues should be more than sufficient to meet the demand for process steam.

After peeling the veneer is too wet to glue and needs to be dried. Historically veneer was dried down to 2-5% moisture content, but today target moisture contents have been raised to 6-12% and even 15%. Veneer with a moisture content as high as 20% can be successfully glued, and this dramatically reduces dryer time and yields more plywood (less shrinkage). However, at the present time the objective would be for the panels to leave the press at 12%. Even with excellent control the moisture content of dried veneer varies quite widely, so it is essential to monitor the moisture content of individual sheets as they emerge from the dryer and to mark and segregate out the underdried material for subsequent redrying. Typically, 10-15% of production needs redrying (Figure 11.8). This is a desirable state of affairs as overdrying not only reduces throughput and increases dryer costs, but it causes unnecessary shrinkage of veneer, makes it more brittle and liable to degrade, and can cause gluing problems at the plywood press. For example McCarthy and Smart (1979) quote an increase in primary dryer throughput of 18% by raising the redry rate from 5 to 16%. Better utilization of the dryer is achieved by batching veneer to take account of large variations in initial moisture content. Moist sapwood, drier heartwood, and veneer to be redried require progressively milder drying schedules.

Continuous dryers. Very high throughputs can be achieved but it is essential to segregate the veneers according to species group, thickness, moisture content, e.g. heartwood or sapwood, and adjust the drying conditions accordingly. The veneer is restrained and kept flat by rollers or mesh wire and passed slowly through a long heated tunnel (15-100 m long) that has a number of independently controlled sections. The dryer can have multiple decks, typically four, which increases throughput. High temperatures (150-200°C) can be utilized in the first few sections of the dryer where the veneer is very wet. With jet impingement the hot gases are directed through small holes to impinge perpendicular to the veneer faces at very high velocities (20 m s^{-1}). The impact breaks up the thin stagnant boundary layer, that normally inhibits rapid heat transfer between the circulating air and the veneer surface, and drying is enhanced. Wet sapwood (>100% moisture content) can be dried in 6-8 minutes. The last section cools the veneer as the application of adhesive to hot veneer can create problems of excessive evaporation of water in the adhesive resulting in poor spreading and partial curing before pressing. The recorded temperature drop as the air passes over the veneer is indicative of the amount of evaporation taking place, which in turn provides a means of estimating the moisture content of the veneer. A large temperature drop indicates wet veneer with the air stream being cooled as a result of rapid evaporation. The dryer is adjusted to reflect the actual conditions within each section of the dryer.

Platen dryers. Drying systems have been considered that heat the surface of the veneer directly with heated platens (Loehnertz, 1988; Pease, 1980). A single veneer is placed on the lower plate in each daylight of the multiple daylight press and the platens closed (100-200 kPa pressure on the veneer) so keeping the veneer flat



Increased productivity through redrying

Drying time	% redry	Production including redry
11·0min	5·2%	7·35 m²min⁻¹
9·3	16·0	8·69
9·0	19·8	8·76

Figure 11.8. Effect of redry rate on throughput of dried veneer (McCarthy and Smart, 1979).

during drying. A platen dryer is unable to dry random widths (too much delay in loading) and the veneer has a pattern on the back as the platen has to be textured to allow the moisture to escape whilst pressing. The press dryer radically reduces steam and electrical consumption relative to a jet dryer of similar capacity, by 50%. Platen presses cost at least 25% more than a conventional jet dryer but a better return on investment is claimed as the running and maintenance costs are lower. Further it gives a flatter veneer having a more uniform moisture content. There is little shrinkage, which enables smaller sheet widths to be clipped. For example, full width sheets can be clipped to 1.285 m if press-dried rather than to 1.36 m. However much of the benefit of increased sheet width is offset by a corresponding decrease in veneer thickness. Wellons *et al.* (1983) noted that Douglas fir veneer loses only about 4% of its thickness during conventional drying compared to about 8% with platen drying. In other words restraining the individual veneers in the tangential direction reinforces shrinkage to the radial direction. Microchecks appear throughout the veneer, which is a consequence of this redistribution of the natural shrinkage pattern. Such veneer is fine for inner plies or for the outer plies of sheathing panels, but can cause appearance problems in sanded or siding panels.

Radio-frequency dryers are used to redry batches of veneer. These dryers are effective as the heat generated as internal friction by the vibrating water molecules is concentrated in areas where the moisture content is high. Some moisture is removed while the remainder is distributed more uniformly amongst and within veneers.

Veneer plugging and unitising. It is often desirable to recover a larger proportion of better grade veneer by cutting out/punching out defects and inserting a precisely fitting patch in the veneer sheets. In the past this has been a manual operation, but now automated systems feed the veneer to the router, cut out the defects, press in the patches and secure them with a couple of drops of hot-melt adhesive. These machines can be linked to automatic defect detectors that automate the process. However, the trend is to omit veneer patching and to patch the panels instead.

Manual layup of plywood can be done with random width cross-plies, two-piece centres and full sheets for faces and backs. It is labour intensive. On the other hand, automated layup systems require all strips of veneer to be jointed together into either continuous or full size sheets. This is done by a process known as unitizing where the strips may be edge glued before being butted together, usually by friction rollers. Edge jointing options include the use of tape, glue, string or a combination of glue and string. For example fibreglass strings pre-coated with hot-melt adhesive can be applied to the veneer in a number of places using a heated roller. Full sheets of jointed veneer can be readily handled as single pieces. Core unitizing simplifies mechanical layup and reduces the veneer losses and downtime at the layup.

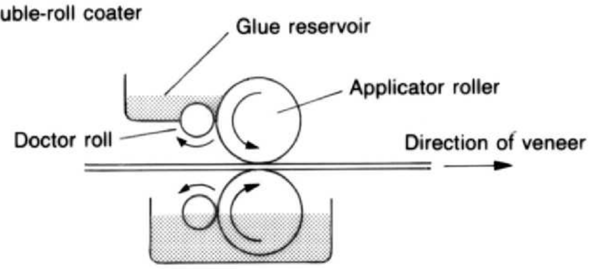
Green veneer can be edge-stitched/sewn using either a zig-zag or looper stitch. A polyester thread is usually used as it shrinks by about the same amount as the veneer when dried. The jointed veneer is fed into a programmable clipper and onto an automatic stacker.

5.3 Panel layup, pressing and finishing

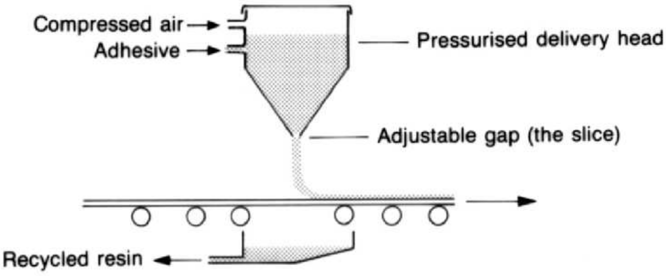
Structural plywood panels are manufactured with phenol formaldehyde resin, which is sufficiently durable to permit the panels to be used in exterior situations. With the traditional roll coater the amount of adhesive that is spread on the veneer is regulated by adjusting the gap between the steel doctor roll and the rubber applicator roll (Figure 11.9a). Glue coverage can be uneven if the veneer thickness is highly variable, with little glue coverage on the top face where the veneer is too thin to touch the adhesive film on the upper roll. While uneven coverage is undesirable it warns management that there is poor control of veneer thickness at the lathe. Unacceptably thin veneers are removed: their inclusion in a sheet of plywood would downgrade the board if that is not of the required thickness. Roll coaters remain popular in smaller operations making specialty and high quality plywoods.

With curtain coaters glue is forced from a reservoir through a narrow elongated gap or slit and falls as a continuous thin curtain across the entire width of the veneer

a) A double-roll coater



b) A curtain coater



c) Foam adhesive extruder

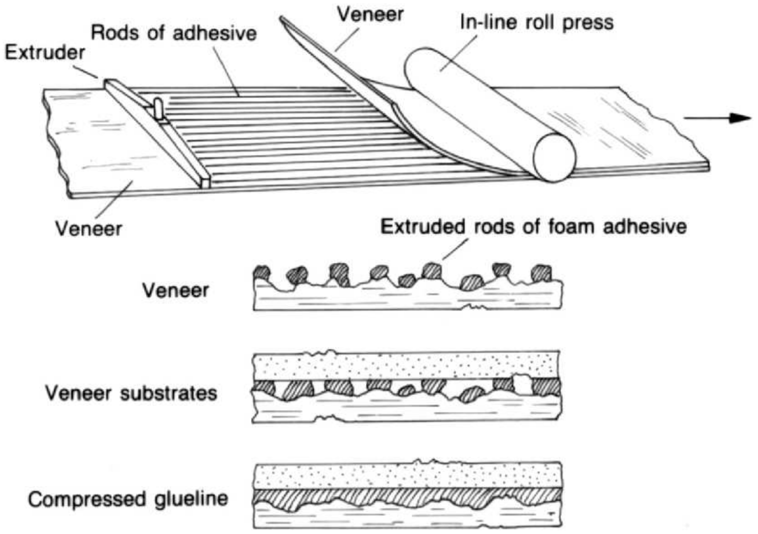


Figure 11.9. Various glue spreaders (Sellers, 1985). (a) Roller applicator. (b) Curtain coater. (c) Foam extrusion with in-line roll prepress.

which passes steadily underneath (Figure 11.9b). The amount of glue applied is controlled by the pressure head in the reservoir, the width of the gap, the viscosity of the glue and the speed at which the veneer passes under the coater. Glue that falls to either side of the veneers or between sheets can be collected and re-circulated.

Sprays can put small droplets onto the surface as the veneers pass underneath: the droplets spread and give complete coverage during pressing. Alternatively, the resin can applied by foam extrusion, where the glue is extruded through a series of holes spaced 10-15 mm apart and is laid in a series of continuous beads parallel to one another on the veneer (Figure 11.9c). The glue is foamed to five or six times its initial volume on being extruded in beads. These coaters use a continuous roller prepress to squeeze out the foam across the width of the veneer, to fill defects and holes and to ensure good coverage on both veneer faces. The re-circulated glue must be de-foamed before it can be recycled.

Such alternative methods of glue spreading can reduce glue consumption by 20% or more and are suitable for mechanical layup systems. Resin costs are contained further by adding fillers and extenders that both bulk and contribute to adhesion. They modify many resin characteristics such as viscosity and cure rate, and can contribute up to 50% of the resin volume.

Glue consumption (g m^{-2} of veneer per single glueline) is a function of the glue mix and a number of processing variables. For example:

- Rough veneer requires a higher than normal glue spread. Technical adjustments to the adhesive formulation are necessary to ensure that the gap-filling strength of the glueline is acceptable.
- Hot veneer (>35°C) requires more adhesive to counteract evaporation of moisture prior to closed assembly of the panel.
- Overdried veneer requires more adhesive to get good adhesive spread; while high moisture content gluing calls for glues with high solids content.

The total assembly time, from the application of the adhesive to entry into the hot press, ranges from 20 to 40 minutes. For part of that time the glue is exposed and can lose moisture rapidly. The viscosity of the glue and other adhesive characteristics change over time and the bonding strength after curing in the hot press is influenced by such factors. Automated layup minimizes open assembly and total assembly times.

Automated layup. Conveyors pass veneer under a series of gluing heads, cross-ply veneer is dropped on top before being passed to another gluing head where the next veneer is added, and so on until the desired number of plies are laid up. This process works for full sheets and with continuous jointed veneer that is cut to width at this point. There is a reduction in glue usage due to the ability to recycle and about a 4% decrease in the wastage of veneer at this stage due to better handling. However prior clipping and jointing of veneer is required. High production automated systems save skilled labour. They have better control and produce a more consistent product.

Cold pressing. Stacks of panels are pre-pressed cold for 3-5 minutes before being loaded into the hot press. The cold press ensures that the adhesive which is applied to one face of each veneer is transferred to the veneer on the other side of the glueline. Subsequent handling of panels is easier and more efficient.

Hot pressing. These presses are hydraulically operated and have 10-50 openings (daylights), each of which can hold one sheet of plywood. The trend is towards more daylights which means that hand loading is not fast enough. Instead the plywood is preloaded on racks and fed into the press in a single movement and simultaneously the hot-pressed panels are unloaded.

The press performs a number of functions. The initial pressure in the press, generally between 1200 and 1400 kPa, together with the plasticization (softening) of the veneers under the combined influence of heat and moisture, ensure intimate interfacial contact: the glueline film is less than 0.5 mm thick. The circulating medium heats the platens to around 140-165°C (for phenol formaldehyde resin) and as the heat migrates into the gluelines the resin polymerizes and hardens. Pressing is complete when the gluelines have been cured. Curing and moisture loss are rapid above 100°C and pressing is complete within two minutes of the innermost glueline reaching this temperature. Sellers (1985) provides indicative press times (Table 11.6). Wood veneer is a poor conductor of heat and this restricts the speed of glue cure at the centre of the board: heat transfer by evaporation of moisture from the surface veneers and its migration to the centre of the panel is not as easy as it is through a more open particleboard mat.

Table 11.6. Hot press schedules for phenol formaldehyde bonded southern pine plywood, 1980 (Sellers, 1985). Loading, press closure and unloading require a further minute or so.

Panel thickness[a] (mm)	Number of plies	Press time (in min.) from full pressure at:		
		140°C	150°C	160°C
9.5	3	3.5	3.0	2.5
12.5	3	4.0	3.5	3.0
12.5	4	4.5	4.0	3.5
12.5	5	5.0	4.5	-
15.5	5	6.0	5.5	5.0
19.0	5	7.5	7.0	6.5
19.0	7	8.5	8.0	7.5
22.0	7	10.0	9.5	9.0
25.0	7	12.0	11.5	11.0

a) Approximate metric equivalents, rounded down to next 0.5 mm.

Pressure is applied to consolidate the plywood and to ensure intimate contact at the gluelines. However, the hot moist plies can be densified, especially if the wood is a low density species, so as pressing progresses the pressure is reduced steadily to avoid unduly reducing the panel thickness. Wellons *et al.* (1983) observed a thickness loss of as much as 11% when Douglas fir veneer at 6% moisture content was pressed at 166°C and 1380 kPa pressure. To minimize thickness losses the closing pressure should be low and reduced further as quickly as possible. These losses are greater with rough veneer as greater pressures are needed to achieve intimate contact across all gluelines. There is some springback (2-5%) on unloading;

and by lightly spraying the panel surfaces with water a further 1% recovery is achievable. Low press pressures will be needed if the trend to high moisture content gluing, where boards leave the press at 12% moisture content, is to be achieved.

There are a number of variables that influence panel formation. They include press temperature, press time, moisture content, glue formulation, and modulation of the pressure. The influence of these variables is discussed further when considering the manufacture of fibreboard and particleboard (Chapter 12). The trend to pressing high moisture content veneer suggests that moisture migration through the veneers will contribute more to heat transfer than hitherto.

Inadequate cure or adhesion at the glueline due in part to high moisture can result in delamination when the boards are removed from the press. At the same time it is not economic to continue pressing until resin polymerization is complete, therefore curing of the phenolic resin continues after the panels have been removed from the press. Ultrasonic scanners at the outfeed of the press can detect air gaps (blisters) between veneers and suspect panels are marked and offloaded for further checking. This system reduces the number of defect boards being processed further and allows better feedback on the layup and pressing procedures.

From the press the phenol formaldehyde bonded boards are held in stack for further curing before edge and end trimming. The same does not hold for urea formaldehyde bonded boards. Urea formaldehyde panels are pressed at lower temperatures (<130°C) and should not be heated for prolonged periods as the resin is degraded by heat over 70°C. These panels should be cooled on leaving the press.

Panels are graded according to the veneer on both face and back. Splits, knots, knot holes and resin pockets are cut or routed out before being filled with putty or patched. Wood patches are being superseded by chemical patches, such as high density polyurethane foam which can be cured with heat lamps. It is not unusual to see sanded Douglas fir plywood with 20 plugs on the face veneer. Finally the panels are sanded. Modern high speed (0.75 m s^{-1} or more) widebelt sanders use a series of belts which give successively smoother surfaces.

Plywood can be processed further – with tongue-and-groove edges; overlaid, painted or given a textured surface finish; and edge-jointed to give oversized boards.

6. COMPETITION AND TECHNOLOGICAL CHANGE

The 1970s and 1980s, saw considerable innovation in the plywood industry, as it has responded to the decline in log size and quality, and to enormous competitive pressures from other panels such as waferboard and orientated strand board. The rate of application of new technology in North America is illustrated in Table 11.7. The effect of these changes on production costs and the competitive position of plywood *vis-à-vis* other structural wood panels are shown in another study by Spelter (1988). The interesting feature is the convergence of wood and resin costs for plywood and OSB/waferboard (Table 11.8). The loss in competitive position in the early 1970s was primarily the result of the policy of purchasing peeler logs, when the industry could have survived more profitably on a poorer mix of logs which would still have yielded the small proportion of A and B grades of veneer that was actually needed.

The misapprehension lay in the belief that all logs should be of peeler grade, whereas cheaper, lower grade logs would be adequate for core plies or even face veneers. Jointing of veneers and of plywood panels is significant as it allows the manufacture of enormous panels from low grade material, and offers greater flexibility in that the panels can be cut to the precise dimensions sought by assemblers of mobile homes, cabinet makers, *etc*. The challenge for the plywood industry today is to survive and profit from small logs at pulpwood prices. In Japan interest in the Arist-lathe and the spindleless lathe lay in the opportunity to peel short length veneer from low grade thinnings coming out of the indigenous forests. It is exemplified by the conceptual work of Okuma and Lee (1985) who examined the properties of laminated veneer board made from a 'patchwork of small, 450 x 900 mm, veneer elements' jointed into large sheets and then formed into plywood.

Wood composites today represent a matrix of opportunity. Each product seeks its own distinctive competitive advantage. A few of the commercially available products include:

- Blockboard, the original and still highly successful composite, with a side-butted core of timber overlaid by veneer.
- Plystran or Com-Ply with an orientated strand core aligned across the panel and overlaid with veneer aligned parallel to the panel length.
- Triboard with a thick orientated strand core overlaid with a layer of medium density fibreboard, so combining excellent strength with a smooth hard surface.

Table 11.7. Adoption of recent technological innovations by North American plywood mills.

Manufacturing technology	Number of units in service						
	1979	1980	1982	1984	1986	1988	1990
Charging:							
X-Y charger	1	3	70	120	135	140	>155
Peeling:							
powered backup roll			10	35	55	110	115
powered nosebar					70	120	140
peripheral drive lathe						1	2
hydraulic knife positioner			10	40	50	65	>100
spindleless lathe					1	1	4
Clipping:							
rotary clipper	1	2	6	45	90	105	>140
Drying:							
dryer control	-	-	-	1	5	7	>50
RF redryer	-	-	-	-	4	5	6
Gluing:							
foamed glue	--	-	-	-	6	7	8
Pressing:							
pressure controls	-	-	-	-	-	108	108
watering	-	-	-	34	43	36	36

Data from several plywood machinery suppliers (Spelter and Sleet, 1989). The 1990 estimate is supplied by Sleet (*pers. comm.*). With approximately 200 lathes in the United States and with major lathe changes too expensive for the smaller mills adaptation of 140 or so corresponds to effective market saturation.

Table 11.8. Impact of technological change on the estimated production costs of plywood and OSB/waferboard sheathing.

	Plywood		OSB/waferboard	
	Mid 1970s	Late 1980s	Mid 1970s	Late 1980s
Wood, net	66	37	32	28
Adhesives/wax	15	12	34	20
Energy	14	10	19	25
Labour	35	28	14	11
Overheads	26	26	26	26
Depreciation	7	7	12	12
Total	162	121	137	123

US dollar costs per m^3 for 9.5 mm (3/8 in) panels. The higher energy charges for OSB in the late 1980's is due to less wood waste and the need to buy more power. Assumptions include plywood bolts decreasing from 355 to 230 mm, with target core sizes of 135 and 50 mm respectively; and that OSB resin switching from 5.6% liquid to 2.1% powdered PF resin.

7. SLICED VENEER (LUTZ, 1974)

Sliced veneer operations are comparatively small scale with most mills processing less than 30 000 m^3 of logs per year. They cut a diversity of species. Slicing produces highly valued, figured veneers for face stock. The veneer is sliced very thin, 0.25-2.00 mm, typically *c.* 0.8 mm, to maximize the area of face veneer cut from expensive logs. Sliced veneer tends to be more brittle and to buckle and wrinkle on drying due to the wilder grain variation. Much of this thin sliced veneer is used for face veneer and may be laid on cheaper, non-decorative veneer. 5-, 9- and 15-layered plywood extends the surface coverage of valuable veneer since the consumer is not particularly interested in the material used as a substrate. For face veneer uniformity of colour is important and often requires the separation of sap and heartwood. Tradition or fashion dictates preferences for white or light-coloured woods or for darker woods. While many species would be suitable for slicing, selection is limited to those which are available in adequate volume, are of adequate diameter and free from excessive defects. Lutz (1971) indicated a minimum log diameter of 0.45 m for flat slicing and 0.6 m for quarter slicing, since the width of veneer strip that can be cut is limited by diameter. The visual characteristics that determine the value of a particular veneer relate to figure and colour of the wood and the manner in which the logs are sliced (Figure 11.10). Species with interlocked grain are best quarter sliced. Here the periodic reversals in the inclination of the fibres with respect to the axis of the log result in dark and light bands running the length of the veneer: if the veneer is reversed with respect to the lighting, the dark bands become light and *vice versa.* This is a characteristic of many tropical timbers, e.g. mahogany. Taste dictates that veneer with a narrow ribbon or stripe is more valuable. Wavy grain or irregular grain (Harris, 1989) is better flat cut, e.g. teak. Such veneer in violin backs is described as fiddleback, e.g. maple and walnut.

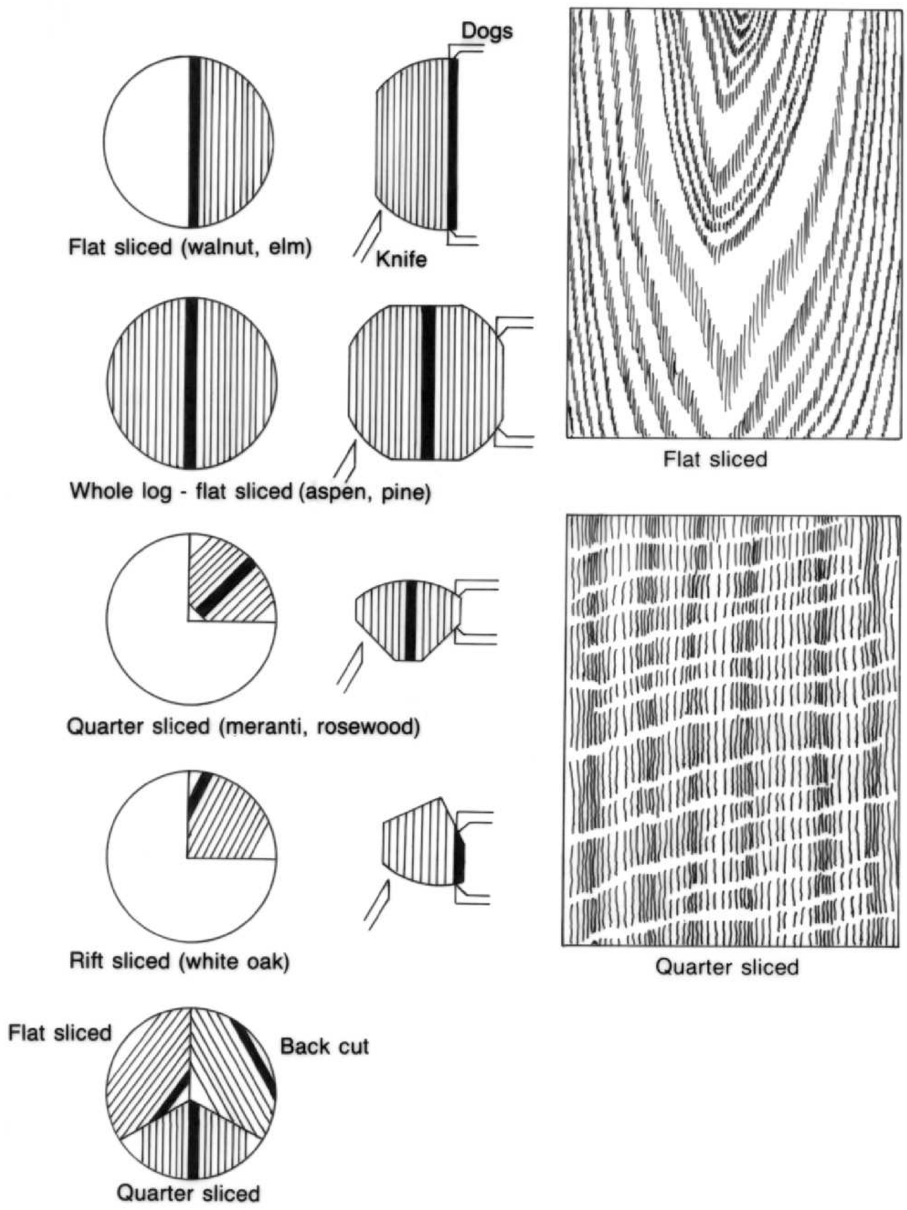


Figure 11.10. Veneer slicing (Lutz, 1974). Methods of breaking logs into flitches, and slicing strategies. Many species are flat or quarter sliced, the choice being determined by the log in hand and market demand. The wide dark bands represent the backboard left in the slicer after the veneer has been cut. Where a flitch is cut from pith-to-cambium the veneer is described as back-cut. It is used where the heartwood is narrow and highly prized, e.g. rosewood.

Generally logs are cut to length and sawn into flitches (Figure 11.10) before heating in vats. Some hardwoods are steamed as whole logs as this minimizes losses from end-splitting, and from the enlargement of existing ring (tangential) and star (radial) heart shake (Figure 6.16b). These wood failures arise in response to large growth stresses or to damage during felling: such trees should be laid down rather than be dropped. Internal splitting of the log is less of a problem when slicing than when peeling. It is usually possible to eliminate the effects of splits when cutting flitches by making the first saw cut along the worst split. Subsequently the flitches are dressed/planed before slicing. The high value of veneer logs justifies the high labour cost of these operations.

The cutting action is similar to that involved when rotary peeling except that cutting is intermittent (30-80 slices per minute) using an eccentric crank drive. The flitch must be firmly dogged and held against a vacuum table. The longitudinal axis of the flitch is skewed at a slight angle to the knife so that the blade does not impact simultaneously with the whole length of the log. There are two possible configurations. Either the knife is fixed and the flitch is fed into it or the flitch is fixed and the knife moves over it. Discharge belts lift the veneer away from the knife for stackers to handle in safety. The veneer from each flitch is stacked in sequence and each flitch is clearly identified. The character of the flitch can be ascertained by examining just three sample sheets: one from the top, one from the middle and one from the bottom.

Narrow veneers are jointed to make up full sheets that can be laminated onto any panel to provide a decorative finish: the panel requires a balancing veneer on its reverse face but this need not be of similar quality if it is not seen. Where alternate strips are turned over to become mirror images of one another the pattern is called book-matched. In this situation every second strip will have its loose face in view, and smooth tight veneer is essential if a high quality decorative finish is sought.

Flitches can be sliced longitudinally (Sakamoto, 1987), which makes the machine much more compact. With this slicer a small quantity of veneer can be cut from selected high quality boards/flitches coming from a sawmill. Individual flitches are held down by an overhead conveyor belt and driven over a flat machine bed having a protruding knife and nosebar. With a roundabout feed system 15-20 veneers can be cut per minute. The feed system allows flitches to be sliced down to a 5 mm backboard rather than to 30 mm as in a conventional slicer (Figure 11.10). The machine is not a high production unit but it recovers high quality veneer 0.2-0.5 mm thick from the best boards in some sawlogs.

8. TIMBER-LIKE PRODUCTS

There have been many interesting approaches to overcome the shortage of high quality, large dimension timber. Engineers have turned to trusses, I-beams, and space frames to achieve what had previously been accomplished by solid timber beams. Composites like glulam and the new products discussed below provide substitute elements that can be incorporated into the kinds of modern designs just alluded to. The thrust in the development of these new products has been improved reliability (strength and stiffness) and competitive marketing. There must be an overall advantage or financial saving. For example, the lightness of the timber/composite structure can reduce the cost of foundation work or it can reduce construction time, and so be an attractive solution even where the new product is more expensive.

8.1 Laminated veneer lumber (LVL)

The intrinsic efficiency of peeling logs to yield veneer has suggested that the same process should be applicable to the manufacture of laminated structural members. Laminated veneer lumber (LVL) was first produced in the early 1970s, and since then has been commercially available in many countries. It is now the most widely used structural composite lumber product in the US residential housing market.

In the manufacture of LVL, unlike plywood, all the veneers laid parallel to one another. It is produced by bonding layers of wood veneer using phenol formaldehyde resin (typically) in a large billet (1200 mm wide) under proper temperature and pressure in a stationary or staging hot press, or in a continuous hot press. To achieve the desired engineering design properties individual veneer sheets are transported through a veneer grade tester for measuring moisture content, density, and stiffness values. Acoustic or ultrasonic propagation time is used to grade veneer for stiffness in some LVL production lines. Scarf and lap joints are used to form an end jointed veneer sheet to a desired length. End joints between layers are staggered along the length to disperse their strength-reducing effects. The length of the scarf is typically 8-10 times the veneer thickness.

The thickness of the LVL can be from 19 to 75 mm and is available in lengths up to 25 m. Subsequently the material is cut to the required profile or dimension for beams/headers, I-joist flanges, scaffold planks, truss stock and for joinery work where its straightness and stability are positive characteristics. There is no limitation on the wood species for LVL. Any species used for plywood can be used for LVL. Low-grade or previously under utilized species can be used.

Laminating improves the strength of wood composites by reducing the defect area in any cross-section: by dispersing the defects, by averaging the wood densities of individual veneers, and by excluding the worst juvenile wood by confining it to the peeler core. Stiffness is a more tractable issue as grade stiffness values are taken as the mean of the grade population rather than the lower fifth percentile as for strength: hence the benefit of acoustic grading, sorting and screening of veneer. Indeed some companies are adding high stiffness hardwood veneer, e.g. plantation eucalypt, in their products. Research has considered incorporating a layer of fibre reinforced polymer or synthetic woven fabric into the LVL layup to improve the stiffness and strength (Laufenberg *et al.,* 1984; Dagher *et al*., 1999). Typically, LVL is about 1.5-3 times stiffer and stronger than stress-rated timber.

Schaffer *et al.* (1972, 1977) examined the prospects for thick peeling southern pine, press drying, applying adhesive and then relying on the residual heat within the veneers to cure the laminated members. A phenol-resorcinol adhesive, which cures at moderate temperatures, was considered rather than a conventional plywood

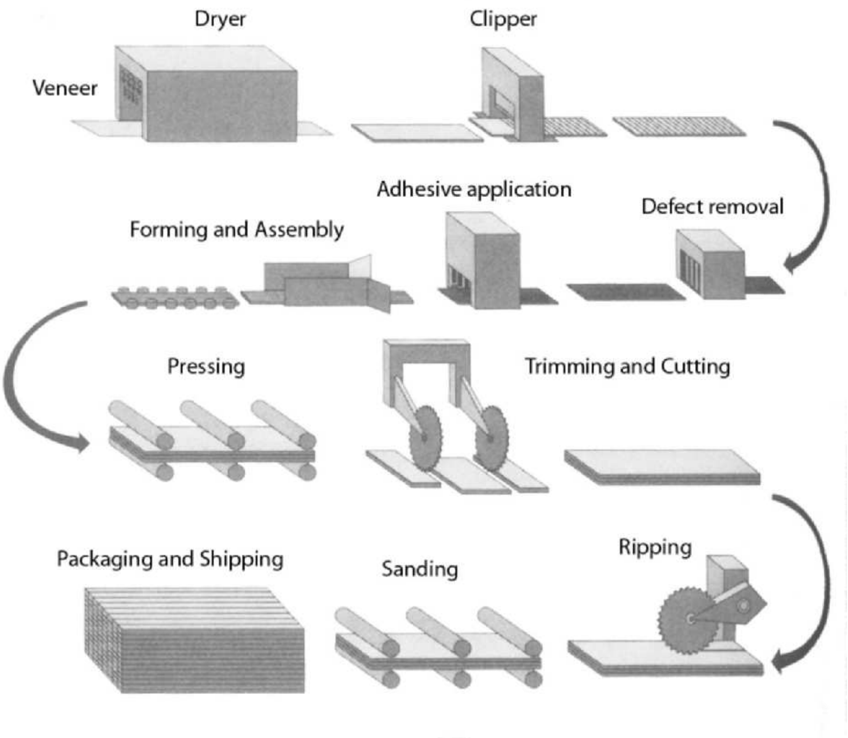


Figure 11.11. Manufacturing process for PSL (Williamson, 2002).

adhesive so that the laminated veneer would only need cold pressing. While the original scheme contemplated using thick veneer (up to 13 mm) to minimize the number of gluelines, these have very deep lathe checks and require much higher glue spreads (c. 50% more) than for plywood.

8.2. Parallel strand lumber (PSL)

Parallel strand lumber (PSL) was introduced to market by MacMillan Bloedel Ltd in the 1980s. Figure 11.11 shows the PSL manufacturing process. Residues from plywood and LVL plants can be used as the raw materials for the PSL – mainly Douglas fir, hemlock, southern pine, or yellow poplar.

It is manufactured from veneer (<6 mm) cut to a certain length (about 150 times the thickness of the strand), and a certain width (<18 mm), mixed with 4-6% phenol-resorcinol formaldehyde adhesive and cured by microwave. The long strands allow more complete transfer of load across the glue lines (Figure 11.12) so that the material approaches the ultimate strength of clearwood, partly because the requirement for long veneer lengths eliminates strands with knots and wild grain

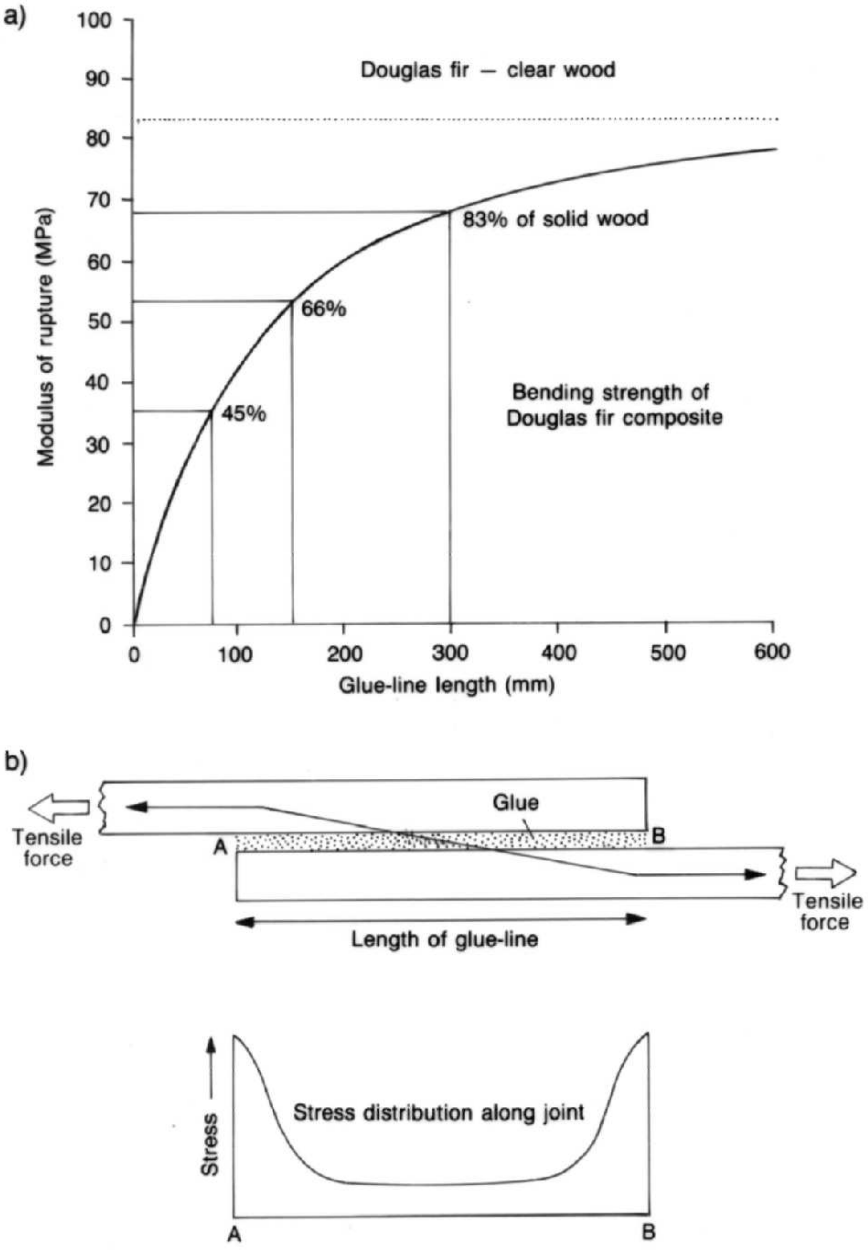


Figure 11.12. The strength of a glueline (Barnes, 1988). (a) Increasing the amount of strand overlap increases the joint strength. (b) Glueline strength is determined by the localized stresses at each 'glue joint' and the angle through which the load is transferred from strand to strand.

(Barnes, 1988). Maximum strength is achieved by accurately aligning straight-grained strands parallel to both the axis of production and the length of the eventual beams. Steel belts pull the mat of strands into a continuous press where the resin is cured with microwaves (Figure 11.13). Microwave energy penetrates and disperses uniformly across the large section which permits much faster curing of resin than would be possible with a conventional hot press: a hot press relies on heat transfer to cure the resin in the core and this is slow and uneconomic for thick members.

Technically, there is no length limit for parallel strand lumber since a continuous pressing operation is used. However, considering handling restrictions, PSL billets are usually cut to 20 m lengths, by up to 280 x 480 mm in section. The billets are recut to desired dimensions for use as beams, headers, columns, and studs.

PSL is very strong in its primary axis. The strength properties are higher than sawn lumber. Additional strength is gained from the 10% densification relative to the original timber. Strands fail in tension only because strand overlap is large and resistance to shear is greater than the tensile strength of the strand.

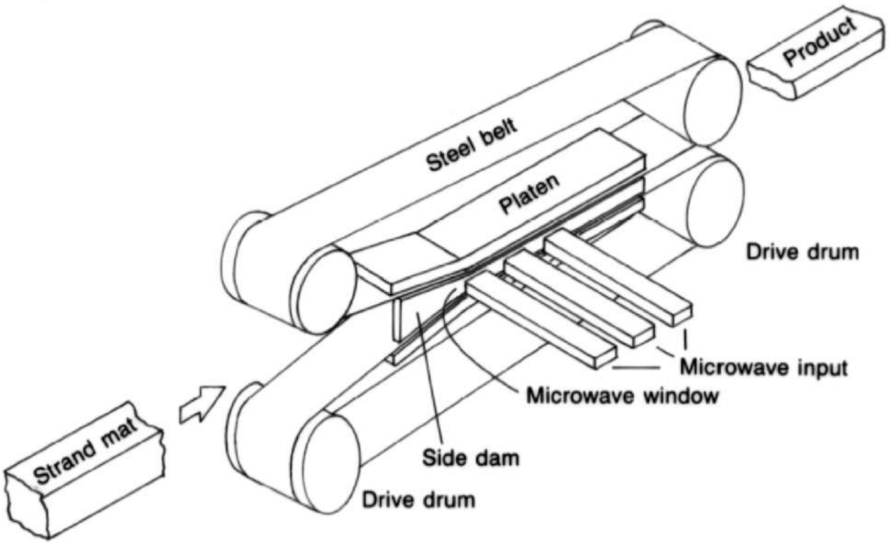


Figure 11.13. A 300 x 375 mm continuous press, for the manufacture of parallel strand lumber (Churchland, 1988). Four drive drums draw the strands into the press. The throat acts as a prepress reducing the thickness of the loose mat to 35-40% of its unconsolidated thickness. Both platens and side dams apply compressive forces to the mat that is cured by microwave energy admitted through ceramic windows in the side dams. These are transparent to microwave energy and yet sustain the full compressive forces on the edge of the product.

8.3. Scrim-based lumber

Scrim-based lumber (Hutchings and Leicester, 1988; Seale, 2004) is a product that utilizes low grade small diameter wood (76–203 mm). It was initially developed by

CSIRO in Australia and trademarked as Scrimber. Today it is being relaunched in the U.S. as TimTek. First, the roundwood is debarked, and each log flattened and crushed to form a mat of interconnected fibrous strands in a series of grooved rolling mills. The individual mats of flattened scrim (*tr.* a cloth) are passed through a continuous dryer before being collated and offset with respect to each other (as in LVL), coated with adhesive (such as phenol formaldehyde) and consolidated to a cross-section 180 x 1200 mm. The mat is passed through a steam injection press to be formed into beam product. Once cured, it is re-sawn into standard section sizes and cut to required lengths. This product is subject to a total quality management program throughout its manufacture. Its principal market has been identified as heavy section construction members and as such it competes directly with concrete, steel and timber beams. Figure 11.14 outlines the manufacturing process for TimTek scrim-based lumber.

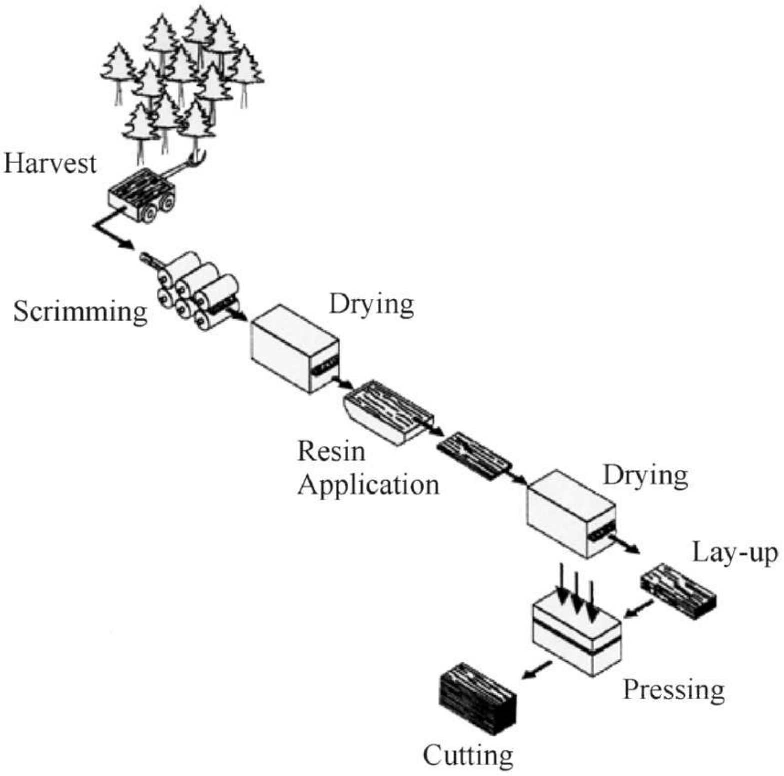


Figure 11.14. Scrim-based lumber uses young wood or thinnings from short-rotation plantations in a simple process to manufacture an engineered product of uniform quality (courtesy of TimTek Ltd).

The wood resource for scrim-based lumber is much inferior to that used in LVL or parallel strand lumber. The small diameter wood has much juvenile wood, but the split strands are very long and provide good transfer of stresses across the glue line. Scrim-based lumber has the potential to be made approximately twice as stiff and strong as the original (inferior) juvenile knotty timber. Scrim-based lumber is positioning itself in the general structural market where it aims to be competitive on price. LVL and parallel strand lumber have much superior properties and sell at a higher price for more specialized markets.