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Recent advances and trends in plywood technology

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RECENT ADVANCES AND TRENDS IN PLYWOOD TECHNOLOGY

by

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Finally, to my wife, Sarwar Qaiyum, and my children, I offer an apology for turning down their "stay home" pleas which constantly keep on ringing in my ears.

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INTRODUCTION

The plywood industry has had a great production boost in recent years. A growing concern for conservation in the use of wood as a raw material, the ease of handling and working with plywood sheets, and their extraordinary dimensional stability have collectively contributed to the adoption of plywood as an important constructional material all over the world. In the United States also, as shown in Table 1, the apparent consumption of plywood has increased greatly during the last quarter century while that of lumber has remained almost static (69).

Concomitant with the great rise in consumption have been the advances in plywood technology. Veneering has come a long way from the first historically recorded craftsmanship of over 3000 years ago, evidenced in the artifacts excavated from the tombs of the Egyptian Pharaohs. Then, and in the intermediate period, veneering was merely a form of art, patronized exclusively by the rich. "The proudest possession of Caesar was a table, beautifully veneered," says Pliny in his Natural History, written in the first century A.D. Inlay, Intarsia and Marquetry were the hallmarks of woodworking till 1720. "The Bureau du Roi," a desk, which took 9 years (1760-69) to make and cost a million francs to Louis XV, has been described as having the construction of plywood throughout--in principle and in fact. From 1720 to 1840, Chippendale, Adams, Hepplewhite and Sheraton in Europe and Duncan Phyfe in America--all furniture makers--laid the foundations

Table 1. Apparent consumption of plywood and lumber in the United States of America.

Year	Lumber (billion B.F.)			Plywood (million sq.ft. 3/8"basis)		
	Total	Softwood	Hardwood	Total	Softwood	Hardwood
1951	38.7	30.9	7.1	4241	2995	1246
1952	39.2	31.9	7.3	4450	3166	1284
1953	38.9	31.6	7.3	5222	3839	1383
1954	38.7	31.5	7.1	5405	3983	1422
1955	40.1	32.5	7.6	7071	5276	1795
1956	40.9	32.8	8.1	7262	5418	1844
1957	35.0	29.2	5.8	7412	5639	1773
1958	36.1	30.0	6.1	8267	6475	1792
1959	40.5	33.7	6.8	9945	7664	2281
1960	36.0	29.6	6.4	9571	7757	1814
1961	35.5	29.5	6.0	10523	8495	2028
1962	37.3	30.8	6.5	11716	9311	2404
1963	39.2	31.8	7.3	12984	10367	2617
1964	40.8	33.4	7.4	14380	11431	2949
1965	41.1	33.4	7.7	15492	12402	3090
1966	40.8	32.8	8.0	16126	12804	3321
1967	38.8	31.1	7.6	15909	12758	3152
1968	41.5	34.0	7.4	18213	14332	3882
1969	41.0	33.2	7.8	17314	13354	3960
1970	39.5	32.1	7.3	17822	14038	3784
1971*	43.5	36.4	7.1	20718	16258	4460
1972*	47.4	40.0	7.4	22991	17624	5367

* Estimated.

of what later came to be called "cross banding" and ultimately developed into the plywood of the twentieth century. Today's plywood, first manufactured in 1905 in honor of the Lewis and Clark Exposition, is now being produced on a massive scale with highly efficient machines, essentially as a utility item (4, 44, 72). It has been variously defined, as under:

> Webster's Third New International Dictionary of the English Language (1971 Edition): "a structural material consisting of wood glued or cemented together with the grains of adjacent layers arranged at right angles or at a wide angle and being made up (1) wholly of uniformly thin veneer sheets or (2) of usu. equal number of veneer sheets on either side of a thicker central layer" (71).

> American Plywood Association: Softwood plywood is "a flat panel, built up generally of an odd number of thin sheets or veneers of wood in which grain direction of each ply or layer is at right angles to the one adjacent to it. Face and back plys and all odd number plys generally are oriented with grain direction parallel to the long dimension of the panel. The sheets of veneer are united under pressure by a bonding agent to create a laminated panel with an adhesive bond as strong as or stronger than the wood" (3).

In this paper, my endeavor was to put together the latest on process and product innovations. I have also discussed utilization and the state of the industry. The last chapter provides perspective for the future.

CHAPTER II

PROCESS INNOVATIONS

Heating of Logs

Wood logs often need to be softened before they are peeled or sliced. This is accomplished by steaming or steeping logs in hot water. Particular care is necessary during winter months for frozen logs should be warmed up slowly. Heating or steaming is done in concrete lined chambers or pits in which pipes are laid, through which steam or boiling water is conveyed. The waste water or condensed steam is carried off through a drainage system (72). The logs should be kept submerged under hot water while heating because floating logs heat up much more slowly than submerged logs. However, for a given temperature of the heating medium, water and steam heat logs at about the same rate. The green specific gravity of a log is a major factor affecting the heating time; the higher the green specific gravity of a submerged log, the longer the heating time (32).

Veneer Cutting

There are two recognized methods of veneer cutting, viz., rotary cutting and slicing. The former is the one most extensively used. Slicing is mainly done to obtain thin decorative veneer for face plys. The large bulk of the softwood rotary veneer is cut in thicknesses of 3/6 inch, 1/8 inch and 1/10 inch while the most common sliced face veneer thickness is 1/28 inch. Occasionally, some precious woods like mahogany and Spanish cedar are sliced as thin as 1/100 inch (53, 70).

Rotary cutting. The object is to obtain the most economical quantity of veneer of uniform thickness and acceptable quality from a peeler log. To achieve this objective, the points requiring utmost consideration in operating the rotary cutting machine, called the lathe, are: (1) grinding of knife, (2) knife-pressure bar-spindle alignment, and (3) most economical recovery of veneer.

The edge of the veneer knife should be straight and sharp for producing smooth veneer. For the knife edge to be sharp and straight, it has to be periodically ground and honed. The knife is made up of two slabs of different steels bonded together--the body being the mild steel and the cutting portion, an inlay, a highly refined hardened steel. In the northwestern region of the United States where softwood veneer is peeled at high speeds from knotty bolts, the knife gets damaged very frequently. The knife in this region, therefore, consists of two or three parts clamped together so that only the damaged part is taken out for grinding and honing. The knife pieces are also pure hardened steel to withstand heavy wear and tear. Oftentimes a micro-bevel of 25 to 30^{o} is formed on the knife to increase resistance to damage by knots and grit, as shown in Figure 1. The grinding of the knife is accomplished with the help of precision machines containing a grinding head, knife bar and a pumping system to provide a stream of coolant--pure water or a mixture of emulsifying oil and water--at the point of contact between the grinding wheel and the knife. The wire-edge formed after grinding is removed by honing the back of the knife with a stone of medium grain and hardness. When the wire-edge falls off, honing is completed with a few additional passes with a fine

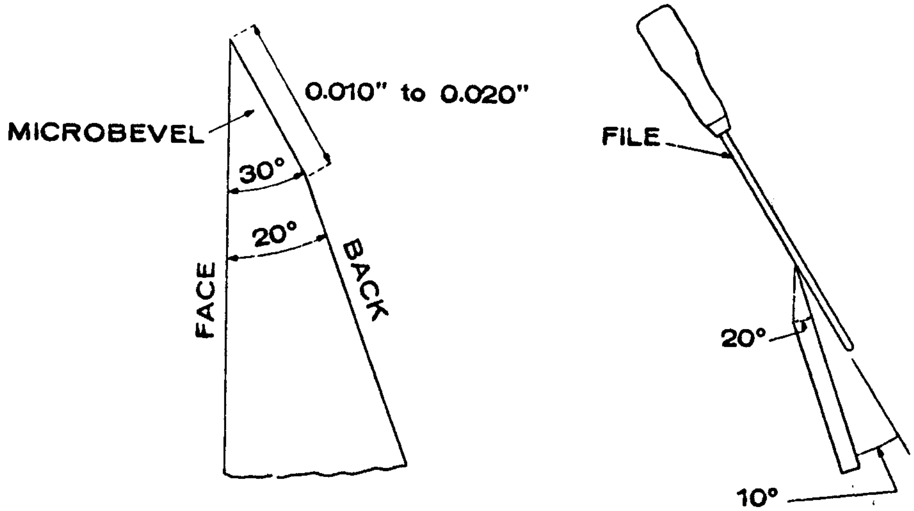

Figure 1. Left: Profile of knife tip with microbevel.
Right: Position of file to produce a microbevel.

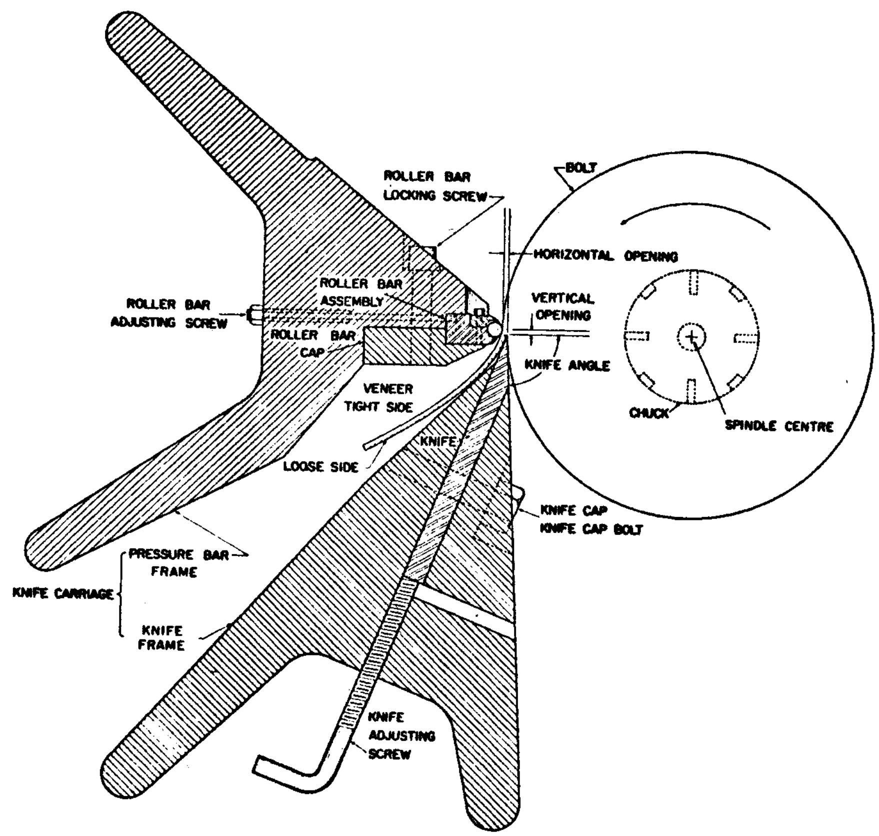

Figure 2. Diagram of a lathe equipped with a rollar bar.

textured stone saturated with kerosene oil. The knife is now ready to be installed. Another serious problem encountered in grinding is overheating of the knife. This results in drawing of the temper from the steel and production of microscopic cracks along the knife edge. The causes of overheating are simple, such as, haste in grinding, inadequate cooling, clogged grinding wheel and improper grade of grinding wheel which can be easily avoided (38).

A rotary cutting lathe consists of a bed and its strongly built frames, supporting a bridge frame in which spindles and their bearings are mounted. The wood bolt is centered to the spindles so as to be revolved against a knife running the whole length of wood. The knife carriage is equipped with an automatic advance system that feeds the knife and pressure bar assembly toward the center of the log at a certain controlled speed so that the knife may cut the log into veneer of the required thickness and let it pass between the edge of the knife and the pressure bar (27). A cross-sectional view of a rotary cutting lathe is provided in Figure 2.

One of the primary adjustments required to be made while operating a lathe is the alignment of the knife tip with the center of the lathe spindles. Any error in this adjustment results in the production of veneer of irregular thickness (36). A knife angle setting of $90^{\circ} \pm 30'$ is considered suitable for satisfactory veneer. Lower knife angles produce wavy veneer and veneer of nonuniform thickness while the higher angles cause corrugation in veneers. Another important adjustment is that of the horizontal and vertical openings. Reduction in horizontal gap up to the point where overcompression results in a reduction in the thickness of the veneer being cut, is effective in reducing both the severity of the lathe checks and the roughness of the veneer. Excessive compression in some softwoods causes shelling or slivering due to a separation between the springwood and summerwood. The vertical gap, on the other hand, has a linear relationship with the thickness of the veneer varying from a low of 0.005 inch for 1/100 inch thick veneer to a high of 0.030 inch for 1/8 inch thick veneer (37). Horizontal opening for thicknesses of 1/42 inch and lower should equal veneer thickness or, in other words, there should be no compression (35).

The shape of the pressure bar greatly influences the quality of the veneer produced. There are four different types of pressure bars in use these days, as shown in Figures 3 through 6. The conventional flat bar, shown in Figure 3, has its face inclined at an angle of 14° with the vertical and a modified version of this, Figure 4, is called a double surfaced nose bar. Whereas they do prevent splitting of wood ahead of the knife, there is an inherent disadvantage in these pressure bars, i.e., the slivers tend to accumulate between the bar and the log, causing scoring or overcompressing of the veneer (57). In the mid-1920's George H. Osgood and Adolph Gaines devised and patented a roller bar (31). The single roller bar, Figure 5, is usually 5/8 inch in diameter and turns at the peripheral speed of the bolt. The splinters and pitch get pushed through, thus reducing damage to the veneer. An improvement upon this is a driven roller bar but its drawback is that its driving gear limits the minimum diameter of the core to about 1.5 inch more than the diameter of the log chucks. To eliminate this loss in veneer yield, a double roller bar arrangement, Figure 6, was developed in which

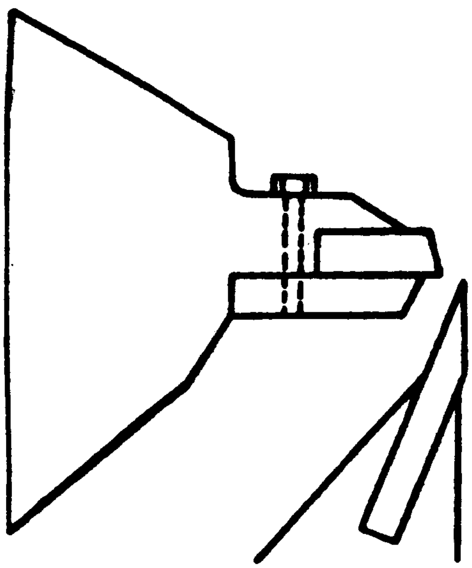

Figure 3. Flat pressure bar.

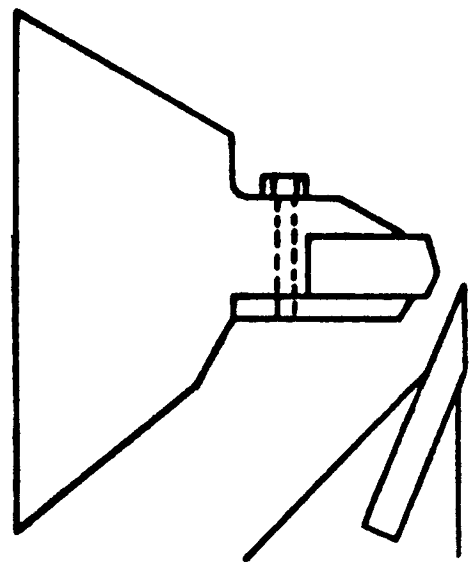

Figure 4. Double surface nose bar.

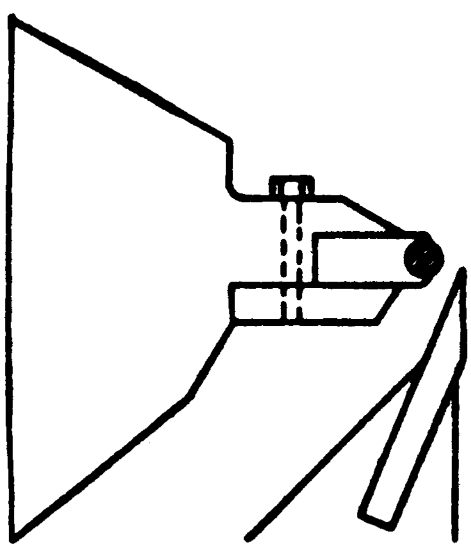

Figure 5. Single roller bar.

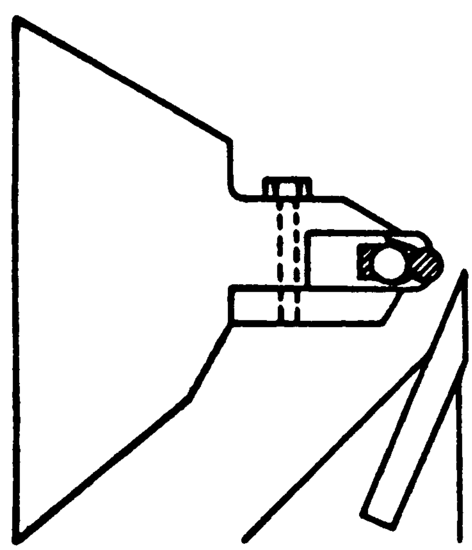

Figure 6. Double roller bar.

the roller bar is rotated by a back up roll that is driven through a gear and synchronized motor assembly. The two bars are made up of dissimilar materials--usually phosphor bronze, silicon bronze or manganese bronze for the roller bar and back up plate and steel for the drive roller.

The wear of a roller bar is so great that it needs to be replaced about every two weeks. In order to reduce wear, two new kinds of roller bars, called floating bar (33, 34) and hydrostatic roller bar (57), are being experimented with. The former aims at keeping the distance between the knife and the bar constant and thus control wear and backlash in the screw adjusting mechanism, while the latter employs the principle of hydrostatic lubrication of the roller bar with a liquid fluid.

Yet another concept of eliminating altogether the direct bar pressure on the veneer is under study in Japan (42, 65, 66). A jet of compressed air of up to 10 kg/cm^2, passing through a slit of around 0.15 mm width, is impinged along the length of the bolt and in the vicinity of the knife tip, at different angles of inclination. It has been found that besides elimination of the wear problem, the quality of the veneer is appreciably improved in terms of reduction of the veneer curl and of the depth and penetration angle of lathe checks. Also, "comparing recommended optimum range to set the nozzle and the conventional fixed rigid nosebar to produce equivalent qualities of veneers, the former would accelerate operation and shorten the time to set knives and pressure sources when the jetted air pressure system is applied in commercial lathes" (67).

In an endeavor to get maximum recovery of veneer, peeling is nowadays done to as low a core diameter as $1\frac{1}{2}$ inches. Peeling to such thin core diameters causes two problems, one of chucking and the other of the deflection of the core due to pressure from the roller bar and knife. Both problems have been overcome by introduction of retractable chucks and back up rolls, respectively. However, of late, a question has arisen as to whether it was economical to go to such small diameters, especially in view of occasional high lumber prices. An answer has been provided in the following equations (28):

$$BEP = \frac{(SP - MC)SF}{FBM} + SC \pm CV$$

where: BEP = Break-even price, \$/M fbm net F.O.B. mill for additional lumber recovered;

SP = Selling price, \$/M sq. ft. net F.O.B. mill for veneer or plywood sacrificed;

MC = Manufacturing cost, \$/M sq. ft. for veneer or plywood;

SF = Sq. ft. of veneer or plywood sacrificed;

FBM = Additional board feet of lumber recovered;

SC = Additional saw milling costs, \$/M fbm for additional lumber recovered;

CV = Difference, \$/M fbm of lumber, in chip value generated.

The area of veneer or plywood sacrificed can be calculated as follows for peeler blocks, 8 ft. in length:

$$SF = \frac{(D^2 - d^2)\pi k}{6t}$$

where: D = Diameter in inches of larger core;

d = Diameter in inches of smaller core;

t = Veneer or plywood thickness in inches;

k = Proportion of veneer in D - d which is normally recovered;

$\pi = 3.1416$

Slicing. There are two types of slicers in use these days. One is the "vertical type" in which the knife is fixed and the bed carrying the flitch moves. In the "horizontal type," the flitch is fixed and the knife is driven across it.

In the vertical type, common in the United States, a properly heated flitch is held to a heavy frame, called the "flitch table," by dogs. On each downward stroke the flitch is drawn against the edge of the knife which is held in rigid alignment with a pressure bar, and a slice of veneer is thus cut off. During the upward motion of the flitch, the knife automatically recedes to avoid interference and then comes back and advances equal to the thickness of the veneer for the next cut. The veneer passes through a slot between the knife and the pressure bar (70).

In the horizontal type, the knife is secured to a box-like frame which moves diagonally across the bed of the machine to which the flitch is fixed. The veneer is produced by a shear cut and emerges between the cutting edge of the knife and a pressure bar which runs immediately ahead of it. At the end of each forward stroke, the knife comes back to its original position and in doing so it operates a rachet which raises the flitch by a distance equal to the thickness of the veneer to be cut (72).

Experiments are underway at the Forest Products Laboratory, Madison, Wisconsin, for producing up to 1-inch thick sliced veneer. These experiments were initiated on predictions of a log shortage calling for most efficient utilization of the available raw material. One method, of course, is thick slicing of wood instead of sawing, thus eliminating kerf and reducing planing and sanding because the slicing process yields a relatively smoother surface. So far the biggest difficulty encountered is that of fracturing, similar to knife checks in veneer. The quality of the thick-sliced wood has also been found to decrease with increasing cutting speeds (56).

Veneer Clipping

The green veneer which comes off the lathe in the shape of a continuous ribbon is cut at the clipper into usable widths. The clipper operation these days is very much automatic and often computer controlled. A computerized clipper control, in principle, substitutes the accuracy, speed and untiring response time of a computer for that of the human operator. The basic components of such a system are (1) an electronic scanning device, (2) a speed measuring device, and (3) a computer which can be programmed to operate the clipper for accurately cutting out defects, such as splits and knots exceeding a predetermined size. An auxiliary device incorporates two laser beams which detect thickness variations for accurate thickness control (9). The scanning device detects defects and actuates the clipper knife accordingly. The clipper knife cuts veneer into "54s," "27s," randoms down to a predetermined width, generally 6 inches, and fish tails. In some outfits, a moisture detecting device is also installed which helps distinguish the sapwood veneer by spraying a dye on it. Some clippers are equipped with automatic moisture detecting devices as well as automatic stackers so that the full width sheets are sorted into super-sap, sap and heart, and stacked automatically.

Veneer Drying

There are three types of dryers, based on airflow pattern classification, viz., longitudinal circulation, cross circulation and jet or impingement dryers. In the longitudinal type, the direction of air flow is along the length of the dryer with or against the direction of the veneer travel. In the cross circulation type, the air flows across the direction of veneer travel and the direction of air flow alternates from one zone to the next. A jet dryer is somewhat similar to a cross circulation dryer in that the air is moved across the dryer but the air flow direction is the same throughout the entire dryer. The air is blown across the top plenum chamber of the dryer, down the supply side and into the jet tubes. From the jet tubes, the air is directed at right angles to the veneer from both sides of the veneer to sweep away moisture at the surface.

The second classification is based on the method of heating, i.e., steam heated coils and direct fired gas. Steam heat has been used for drying veneer from the beginning. Steam coils are located in the plenum chamber at the top of the dryer where recirculated air is heated and also between the lines in the drying space. Both longitudinal and cross circulation dryers have the same system. In jet dryers, however, the heating coils are only in the plenum chamber. Direct fired heating, either oil or gas, has been in vogue only for the last 20 years or so. At this time, there are no oil dryers still in operation. All the original oil dryers have either been dismantled or converted to gas. Both longitudinal and jet dryers can be heated by gas. The burner is located in the plenum chamber above the drying space.

The air is heated as it flows past the burner and thus the air circulating in a direct fired dryer contains all the products of combustion (30).

Veneer drying is a crucial operation having direct bearing on the ultimate quality of the plywood panel. Both overdrying and underdrying have deleterious effects on bond quality in hot pressing. Variability of moisture content within the same piece further complicates the problems. If the veneer is too dry or too hot, the water leaves the glue line too quickly resulting in a "dried out" glue line. On the other hand, if the moisture content in the veneer is very high and the plywood is pressed too soon, the resulting glue line will be "under cured" or the panel will "blow" or "blister". The total moisture contributed by the veneer and the glue line should not exceed 14 percent. In case it does, it becomes almost impossible to get a proper phenolic glue bond. At 235°F, in a pure water-vapor atmosphere (superheated steam), the EMC of wood is 6 percent and therefore the veneer coming out of a dryer having such conditions will have a uniform moisture content of 6 percent. The veneer, however, will take much longer to dry at such a low temperature. Instead of having the aforementioned conditions in the entire length of the dryer, it has been suggested that a humidity chamber operating at temperatures in the range from 225 to 260°F be added as a section at the end of the last zone of a conventional dryer. Such a system will deliver veneer with moisture content varying from 9 to 3 percent (22, 23).

Gaseous emissions from dryers basically consist of warm air, water vapor, a small amount of solid particulate matter, and hydrocarbons. A component of the hydrocarbons condenses after coming in contact with ambient air and is considered responsible for a bluish haze visible from some veneer dryers. This component was also found to be nonreactive in the context of photochemical smog reaction. The volatile component of the emitted hydrocarbons, considered moderately reactive, is similar to the one emitted naturally by growing vegetation. Neither type is emitted in significant quantities, nor is there evidence that veneer dryer emissions are harmful to humans, animals or plants (20). The opinions, however, differ on the subject. A project under study at Washington State University reveals that the natural hydrocarbon emissions from natural vegetation are highly reactive in the presence of air, nitrogen oxides and simulated sunlight (58, 59).

Veneer Jointing, Splicing, Stringing and Repairing

The jointing of veneer means production of a square, straight edge on a piece of veneer so that two sheets of veneer can be taped or spliced together. Two types of jointers--one with a traveling head and the other with fixed head--are in use. In the traveling-head type, a multiple knife cutter head passes along the edges of the veneer sheets held under a clamp taking a light cut and producing a smooth, square straight edge. In some machines there are two cutter heads, one taking a heavy roughing cut and the other a light finishing cut. In the fixed cutter-head type, two cutter heads are in operation simultaneously. Two feed belts running in opposite directions carry the veneer bundles over cutter heads. An operator feeds the bundle of veneers from one end and as it passes over the cutter head, one edge gets smoothed. The operator at the other end turns the bundle over, shakes it, and feeds back via the other belt and thus the second side gets straightened. If the veneer being jointed is intended to be spliced later on, gluing of edges is accomplished along with jointing with the help of glue applicator rolls mounted behind each cutter head.

Splicing, that is gluing the veneers edgewise, is accomplished with or without the help of a tape. In tape splicing, two pieces of veneer to be spliced are fed through a paired series of live rolls, the shafts of which are angled in such a manner that the two pieces of veneer are butted together as they pass across the table. Above the table is suspended a roll of gummed tape which passes over a moistening device and under the rolls to the joint. A heated roll sets and dries the tape while it is pressed firmly against the veneers. Tapeless splicers are similar in construction except that the veneer sheets with glue applied to the edges are carried over an electrically heated strip which cures the glue. This method has an advantage over the tape machines inasmuch as there is no tape to sand off the faces of the panels after their manufacture (53, 72).

In some softwood plants, like the U.S. Plywood Plant at Bonner, Montana, one piece cores are prepared by stringing the random width strips of veneer. The veneer from the dryers is automatically fed into the string machine where veneer strips get crowded together edge to edge and a hot-melt string in four strands on either side is applied. The 8-ft. wide continuous sheet thus formed is cut in the middle by a circular saw and then clipped in nominal 8-ft. lengths and stacked automatically.

The grading rules of the softwood plywood industry permit repairing of defects by the application of patches within certain limits. So, for improving the appearance of the veneer and consequently the grade, the defects are mechanically cut out and clean wood patches are simultaneously inserted in their place. The shapes of patches vary from "dog bone" to circular, elliptical or lenticular. But the most commonly used shape in the west coast softwood plywood industry is the lens-shaped boat patch (26).

Assembling

The veneer sheets, after going through the operations hitherto mentioned, are now ready to be glued together, laid up and pressed to form plywood panels. For glue spreading, the most commonly used machines are the soft rubber-roller spreaders. This machine consists of two power driven grooved rubber-covered spreader rolls and a steel doctor roll attached to each spreader roll. The quantity of glue spread on the veneer is controlled by adjusting the pressure applied by the doctor roll to the spreader roll. A crew of four persons works on the machine. One of them is the "core feeder" who feeds the core through the spreader rolls. The "core layer," on the other side of the machine, collects the glued core pieces and lays them on the backs and centers already laid on the table by the two "sheet turners." The operation of laying up a 5-ply assembly, for example, is as follows: The two sheet turners first of all place the caul in front of the core layer and upon the caul they place the veneer sheet to form the back of the panel. When this is accomplished, the core feeder starts feeding the cross band pieces through the spreader rolls. The core layer collects the glued pieces as they come off the spreader and lays them on the back already in place. The cross band having been laid, the sheet turners bring in the center and place it on the cross band. The core feeder then starts feeding the second cross band pieces which are collected and placed in position by the core layer. Lastly, the sheet turners together bring two sheets--one for face of the assembly in making and the second for the back of the next panel--and place them on the last layer of cross band in position. In this fashion, assemblies of five plys are placed one above the other to form a press load (53, 72). In 5-ply, good one side, sanded panels, laying of veneers starts with a face instead. In this manner, dropping of knots from grade C or D backs on the face veneer and causing indents thereon is avoided.

Many plywood plants have spray systems installed for glue spreading. There are two different processes of spraying, viz., airless spraying and conventional spraying. In the airless spraying system, a single spray head supplies adhesive to the top surface of veneer passing beneath it. The head is located about 5 ft. from the veneer and it applies adhesive in a fan like pattern of droplets. In airless systems, the pump pressure breaks up the droplets and overspray is minimized. In the conventional spray system, the liquid adhesive is mixed with air under pressure to atomize it inside the nozzle of a spray head. The system applies adhesives in droplets instead of an even coating only on one side and a piece of veneer coated in such a fashion still shows much bare wood (41).

Curtain coating is the most recently developed technique of glue spreading. The machine is called a "glue pressure coater" and is sketched in Figure 7. To operate the machine, first of all the orifice, or the knife opening at the bottom of the head is closed and the air bleed valve at the top of the head is opened. The positive displacement pump is started, which pumps the glue to the head. There are sight glasses through which one can see the glue rising in the head. During the period the glue is rising in the head, the air bleed valve is kept open. Once the head is three-fourths filled, the air bleed valve is closed, trapping the air in the head. Simultaneously, the orifice is opened and the glue starts squirting through the knife opening ready to coat the sheets of veneer traveling beneath it (10, 41, 50). This machine provides a very fast glue spreading device and is generally used in automatic plywood lay-up in conjunction with a string machine which supplies the single piece cores.

Automatic Plywood Lay-up

An automatic lay-up system cuts down substantially on costs. it saves on labor and wastage and speeds up the lay-up work. It includes the following sub-systems: (1) system for economical formation of one-piece core sheets; (2) automatic adhesive spreading system (3) automatic veneer feeding and conveying system; (4) automatic veneer stacking system with or without adhesive preapplied; (5) veneer thickness gauging system; and (6) control system with sufficient versatility to program the wide variety of lay-up construction required by a broad product line.

One system works like this: One man feeds the individual pieces of veneer into the "tenderizing" machine. Tenderizing is accomplished with a machine equipped with rotary knives that cut slits parallel to

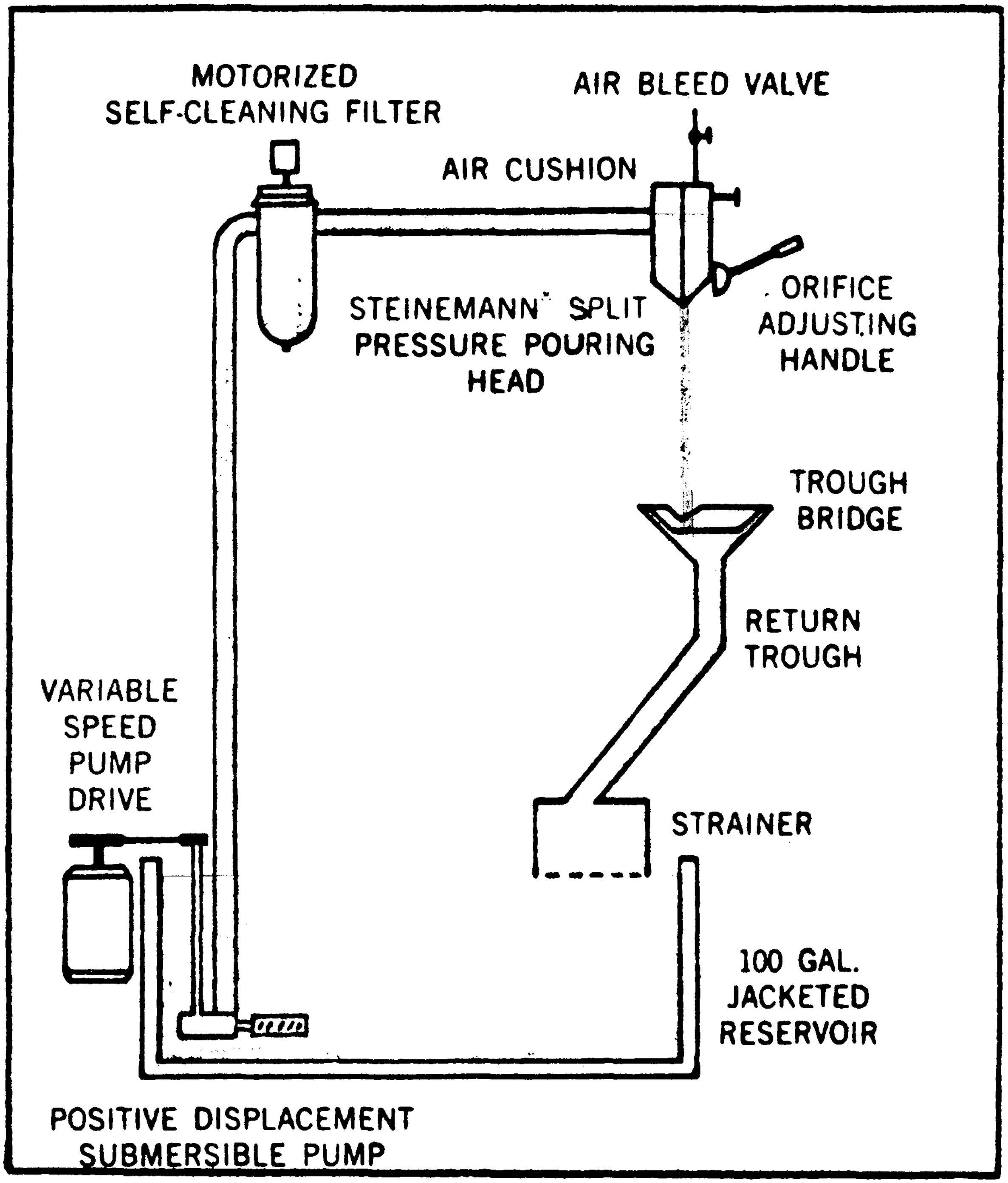

Figure 7. Glue pressure curtain coater.

the grain and spread approximately 1 inch apart on both sides of the veneer. The slits are so positioned that the cuts on one side of the veneer are half way between the cuts on the opposite side. With proper depth of cuts, uniformly flat sheets can be produced. After tenderizing, the veneer sheets, via conveyor belts, arrive at a string machine. The operator at the string machine discards the defective pieces and minotors the rest of the operation, consisting of one-piece core formation and automatic stacking, on a closed TV circuit. The lay-up line, consisting of five vacuum feeder heads, a veneer cleaning station, one curtain coater and a veneer stacking station, is also controlled by only one man. The line can handle 6250 sheets of veneer or 80,000 sq. ft. of double glue line per shift on 5-ply construction (25).

This automated system for plywood lay-up can be used for any kind of softwood plywood and it can utilize all grades of veneer. Its versatility allows for quick switch from one product to another. The system is economical and it also turns out better quality products. There are no core gaps or overlaps. No labor or space is needed for glue mixing because the curtain coater uses resin directly as supplied by the manufacturer. The lay-up crew is reduced from the conventional four to two. There are also savings on wood with corresponding savings on glue because the core material is clipped to exact required sizes (25).

Pressing

Pre-pressing. Pre-pressing can be defined as "compression or consolidation of the panel assembly to near its final thickness without obtaining the final polymerization or cured state of glue line" (18). Its advantages are: (1) reduction in reject panels--curling and folding of face plys during hot press loading is eliminated; (2) since the assembly is consolidated to near final thickness, it can be loaded faster into the hot press for final curing; (3) veneers remain in intimate contact for longer periods of time and hence better adhesion; (4) threat of precure is reduced and dry outs minimized; and (5) improved hot press design. The disadvantages are: (1) inability to correct misaligned panels, and (2) possible higher adhesive costs (18).

Cold pressing. Cold or hot pressing depends on the kind of adhesive used. If pressing can be accomplished at room temperatures, it is cold pressing. There are two general types of cold presses, viz., hand-screw and power presses. The former are used in small shops where production is limited. Power presses are either hydraulic type where one or more hydraulically operated rams lift the lower platen and press, or power-screw presses where threaded strain rods carry upper platen to open or close the unit and to apply or release the pressure, as may be required. Two cold pressing methods are in extensive use. One method consists of applying the pressure with hydraulic press and then keeping the panels under pressure with retaining clamps until the next day. The other method, used only with certain types of glues, requires the panels to be pressed only for a few minutes until the glue takes an initial set. The panels are then carefully removed from press and stored undisturbed at the necessary temperature. Cold pressing is generally practiced with starch, casein, animal, most soybean adhesives and with some urea type resins. Pressures generally range from 100 to 200 psi depending upon the kind of wood and types and consistency of the adhesive used (53, 68, 72).

Hot pressing. The modern hot pressing equipment consists of a framework, at both loading and discharging ends of the press, which carries a series of platforms lying level with the platens of the press when in operation. The platforms at the loading side are filled with pre-pressed or fresh assemblies, as the case may be. The press is opened and reloaded with a mechanical device which pushes the assemblies into the press openings. As they are forced in, the pressed panels are ejected on to the discharge side platforms. Presses with as many as 40 "daylights," or openings, are in use these days.

Two-step pressing is being used increasingly to increase product volume by the west coast plywood plants in the United States. The press is closed, and initial relatively high pressure of up to 200 psi is applied on the wood at a temperature varying from 230° to 315°F, depending upon the type of adhesive and thickness of panel. This pressure is held for one or two minutes and then reduced to 100-130 psi for the final curing of the glue lines. The initial high pressure is used to make a good contact on all glue lines. The final curing of the glue lines is done at lower pressures (10, 72).

Finishing

Panel sizing. The pressed panels coming out of the presses are slightly oversized. In order to reduce accurately the oversize panels to exact size and rectangular squareness, panels are first passed through the "skinner" saws where both long edges are cut simultaneously.

The panels next pass through the trim saws which simultaneously remove the end edges and determine the length. The panel saws are carbide tipped saws which produce thinner kerf and cause less splintering (26).

Panel grading and sanding. Some panel grades such as sheathing are sold and used in their unsanded state. Such panels are, therefore, graded at the sawing operation before stacking. Generally, the grade-line conveyor belts transfer single panels from the trim saws to the grader where they are automatically turned over so that he may see both sides and the edges. After grading, he activates the proper switch to drop the panel in the specified bin (26).

For sanding, mainly two types of machines are used, drum sanders and wide belt sanders. Drum sanders usually consist of eight drums, 48 inches to 60 inches wide and about 11 inches in diameter, double decked with four upper and four lower drums. The first pair of drums on the infeed end has coarse sand paper wrapped around them as compared with the succeeding pairs, which are progressively more fine in grit. Metal feed rolls, located between drums, hold the panel in line and transfer it through the machine, as shown in Figure 8.

The wide belt sanders come in various combinations of one, two, four or six belts and operate on the same principle as drum sanders, with the only difference that the sandpaper here is tension-held and driven by several drums. For touch sanding, machines with only one or two belts are used. A wide belt sander is shown in Figure 9.

Panel patching. Some panels reveal defects after sanding. These defects are removed and replaced with patches of sound wood or

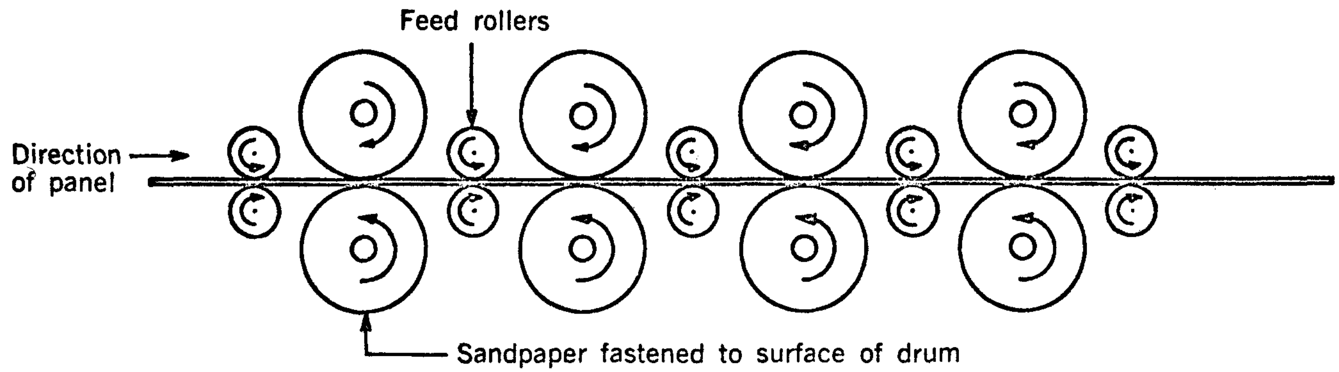

Figure 8. Drum sander.

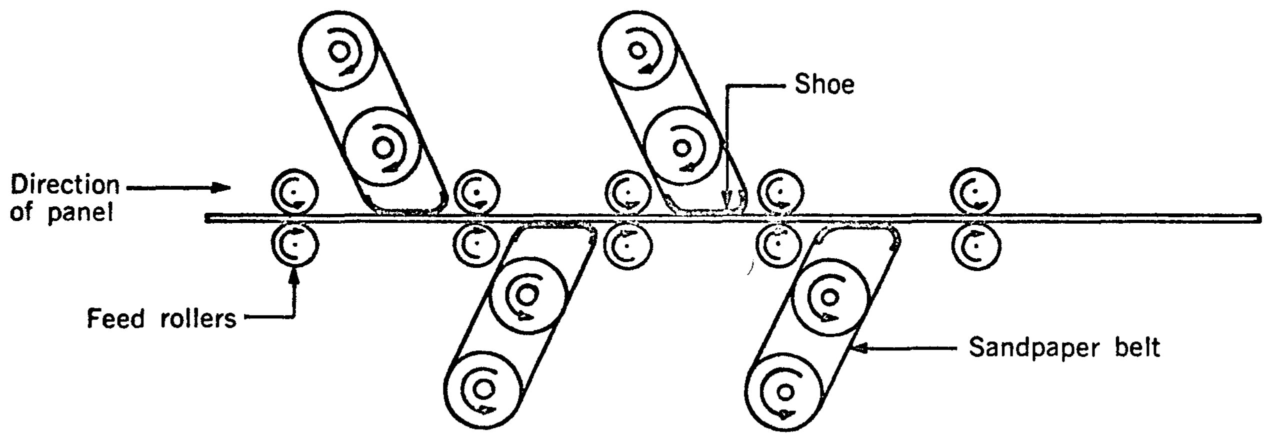

Figure 9. Wide belt sander.

filler. Panel patches are of two types, shims or router patches. Shims are narrow long strips of veneer not over 3/16 inch wide. These are used to repair slit-like defects. The defect is cut out to a shim-sized opening with a small power saw and then the shim is glued in and pressed. Router patches are long narrow pieces with rounded ends and straight beveled sides, called "Davis patches". A power router removes the defective wood and then the pre-cut patch, with adhesive applied to its bottom, is pressed into place. Panel patches are purposely set slightly above the panel surface so that subsequent resanding will insure smooth continuous panel surface. Usually, only the best faces, generally C-plug and better, are patched (26).

CHAPTER III

PRODUCT INNOVATIONS

Overlays

High density overlays. This type of overlay is manufactured by impregnating a continuous cellulose sheet, primarily paper, with a suitable synthetic resin of the phenol formaldehyde type. Special fillers are often included in the paper during manufacture; for instance, titanium dioxide is added to improve color and opacity of the high density overlay after pressing. According to U.S. Product Standard PS 1-66, "the surfacing on the finished product shall be hard, smooth and of such character that further finishing by paint or varnish is not necessary." The total resin-impregnated materials for each face shall not be less than 0.012 inch thick before pressing and shall weigh not less than 60 lbs. per 1000 sq. ft. including both resin and fiber. The cellulose fiber sheet or sheets will contain not less than 45 percent resin solids based on a volatile-free weight of fiber and resin and will be self-bonding to the plywood surface under heat and pressure. The normal method of application to a plywood substrate is to bond the overlay to the substrate at the same time the veneers are being bonded. This is termed as a "one-step" overlay application. In a "two-step" operation, the plywood panel is prepared first and the overlay added afterwards (3, 15, 62).

The high density overlaid panels have as their characteristics greater abrasion and scratch resistance, resistance to chemical action and very low water absorption. Phenol formaldehyde overlay in the form Tego 29/A film has given excellent protection against weathering and high temperature treatment. Maximum use of high density overlaid panels is found as concrete form panels. Approximately 60 percent of production goes into concrete form. Out of the remaining 40 percent, 30 percent is used in the construction of highway signs and the balance of 10 percent goes into various other end uses (15, 19, 52, 62).

Medium density overlays. The medium density overlays can be manufactured in two distinct ways. One is similar to that used in high density overlays, i.e., saturation of a continuous paper web with a synthetic resin solution. The other method involves the addition of a synthetic resin to the paper pulp just prior to the paper formation on the Fourdrinier wire. The pH of the pulp is adjusted accurately to effect precipitation of the synthetic resin molecules on the cellulose fibers. After paper formation, the product is calendered and special additives added, if desired. According to the U.S. product Standard PS 1-66, "the resin-treated facing on the finished products shall present a smooth, uniform surface intended for high quality paint finishes." The cellulose-fiber sheet shall contain not less than 17 percent resin solids for a beater-loaded sheet, or 22 percent for an impregnated sheet, both based on the volatile free weight of resin and fiber, exclusive of glue line. The resin, of course, will be a thermosetting type, i.e., a phenol or melamine type. The resin treated material shall weigh not less than 58 lbs. per 1000 sq. ft. of single surface including both resin and fiber but exclusive of glue line. After application, the material shall measure not less than 0.012 inch thick.

The material is available in rolls or sheets for subsequent bonding to the surface of various wood substrates. As compared with high density overlay, medium density overlay has low synthetic resin content and is made up of heavy paper and, therefore, requires an additional adhesive for bonding. Bonding can be achieved by an integral phenolic resin glue line applied to one surface or by the use of a separate dry phenolic film adhesive under heat and pressure. Like high density overlay, both "one-step" and "two-step" methods are used. Medium density overlays are designed for painting and, therefore, many mills turn out pre-primed products. There is more demand for complete pre-finished panels and the mills are making every endeavor to satisfy this consumer demand. Plywood, in its ordinary form, has an undesirable characteristic of checking and cracking in exterior environment. Medium density overlay eliminates this shortcoming. Therefore, maximum use of medium density overlaid plywood--up to 80 percent of the total production--is found in exterior residential siding and highway signs. Lower grade face veneers can be used in making medium density overlaid panels as most of the defects get masked under the overlay (3, 15, 52, 62).

Special overlays. There is a wide variety of special kinds of overlays being produced by the industry. An acrylic surfaced paper in various colors, bonded to plywood with various combinations of overlays and glue lines, provides a good, colored and weather resistant surface for highway signs. One special overlay, using fiber glass application on both sides of exterior grade sheathing plywood, is used to produce concrete form panels of unusual seamless width and with a structurally sound rating. This enables vast expanses of smooth and unscarred concrete. Fiber glass-reinforced plastic (FRP) plywood is an engineered product being extensively used in truck and trailer bodies and in the shipping containers industry also. The material of this overlay consists of (1) a fiber glass woven roving saturated with resin cured under heat and pressure, (2) glass fiber mats saturated with resin, partially cured with final cure and bonding to plywood substrate in a hot press under heat and pressure, or (3) chopped glass strand and resin sprayed on together and process cured under ambient conditions or with heat. There are other materials going under the name of "decorative overlays." Solid paper, colored and printed with random design or wood grain pattern, is impregnated and dried just like high density overlays. The resins used are phenolic, melamine or polyester types. These overlays can be applied to substrates with conventional low pressure hot press equipment with, for example, a cycle of 10 minutes at 290°F and 200 psi pressure. These are being widely used in furniture and cabinet making where high impact, abrasion and chemical resistance is not required. Metal overlaid plywood is in high production, too. Aluminum is the most widely used metal for siding panels and small quantities of stainless-steel overlaid plywood panels are used in the construction of truck sides and doors. Lead containing plywood is in the making for industry making use of radio-active material and X-Rays. Chlorosulfonated polyethylene, a synthetic polymer, available in the shape of calendered films, can be bonded with special modified phenolic film glues in conventional hot presses. Polyvinyl flouride films, sold under the trade name of "Tedler," are being extensively used for siding on a 15-year paint free guarantee. These overlays may be hot-press bonded with dry phenolic film glue or cold pressed using acid-curing phenolic resin systems. Vegetable parchment when bonded to plywood with a dry phenolic film glue provides good paintability for interior applications. Plywood glued with powdered glue using green veneers and topped with a phenolic type overlay is being commercially made. The advantage is that the drying step is eliminated resulting in cost savings. A granular wood fiber overlay is being applied to the surface of boards and pressed in one step along with the curing of the inner glue lines of the plywood panels. A fibrous-type mat overlay is also in the process of commercialization (5, 15, 62, 64).

Coatings

Coatings can be defined as "the surfacing of plywood with other materials that can transform its appearance and durability, adding still new characteristics to plywood's capabilities for efficient space enclosure." It has been felt that plywood must provide superior maintenance-free durable surfaces in order to compete with other materials. Intensive research has resulted in the discovery of many materials used for coating and these materials, many in number, have moved plywood up to the status of a glamour building product. Coatings are available in factory finished form on plywood and many can also be applied in the field. The American Plywood Association has developed a program for evaluating promising new coatings. A material which successfully passes all tests becomes a "qualified coating" and is awarded a certificate of qualification. This certificate can be used for promotional purposes. Some selected coatings are described below:

Epoxy-based coatings. The plywood in finished form has crushed stone aggregate bonded to the panels with an epoxy resin adhesive. A wide choice of aggregate material, textures and colors is available. The very well known and one of the first qualified coatings is Hycon Sanspray. It is used for exterior siding and roof construction. The product is sold on maintenance free guarantee, requiring no painting or protective coating. The product Hycon Sanspray consists of Hycon 75--a 100 percent reactive resin, zero pot life, solvent free epoxy coating--and Sanspray, a process with which aggregate of stones ranging in size from regular 1/4 inch to 3/4 inch are used. Shadowline, another pattern of Sanspray, features regular aggregate with grooves 3/8 inch deep and 1/4 inch wide, spaced 8 inches apart. Sanspray is a factory applied coating.

Coatings for roofs. A field applied liquid system composed of neoprene prime coats and hypalon top coats is available under various trade names. The material is available in a wide range of colors. These are qualified coatings for roofs. Sheet Hypalon, factory bonded to plywood with waterproof adhesives and surface textured is also available in several colors. Other qualified coatings for roofing available are: (1) a field or factory applied roofing membrane that combines asbestos fiber in sheet form overlaid with a pigmented polyvinyl flouride film, and (2) Cocoon #501, a factory or field applied liquid vinyl produced in a variety of colors.

Coatings for exterior plywood. In addition to the Sanspray and Hypalon types which, respectively, are epoxy resin and chlorosulfonated polyethylene, there are a number of other coatings which are used on exterior plywood. These include vinyl-urethane self-priming coating, applied either in factory or field at ambient temperatures down to 40°F, and a polyvinyl flouride film known by the trade name of Tedlar.

Coatings for medium density overlaid plywood. There is a wide variety of chemicals in several combinations which are used as coatings on medium density overlaid plywood. These include an oxirane-polyester, vinyl urethane and polyurethane formulations. These are available in a wide range of colors and are factory and/or field applied.

Coatings for pedestrian decks. There are two qualified coatings. One is a field applied system composed of liquid neoprene-Hypalon plus aggregate. It is available in a wide range of colors. The other goes under the trade name of Travelon, which is a field applied system composed of a Travelon elastic base sheet overlaid with Travelon tile. It is also available in various colors.

Hot melts. This is a cheap type of coating which can help in filling knot-holes and cracks in low-grade plywood. These are thermoplastic blends, usually containing petroleum wax, polymers, resins and minor amounts of other compounds such as anti-toxidants and slip controlling agents. It is solid at room temperature and is applied as a hot liquid and used principally as a coating or adhesive. Lack of high temperature resistance restricts its use. It is good for temperatures below 140°F. Low cost, low fire hazard during application, rapid setting and ability to fill larger defects are its good points (6, 7, 8, 14, 15, 60, 64).

Laminates

High-pressure plastic laminates. Such a laminate consists of a number of papers impregnated with resin which are pressed together under high pressure and at a high temperature into a slab. The top paper, usually melamine, is transparent and impervious to water, while the second provides the decorative pattern. Subsequent plain papers are added to make up the laminate thickness, the bottom paper in the slab also being waterproof. The thickness ranges from 0.8 to 1.5 mm. For bonding these laminates to various substrates, such as plywood and chipboard, different kinds of adhesives are used for serving different purposes. For weatherproof and boil-proof bond, resorcinol formaldehyde adhesive is used while for low volume interior use work polyvinyl acetate adhesive, a thermoplastic glue, is quite suitable. Hot melt adhesives and neoprene rubber impact adhesives are also used where technical standards are not too demanding.

Polyvinyl chloride films. These are characterized by toughness, resistance to abrasion, chemicals and weather, and to acids and alkalies, easy color adaptability and excellent embossing. Rough surfaces are camouflaged and substrate is protected. They are available in a wide range of plain colors, wood grains and metallic finishes and are showing promise as an exterior finish and in paneling.

Polyvinyl chloride films can now be used to laminate three dimensional shapes in furniture and cabinet making. The process essentially consists of spraying adhesive on to the part to be laminated, letting the adhesive reach a tacky state, placing the part into a chamber, spreading the PVC film over the chamber, surface heating the PVC film, in place, up to 250°F and drawing a vacuum. The atmospheric pressure forces the heated film into the shaped part. The vacuum is maintained until the laminated part cools. At this point the adhesive has attained 10-20 percent of its ultimate strength. The part is removed and complete cure develops during the next several days.

Vinyl lamination in simulated wood grains or design patterns is fast becoming a big seller. Its consumption in the hardwood plywood paneling market rose from 4 percent in 1968 to 7 percent in 1970. Other uses are as door skins, exterior surfaces of kitchen cabinets, cabinet and drawer faces, and radio, stereo and TV cabinets.

Other laminates. In the construction of motor homes, sheets of dissimilar material and thickness bonded into a panel are being widely used. The outer side of the panel is aluminum for protection from weathering, the middle layer consists of styrofoam for thermal insulation and sound-proofing, and plywood on the inside for decor and strength (6, 11, 21, 39, 43, 49, 52).

Printed Plywoods

Printed and embossed plywoods are also becoming popular every day. In 1969, in the hardwood paneling market, printed and embossed plywood had a share of 26 percent which rose to 32 percent in 1970 and

47.6 percent in 1972. A new printing technique called WALPAMUR transfer process has been developed. In this process the grain print is applied to a backing film and sold in this form. The panels to be treated are coated with a uniform film of a colored adhesive which also acts as the ground color. The transfer is applied to the panel by pressing and cut to size. The backing film can then be peeled off leaving the print on the panel. Finally, a clear finish is applied to the transfer. This method is very suitable for comparatively small production.

The other printing method is offset gravure process. In the U.S., Lauan and Okoume, imported plywoods, are used for printing and most of the printed material goes into the construction of mobile homes. The grains generally simulated are that of teak, cherry, mahogany, walnut and oak (39, 40, 63, 72).

Pre-finished Plywood

The discriminating person would always select natural wood surfaces, whatever the cost. A prefinish treatment is given to decorative veneer plywoods which adds durability and ease of maintenance to the natural beauty of the wood. The process is like this: First of all, panels are stained to make sapwood harmonize with heartwood. Then a vinyl sealer is applied to the face veneer as well as to the back, to prevent moisture absorption. The sealer is set by passing the panel through an infra-red oven at 125°F. After sanding, a resin filler is applied, which is also set by repassing through the oven. A first top coat is applied by spray or roller and also set in an oven, and then a final coat of thermosetting epoxy or synthetic polymer, polyester or nitro-cellulose lacquer is applied and cured under infra-red or ultraviolet lamps at 150° to 195°F. After cooling, the surface may be burnished to give a high polish or sanded to give a matte surface.

In the hardwood paneling market, prefinished panels still have the largest share, but in the two years from 1968 to 1970, their share has dwindled from 70 percent to 61 percent--and further in 1972 to 40 percent, giving way to printed, embossed and laminated plywood (39, 40, 72).

Textured Plywood

"The American public has fully evidenced the fact that it likes the rustic look of textured plywood, both outdoors and indoors" (14). It is said that textures help fade out surface blemishes while coatings cover them entirely. Textured plywood is mainly used for siding and is available in a large variety of textures, some of which are listed below:

Texture One-eleven. Deep grooves 1/4 inch deep and 3/8 inch wide, 4 inches or 2 inches o.c. are cut into the face for sharp shadow lines.

Texture reverse board and batten. Deep, wide grooves are cut into brushed, rough sawn, coarse sawed or natural textured surfaces which provide deep, sharp shadow lines. Grooves are 1/4 inch deep, 1½ inches wide, spaced 12 inches o.c.

Pin-striped surface. Fine grooves are cut into surface to provide a distinctive striped effect. This grooving reduces surface checking and provides additional durability. Grooves are 1/4 inch o.c., 1/32 inch wide and 0.08 inch deep.

<u>Plank texture</u>. Rough sawn sections create a vertical pattern with grooves every 8 inches.

<u>Kerfed surface</u>. Light touch sanded or rough sawn surface with narrow square cut grooves to provide a distinctive effect. Grooves are 1/8 inch wide, 1/16 inch deep, 4 inches o.c.

<u>Rough sawn</u>. Saw textured surfaces are designed to combine the charm of natural wood with the ease of installation provided by large panels.

<u>Striated</u>. Random width, closely spaced grooves form vertical patterns on surface. The striations conceal nail heads, checking and grain raise and eliminate unsightly joints.

<u>Corrugated surface</u>. Closely spaced corrugations provide distinctive shadow line effect of broad uniform grooving.

<u>Treated Plywood</u>

These plywoods are treated with fire retardants for making them fire proof or with preservatives to save them from decay and mold attack. The treatment is done through pressure impregnation. In the field of fire proofing several combinations of water-borne salts have been developed, viz., ammonium phosphates, and sulphates, borates, zinc chlorides, etc. A clear, water base, fire retardant sealer system based upon amino resins and phosphoric acid has also been examined and found satisfactory but its application on mass scale in the plant has yet to be worked out (29, 54).

When plywood is used in damp conditions, it has to be protected against decay. Preservatives used to protect plywood against decay include oil-borne creosote and pentachlorophenol and various water-borne salt combinations such as chromated zinc chloride, sodium arsenate, copper naphthenate, flourides, and so on. The plywood treated with water-borne chemicals remains paintable (54).

Scarf-jointed Plywood

For preparing panels of larger sizes than the normal, small panels have to be jointed together. Experience has shown that a straight scarf properly made is the most speedy and reliable method of jointing together two pieces of plywood where retention of maximum strength is required without increasing the thickness at the joint or adding appreciably to its weight. The operation demands accurate workmanship. The adhesive has to be a water-proof synthetic resin adhesive. The angle of the cut should be set to give a sloped joint twelve to fifteen times the thickness of the plywood with a minimum of one inch. A blunt edge to the scarf should be ensured, as irregular feathered edges may cause patchy adhesion (72). The joint ultimately should come up to the standards prescribed in the U.S. Product Standard PS 1-66 (3).

ISOS Plywood

A normal plywood panel has the grain direction of the face plys oriented parallel to the long dimension of the sheet. Contrary to this, the ISOS plywood is made with grain direction of the face plys perpendicular to the panel length. This type of plywood has particular advantage in sheathing applications, especially for roof sheathing and sub-flooring. The advantages can be enumerated as (1) greater use of 4-foot logs for face veneers; (2) ISOS plywood panels can be laid with long dimensions of the panel parallel to the framing members, thus giving maximum floor or roof stiffness without need for blocking between framing members; (3) all joints in roof or floor would be made over framing members (no blocking required) and, therefore, have no effect on deflection or strength of the sheathing or sub-flooring; (4) no blocking of plywood edges or special clips would be necessary, thus saving both time and material in construction; (5) since the plywood sub-floor would have no joints, it would present a clean and usable appearance for the ceiling of a basement recreation room; (6) face plys could be made to provide joint-free panels for the full roof or floor span, thus giving greater stiffness through improved T-beam action of the system; and (7) application of plywood in large sheets would reduce labor costs (48).

Molded Plywood

There are three methods in use for preparing shaped and molded plywood:

1. By using shaped male and female molds. The molds may be of wood, metal or concrete. The glued veneers are assembled on the female form, there being a layer of paper between the outer veneers and the caul, and then the male mold is positioned and pressure applied.

2. Vacuum process. The equipment consists of a rubber bag, the walls of which are about 1/8 inch thick, sealed by a quick acting device, which clamps the two opposite walls tightly together near the open end; a vacuum pump; a baseboard to allow free passage of air, which lies, inside the bag, resting on the lower wall; a carrier, which after being entered at the open end of the bag slides the work into position upon the baseboard. The core stock is glued up in the usual way and the veneers assembled on a shaped form and held in position by a few tacks. The assembly is placed on the carrier and slid into the center of the bag which is then sealed and the pump set in action. As the vacuum is affected, the upper wall gradually conforms to the contour of the mold.

3. Autoclaves. The assembly of veneers properly glued and stapled is fitted on the working mold. The mold is placed on a carrier, covered with cellophane, placed in a rubber bag and vacuum applied. The bag after sometime fits snugly on the mold. The carrier is then fitted into autoclave and the door closed. Under steam pressure, the assembly is hot pressed (72).

Densified Wood Laminates

Densified woods are marketed under a great variety of names. Some of the names more commonly in use are "improved wood," "compreg," and "impreg." "Improved wood" is the product of a combination of veneers interleaved with a synthetic resin glue film. After assembly of veneers and glue film into a pack of specified weight, this is placed in a press. Heat and pressure are then applied. "Compreg" is made by impregnating thin sheets of veneer with a water soluble resin forming solution. After impregnation, the sheets are laid up and hot pressed under high pressure. "Impreg" is made by first drying the resin impregnated veneers and letting the resin cure for some time and then laying up and hot pressing them with a resin adhesive at normal bonding pressures. Large quantities of improved wood are used for jigs, press tools and dies. Compreg is used for bar tops, card tables and specialty flooring. It is also used as lift rods for high tension oil circuit breakers, arc control pots, and at a wide variety of places in transformers. In the engineering industry, improved wood is used for gear wheels, pulleys, etc. In sporting goods, it is used for skis, hockey sticks and golf club heads (53, 72).

Veneer and Plywood Combinations

There are many products which are combinations of paper, veneer, plywood or other non-wood products. To count a few, there is a combination of kraft paper which is strong across the grain and veneer. The paper is used as core between veneers and the product is used in packing cases, mirror backs, etc. Papreg and Kimpreg are combinations of phenolic-impregnated paper and veneer or plywood. Veneer being the core, phenolic paper is used as face and back to give a 3-ply assembly used for drawer bottoms and dustproof boards. A combination of veneer and asbestos board having a phenol formaldehyde bond is used for heat protection in radiator enclosures, covering hot air ducts, boat and ship partitions, etc. Flexwood is a combination of cloth and veneer. A thin veneer is laminated under heat and pressure to a coarse cotton fabric and the product is then processed in a flexing machine. The result is a flexible material with a wooden surface and it is used as wallpaper. Woven wood laminates are prepared by coating and impregnating veneer with resin varnishes, cutting into strips and weaving it into sheets and then bonding it with some stiffening material under heat and pressure. The resulting material has a glass-smooth surface which is hard and moisture resistant and is used for table tops and decorating purposes (53).

Press-Lam or Laminated-Veneer Lumber (LVL)

This is a product which is still in its experimental stage and is essentially not a plywood, in that it has all plys laminated in one direction. Press-Lam is primarily intended for elements in which strength and stiffness in one direction are of paramount importance and dimensional stability is of secondary importance. It might be used for something as small as 2 x 3 inches to something as large as a beam. A continuous integrated process is envisaged in which thicker than ordinary veneer is rotary cut, dried quickly in a press dryer and then glued into specific components. The heat remaining in the veneer after drying is utilized in speedy setting of the adhesive, thus reducing the time from the green log to the product to less than half an hour. The experimental production has revealed that the yield of dry product from 12-18 inch diameter logs (rotary cut to 6.5 inch cores) was on the average 60 percent. Press-Lam has potential for use in the housing market and the Forest Products Laboratory is now engaged in examining the processing flexibility of Press-Lam, means of reducing raw material and processing costs and developing design criteria and process quality control procedures (61).

The advantages of Press-Lam are listed as follows:

1. The products can be produced quickly and therefore no large inventories.

2. Defects are dispersed during laminating. So material performance and reliability are improved.

3. A maximum yield of clear, high strength wood from the outside of the log goes into the product.

4. Thick veneer going into the product can be obtained from logs as short as 4 feet and peelable culls.

5. Press-Lam can be produced to any continuous length.

6. Small lathe checks appear in each ply of Press-Lam; through them it is possible to treat the material uniformly with preservatives or fire-retardant chemicals (61).

In Canada, the same product has been called LVL or Laminated-veneer Lumber. There, the federal government house financing authority has given approval for use of Douglas-fir LVL as equivalent of No. 1 grade sawn lumber. It was established that LVL yield from a log is up to 47 percent greater than from sawing. Thus, the twin virtues of less mill waste and conservation of forest resources are achieved. It was surmised that LVL would become more competitive with sawn lumber for general construction as logging costs increase. In the meantime, specialty products, such as long 2-span joist applications, millwork, vertically laminated long-deep beams and prefabricated components of specific design constitute a market. For example, an experimental 32-foot diameter spherical space frame, using LVL members, was built from 1/4 inch thick Douglas-fir veneer, 6-ply laminated and formed in a curved press (17).

Plywood Fasteners

Nails. Nails constitute the most widely used type of fasteners in plywood constructions. Nail-holding strength of plywood is important where plywood is serving as a base for shingles. Tests have, however, revealed that the nail holding power of plywood is considerably above the maximum required in service. The types of nails recommended are non-corrosive for fixing asphalt and wooden shingles and aluminum, screw threaded, shank needle point for fixing asbestos shingles to plywood. Nail holding strength is also important in plywood sub-flooring, particularly when plywood is fixed on green, unseasoned joists. The joists dry out and shrink away causing "nail popping." This can be minimized by setting nails slightly below surface and omitting filling.

Nail bearing strength is usually a measure of the lateral bearing load that can be transmitted from the panel to the shank of a nail driven into a wood framing member. The allowable load for a bright, common wire nail in lateral resistance when driven into the side grain (perpendicular to the wood fibers) of seasoned wood is expressed by the formula

$$p = kD^{3/2}$$

where: p is the allowable lateral load in lbs. per nail,

k is a constant varying from 900 to 1375 for softwood, and

D is the diameter of the nail in inches.

The loads computed with the above formula are only one-sixth of ultimate test values, in order to allow for variations in wood density and quality and possible splitting. Important applications occur in roof sheathing, wall sheathing, gusset plates, diaphragms and nailed box beams. Tests have shown that 5/16 inch plywood is thick enough to develop approximately the full bearing strength of 6d common nails, 3/8 inch for 8d common, 1/2 inch for 10d common, and 5/8 inch for 16d common nails, all driven into wood members of similar density and of adequate thickness. A 3/8 inch edge-clearance is desirable for nailing plywood as nail bearing strength decreases rapidly with lesser margins (1, 54).

Staples. Stapling machines, pneumatic and mallet driven, are in use for attaching plywood to framing and asphalt shingles to plywood. A staple of 14 gauge with 1¼ inch legs has been proved equivalent to 6d common nails, in both lateral bearing tests and in full scale diaphragm tests. Power-driven staples used to attach shingles to plywood sheathing, in general, should be of the following minimum dimensions:

Wood shingles: 16 ga; 7/16 inch crown; length sufficient to penetrate bottom surface of plywood; two to each shingle.

Asphalt shingles: 16 ga; 3/4 inch crown; 3/4 inch length; two to each shingle or six for 36 inch section of strip shingles.

Built-up roofing: 16 ga; 7/16 inch crown; 7/8 inch length; driven through tin caps on 12 inch centers (54).

Bolts. These have only limited use in plywood. However, when used, an end clearance of at least 3 inches and edge clearance from 1 inch to 3 inches should be ensured.

Gluing. Use of glue in various structural components, cabinet work and the like is known as secondary gluing. The glue may be water resistant or waterproof--the most commonly used being Urea formaldehyde from amongst the water resistant types and Resorcinol formaldehyde from amongst the waterproof types (54).

Gusset plates. They constitute an effective and economical means of jointing co-planar truss members and bracing between columns or posts and bearing trusses or beams. High panel shear and nail bearing strengths of plywood are responsible for its success. Gusset plates may be glued instead of nailed (54).

Plyclips. These are patented H-shaped extruded structural aluminum-alloy clips 3/4 inch long and 1-3/16 inch wide. They were developed as roof panel support in lieu of cut-in blocking, primarily for 3/4 inch plywood on 48 inch spans where two plyclips per span were used. These permit significant labor saving over cutting and applying blocking (54).

Structural Components

Structural components, considered the key to the future of the construction industry, are essentially prefabricated assemblies of various material units, such as dimension lumber and plywood, into integral structural members. These components are being manufactured in plants all the year round. Building with components requires a minimum of on-site labor. Using components, in effect, is building with parts rather than pieces, and with assemblies instead of units. Their advantages are: (1) Design freedom and esthetic appeal; (2) high strength-to-weight ratios; (3) smooth easy-to-finish surfaces; (4) uniform manufacture; (5) efficient use of material; (6) lower manufacturing costs; (7) rapid delivery; (8) ease of handling and installation;

(9) reduced on-site labor costs; and (10) rust proof and corrosion resistant materials. Components which are in commercial use extensively are discussed below:

Folded plates. A plywood folded plate is a further adaptation of the diaphragm or plate-girder concept. The simplest form utilizing two diaphragms is the single folded plate. Each of the inclined planes is designed as a diaphragm with upper chord at ridge, lower chord along eaves, and a shear resistant sheathing as a web. Lateral thrust against the side walls is kept within acceptable limits by designing the diaphragm so that its deflection will be properly restricted (see Figure 10). In the multiple folded plates, no interior beams or walls are required for the valleys. The outermost plates, however, act just as in a single unit and are so designed.

A further development of the parallel chord folded plate roof is the folded plates with chords radiating from an apex, called Radial Folded Plates. The folded plate action spans from valley to valley and arch action enables the roof to function with a center support.

Prefacricated panels. Three kinds are recognized, viz., (1) the glued stressed skin panel, (2) the sandwich panel, and (3) the precut, preassembled, nailed or mechanically fastened panel.

Stressed skin panels: These are the most versatile of all plywood components, consisting of plywood sheets glued to the top and in most cases also to the bottom edges of longitudinal framing members, so that the assembly will act integrally in resisting bending stress. They are equally used in floors, walls and roofs. The most practical

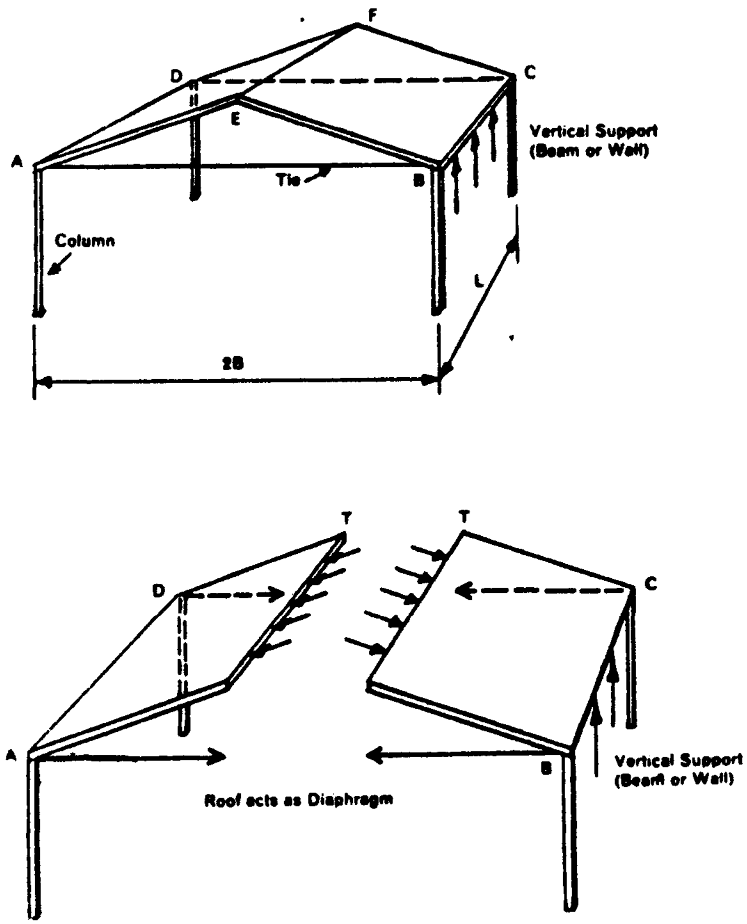

Figure 10. Action of single folded plate.

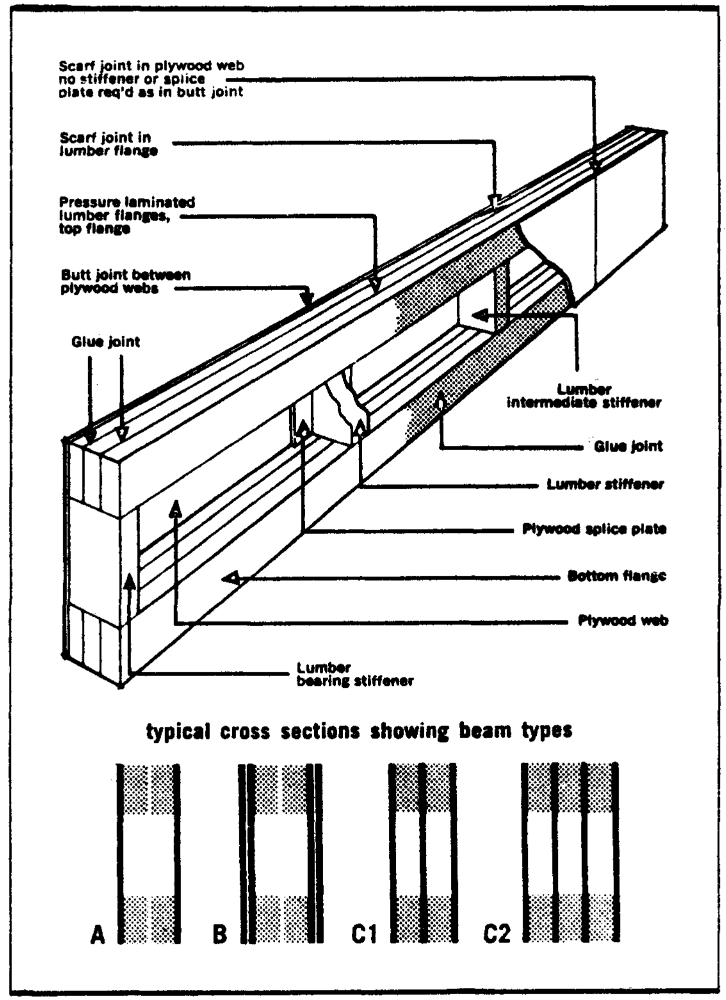

Figure 11. Typical cross sections showing beam types.

roof spans for this type of plywood component are 12 ft. to 32 ft. long.

The curved stressed skin panels are of two types--arch panels and flexural panels. The former are relatively thin in cross section and require end restraint to develop strength. The flexural type are comparatively thicker and designed with flexural strength enough to support design load without restraint (54).

Sandwich panels: The principal involved is the same, i.e., core acts as web and the skins of plywood as flanges. Various materials are used as core or act as fillers. Some of them are: balsawood, expanded rubber or ebonite of onazote variety, polyurethane foam, honey-comb structures of resin impregnated paper, fiber board, etc. These panels are used for partitioning walls, roofing, doors, etc., according to the kind of material placed in the core (72).

Preframed panels: Construction is speeded with preframed panels. These are plywood panels simply nailed to precut dimension lumber, that is, laid out in a form to fit a particular design use. These assemblies become building units that can be installed with a significant reduction in time and job overhead. Preframed panels are often 4 ft. x 8 ft., with lumber framing usually 24 inches o.c. (2, 54).

Plywood box beams. These are hollow structural units consisting of two or more vertical plywood webs which are attached, usually by gluing or nailing, to lumber flanges. Typical box beam cross-sections are shown in Figure 11. The flange laminates may be placed as shown, called vertically laminated, or stacked, called horizontally laminated. Box beams can span distances up to 120 ft., although commonly used spans are 20 to 80 ft. The advantages of box beams are: (1) they can be built in various shapes and cambered, curved, arched or tapered to fit architectural tastes; (2) they are hollow and consequently light in weight, thus expediting transportation and handling; and (3) they are easily incorporated into the framework of a building with standard carpenter labor (2, 54).

CHAPTER IV

UTILIZATION

Building Construction

The maximum use of softwood plywood is found in construction, both residential and non-residential. The statistics indicate that in 1951, 39 percent of the total quantity of softwood plywood produced was consumed in construction work. The ratio rose to 51 percent in 1959 and further to 65 percent in 1963. The increasing use of plywood in construction can be attributed to various reasons, viz., the wholesale price index of softwood plywood has fallen over the years as compared with that of the other constructional materials, including lumber; the labor cost involved in doing building construction is comparatively much less; and the development of structural components, various kinds of coatings, laminates and overlays has made use of plywood more versatile and advantageous (16).

The American Plywood Association and its predecessor, the Douglas-Fir Plywood Association, have played an important role in popularizing the use of softwood plywood. They have been both aggressive and progressive in providing educational materials to the potential customers. The published Product Standard PS 1-66 provides basic information on veneer and panel grades, specialty items, species, strength/span data and much more. They have also published numerous brochures and plans detailing how to specify and install their products for maximum efficiency and economy.

Plywood, in building construction, is mainly consumed in sheathing, both roof and wall, and sub-flooring. Douglas-fir plywood, in particular, is used in huge quantities for concrete forms. Prefabricated houses, mobile homes and trailers also consume substantial quantities of plywood (54). Increasing mobility and sweeping shifts in population have created markets for relocatable structures--buildings which move with people. The American Plywood Association has designed and has already marketed moveable buildings such as self-service post offices, portable supplementary classrooms, offices, living quarters, etc. (12).

The rising levels of income are also responsible for some of the increase in consumption of plywood. This is particularly evidenced in the heavy demand for hardwood plywood for paneling the interior of homes; so much so, that huge quantities of exotic hardwood veneer/plywood are imported every year to satisfy the demand. It is estimated that in 1970 and again in 1971, over 4 billion sq. ft. surface measure of hardwood plywood paneling was used in housing, in commercial construction, in the mobile home industry and by the do-it-yourself people. In 1972, it was expected that the hardwood plywood paneling consumption would approach or exceed the 5 billion sq. ft. surface measure mark (39).

<u>Furniture and Cabinet Making</u>

What was once a craft--furniture making--is rapidly becoming a series of industrial processes. The technological developments in this field have made it possible to manufacture furniture which may, in place of the costly hand-made furniture, be acceptable to the public in design, quality and cost. Veneering and laminated construction are the prominent features of the contemporary design. Matching of grains in veneers, their jointing and splicing with machines, discovery of a veritable host of adhesives, bonding of veneer to substrates of various shapes and easy methods of bending wood have contributed to the development of the modern furniture industry to its present size (24).

Cabinet making consumes large quantities of plywood. Cabinets are of multifarious shapes and sizes meant for different uses. Radio and television cabinets, shop fittings, flush doors, cupboards, chests of drawers, partitioning walls, kitchen cabinets and other built-in cabinets are some of the many items which fall in the category of cabinet making. The size of the kitchen cabinet market alone can be imagined from the fact that in 1969, 3.9 million kitchen cabinets were built, out of which 71 percent were wooden and factory made. The total kitchen market of 1969 was valued at $1.4 billion and out of the total money spent by the members of the National Kitchen Cabinet Association on purchase of material, almost half was spent on the purchase of lumber and plywood. The share of lumber and plywood, however, is decreasing every year, though at a very slow rate. Hardboard, particleboard and plastics are eating into the share of lumber and plywood. From 1963 to 1970, a period of 7 years, the share of lumber and plywood fell from 50 percent to 45 percent, whereas that of plastics rose from 1.7 percent to 6.6 percent and that of particleboard core-stock from 0.6 percent to 4.5 percent (47, 72).

Industrial and Other Uses

Other than building construction and furniture making, one of the biggest users of plywood is the transport industry--sea, air and land. In the shipping industry, use of plywood became popular only after the discovery of waterproof and moisture-resistant adhesives. The main use of plywood in ships is to replace older type of bulk-headings. Previously, solid wood of 1-1/4 to 1-1/8 inch thickness was used for this work and now plywood of 7/8 inch and 3/4 inch thickness is being used successfully, thus making savings in cubical content of wood as well as in costs of labor. Not only employed for bulk-heading, plywood is now being used in ships for bridges, deck-houses, decks, overheads and furniture. Light seacraft, such as yachts and motor boats are also making extensive use of this product (72).

In the aircraft industry, the use of plywood was substantial during the war years but, of late, it has dwindled. Canadian birch and maple were generally used for manufacturing gliders and other trainer machines. The most recent use of plywood in aircraft industry is in the construction of air-freighted pallets. Plywood of 18-25mm thickness and with surface finish of high indentation resistance is used (46, 72).

In the transport industry, by far the biggest users are the makers of trucks, trailers, freight cars and freight containers. For the construction of these containers, and also of trailers, trucks and freight cars, fiber-glass reinforced plastic plywood (FRP) is mainly used. This special plywood is a sandwich of exterior plywood between two plastic skins and can be made in large sizes. For constructing a 20 x 8 foot panel, a mat of fiber-glass woven roving 8 x 20 ft. is placed on a flat surface and saturated with resins. Next, five 4 x 8 foot plywood panels are placed with their long edges butted together.

Then a second fiber-glass mat is laid down on top of the plywood and saturated with resins. The assembly is then cured under heat and pressure. Tests have shown that plywood offers stiffness and bending strength while plastic lends abrasion resistance, good looks, weathering ability and ease of maintenance. The advantages of carrying cargo in freight containers are manifold, namely, reduced handling and documentation, easy interchange between various modes of transport, and a modular storage unit in which goods are protected and pilfer-free.
In the U.S., FRP plywood has penetrated about 30 percent of the cargo container market (5, 6, 46). Plywood overlaid with fiber-glass reinforced plastic has demonstrated its durability through many years of service, and when it is damaged, it can be easily repaired. A marine container equipment certification corporation testifies that the "FRP plywood container maintenance and repair costs are 53 percent lower than metal containers" and that "cargo damage, according to our computerized statistical analysis is 79 percent less in FRP plywood containers" (51).

Other uses of plywood include manufacture of boxes, barrels, baskets, pallets, liquid tanks, crating, shelving, trays, automobile interior furnishing, construction of sporting goods, stage sets, musical instruments, etc. Packaging, especially construction of tea-chests, is another main use (44, 53, 55, 72).

CHAPTER V

STATE OF THE INDUSTRY

Undoubtedly, the plywood industry is one of the major industries of the United States and also one of the oldest. The first patents relating to plywood were taken out in 1865 and 1868. Earlier, however, since the 1830's, it was used in pianos to hold the pins carrying the strings. After the 1860's, its use in furniture developed rapidly. The first standard, all purpose, utility panel was, however, produced in 1905 by the Portland Manufacturing Company which made its debut the same year at the Lewis and Clark Exposition. It was a 3-ply veneer work and the panels were hand made.

In the 1920's, the automobile industry became the top consumer, using plywood in running boards, floor boards and other parts of cars. The usefulness of plywood was, however, limited by its failure to stand up under exposure to weather. Consequently, the auto industry shifted from plywood to metal in the early 1930's, thus aggravating the effects of the Great Depression on the young industry.

The glues in use--animal, starch, casein and soybean--were not waterproof. Efforts to develop waterproof glue bore fruit in 1934 and soon many hot-plate presses were installed in the country. The late thirties saw new markets in prefabricated housing, boats and railroad car lining, and barring a slight setback during World War II when plywood was one of the last industries to be decontrolled, this industry has made great strides ever since (16).

The plywood industry can be divided into three parts, viz., (1) softwood plywood industry, (2) hardwood plywood industry, and (3) imported plywood veneer.

Softwood Plywood Industry

The softwood plywood industry is mainly the Douglas-fir plywood industry. Because of the location of the species, the softwood plywood industry is confined to the northwestern region of the United States. The industry was originally developed in Washington state. In 1947, this state alone accounted for two-thirds of the total softwood plywood production. But by 1953, Oregon's production exceeded Washington's, and by 1958 Oregon enjoyed the same position in the region as Washington did in 1947. The industry further spread to California and in 1960-64, 66 percent of the total was produced in Oregon, 11-15 percent in California, and only 18 percent in Washington. Recent dispersion has been toward the southeast where the southern pines are used for manufacturing plywood. The first plant came up in Arkansas in 1963, and ever since, the industry has been developing rapidly in that region.

The growth of the softwood plywood industry has been phenomenal. The Federal Reserve Board index of average annual growth rates for 1947-62 shows "softwood plywood" leading the list of industries at 14 percent increase annually compared with a 4 percent average annual increase for "total industrial production" in the period (16, 72).

The year 1973 has been remarkable. The total estimated production of the United States, from 186 mills, was 18.5 billion sq. ft. (3/8 inch rough basis) as shown below:

1.	Oregon	79 mills . . .	8.539	billion sq.ft.
2.	Washington . . .	27 mills . . .	2.247	" "
3.	Louisiana . . .	12 mills . . .	1.150	" "
4.	California . . .	13 mills . . .	0.974	" "
5.	Texas	7 mills . . .	0.832	" "
6.	Arkansas	7 mills . . .	0.790	" "
7.	Others	41 mills . . .	3.972	" "
	Total	186 mills	18.504	" "

Last year's production was 18.4 billion sq.ft. and the growth rate was 12 percent. The growth is negligible this year. The two major factors adversely affecting growth was a decline in the number of new housing starts and the energy crisis. The high interest rates and the drying up of available mortgage funds in many areas and ramifications of some of the federal fiscal policies to combat inflation, had impact on the housing field. The energy crisis was reflected in acute shortages of rail cars, which caused a general slow-down in the last quarter of 1973 (45).

Hardwood Plywood Industry

The hardwood plywood industry is highly diversified, though in size it is much smaller than softwood plywood. The industry can be subdivided into three groups: (1) a number of well equipped modern mills which make a wide range of high grade plywood in various sizes; also molded plywood and other specialties; (2) a more numerous group of smaller mills devoted to the production of custom plywood for the furniture plants; and (3) mills producing plywood for packaging.

In numbers, the majority of the mills are situated east of the Rocky Mountains. The location of the factory determines the species of timber used. The main species are birch, maple, gum, aspen, yellow poplar, and basswood.

Over the years, hardwood veneer has been imported in huge quantities from European, West African and Asian countries. The ratio of domestic production to the total consumption, which was 90 percent in 1952, fell to 43 percent in 1962. The domestic production has been increasing, but at a far, far lower rate than the total consumption. The trend continues. The domestic production in 1973 was 2.1 billion sq.ft. in a total consumption of 8.4 billion sq.ft. (surface measure), a ratio of 1:4 (40, 72).

Imported Plywood/Veneer

The importation of plywood has been steadily increasing since the early 1950's. Primarily, hardwood veneer/plywood is imported, the species being lauan, birch, sen, shiva, mahogany and other tropical hardwoods. In 1972, four-fifths of the import was lauan, 5 percent birch, and the rest all combined. The quantity imported in 1952 was 0.84 billion sq.ft., in 1962, 1.439 billion sq.ft., and in 1973, 6.4 billion sq.ft. (surface measure) (13, 40, 69).

CHAPTER VI

PERSPECTIVE

The plywood industry, over the years, has carved out a place for itself in the economy of the United States. It is now so geared to the economy that its state, at any time, is sensitive to the changes in the index of industrial production. In other words, a rise or fall in the index is reflected in the demand of plywood. A sector of the economy which strongly influences the demand of plywood, particularly of softwood, is the number of new housing starts which, in turn, depends upon the prevalent mortgage interest rates. The higher the interest rate, the lower will be the number of housing starts and correspondingly the demand of plywood, and vice versa. If the two variables, index of industrial production and mortgage interest rate, were to be constant, the demand of plywood can be taken as more or less inelastic.

Like any modern industry, if it has to grow and prosper, the plywood industry will have to keep on discovering new products and product uses. Obsolescence is a phenomenon which takes its toll of every industry and plywood is no exception. Emphasis on research, therefore, will have to continue. The field of synthetic resins alone is replete with potentialities. Discovery of new adhesives capable of setting at lower temperatures and in shorter time periods, can tremendously lower the cost of production and hence the price of plywood. The structural components, like radial folded plates, curved stressed skin panels, etc., have already engendered a revolution in the construction industry, and additional innovations will help keep up the tempo. Press-Lam or LVL is a new concept. It should be further advanced. The beams built with veneer laminae are not only esthetically superior but they also represent better and more complete utilization of wood as a raw material. Automation is yet another approach to reducing costs and enhancing efficiency in plants. The breakthrough achieved in automatic lay-up of plywood has brightened the prospects of complete automation in plywood plants, that is, from the stage of heating of logs to the ultimate realization of sanded plywood panels.

In the coming years, the plywood industry will have to battle with inflation, high intersst rates and energy problems. Emphasis, most probably, will be on the non-housing market. But in the long run, potentialities for the development of new products, increased automation and the inherent versatility of plywood itself, hold great future prospects for this industry.

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