c.1

THE SUITABILITY OF CONTINUOUS LAMINATED VENEER LUMBER PRODUCTION TO SOME CANADIAN WOOD SPECIES

by

ADEMOLA ADENIYI AFOLAYAN

B. Sc. (Hons.) Forestry, University of Ibadan, 1970

A THESIS SUBMITTED IN PARTIAL FULFILMENT OF

THE REQUIREMENTS FOR THE DEGREE OF

MASTER OF FORESTRY

in the Department

of

Forestry

We accept this thesis as conforming to the required standard

THE UNIVERSITY OF BRITISH COLUMBIA

October, 1974

Department of Forestry

The University of British Columbia
Vancouver 8, Canada

Date 23-10-1974

ABSTRACT

Laminated veneer lumber was made by gluing six layers of ¼-inch veneer assembled with grain directions parallel and all the tight veneer surfaces outward. A specially modified phenol-formaldehyde plywood resin was used. Shear strength and wood failure of specimens tested dry, and after accelerated aging, were used to evaluate bond quality.

Limited samples of broadleaf maple laminated veneer lumber were used to demonstrate that, with central glueline just reaching 240°F before opening the press, adequate bonds were formed. These were not significantly different from those produced with a central glueline temperature reaching 300°F.

Tests of specimens from small panels of broadleaf maple, black cottonwood, and sugar maple ~~proved~~ showed that a gluespread of at least 42.5 pounds per thousand square feet of single glueline (42.5 lb/MSGL) was required. At this spread, a central glueline temperature of 240°F and platen temperature of 350°F, adequate bond quality was produced at platen pressures of 200 psi, 100 psi and 275 psi for broadleaf maple, black cottonwood and sugar maple, respectively.

Based on the press schedules developed with the small panels, black cottonwood, sugar maple, and white spruce, continuous laminated veneer lumber boards were manu-

factured, using the process described by Bohlen in 1972. Only the white spruce boards produced adequate bonds. Those of black cottonwood and sugar maple failed due to dry-out of glue adjacent to the platens. Although suitable pressing conditions were worked out for single-pressed boards, irrespective of wood species, the glue would need further modification for the hardwoods studied to be used for continuously produced laminated veneer lumber.

ACKNOWLEDGEMENTS

Thankful acknowledgement is made to Dr. W. V. Hancock, research scientist at the Western Forest Products Laboratory, Vancouver, for supervising this thesis project. His constructive criticisms are appreciated and his personal friendship was a great encouragement.

Thanks are expressed to Mr. L. Valg, Assistant Professor in the Faculty of Forestry in the University of B.C. His contributions as faculty advisor and committee chairman for the author are appreciated.

Dr. N. C. Franz, Professor in the Faculty of Forestry in the University of B.C., was a great help in the preparation of this thesis. His position in the author's committee is appreciated.

The contribution of Dr. R. W. Wellwood at the experimental stage of this study is acknowledged.

Thankful acknowledgement is made to Dr. A. Kozak, Biometrics professor at the University of B.C. for his advice on the statistical analysis.

The assistance offered by the technical staff of the WFPL's Plywood Section, and the Biometrics technicians of the Faculty of Forestry in the University of B.C. are appreciated.

The author wishes to thank the Canadian International Development Agency for his financial support for higher education in Canada.

The loving and prayerful support of the author by his wife, parents and many friends are highly appreciated.

TABLE OF CONTENTS

Page

Page

Page

Page

LIST OF TABLES

Table | Page

Table		Page

LIST OF FIGURES

Figure Page

Figure		Page

1.0 INTRODUCTION

1.1 Towards Better Utilization of Wood Raw Material

The production of structural lumber by laminating thick-peeled veneers has made possible the conversion of low-grade or small logs into high-value forest products. Work on this product dates back to the Second World War but its economic potential has been doubted for many years. Recent studies on manufacture of Laminated Veneer Lumber (LVL) at the Western Forest Products Laboratory in Vancouver, and of Pres-Lam at the U.S. Forest Products Laboratory, Madison, Wisconsin, indicate the potential can be realized.

Wood is a versatile engineering and construction material which is in ever-increasing world demand. In the last two decades, lumber production in British Columbia (B.C.) has increased both in total volume and as a percentage of total Canadian output. In 1952, total volume of sawn lumber produced in B.C. was 3.7 billion fbm and in 1971 9.0 billion fbm. This represents a 143 percent increase in production. In the two years, B.C. production was 54 and 69 percent, respectively, of total Canadian production (Government of B.C., 1972). The growing need for, and exploitation of, timber may lead to problems relating to inventory such as a general decrease of the wood bank (standing stock) and a probably equally important problem of disrupting the species balance due to over exploitation of the more accessible and favoured species.

Until 1966, Douglas fir (Pseudotsuga menziesii Mirb. Franco) was the principal species harvested in B.C. (Government of B.C., 1972), although more recent statistics (Dobie 1970) show that, on the coast, Douglas-fir formed only the fifth highest species in inventory volume while it was second highest in 1968 cut. True fir and lodgepole pine which were, respectively, third and fourth highest species in inventory volume, were fifth and sixth highest in the 1968 cut. The Douglas-fir cut was therefore far out of proportion to the supply while true fir and lodgepole pine were cut far less than was justified by the proportion they form of the inventory. This overcutting of Douglas-fir has had a significant impact on wood products manufacturing in B.C.

Douglas-fir is well known in the international market for its sterling qualities which include good workability, ease of peeling, ease of treatment (except the mountain type), and, especially, strength. Also, long experience with use has led to availability of extensive scientific data on Douglas-fir. Probably an important point in market development was the ready availability of large clear sizes of coast Douglas-fir in the early days of exploitation. Owing to these factors of long usage experience, good performance and availability, a whole plywood industry developed around this single species. Over the years, the housing and other panel and lumber using industries have developed a preference for Douglas-fir.

A shortage of readily available old growth Douglas-fir, and the general change in inventory balance has forced the forest industry in B.C. to take corrective steps. These include diversification of the raw material base for lumber through introduction and promotion of new species, a progressive phasing out of the Douglas-fir base for the softwood plywood industry, closer utilization of available raw material, utilization of second growth Douglas-fir and of inferior species, and so of smaller and smaller logs for making plywood. They have fitted well with the general trend in the industry toward sheathing plywood production and away from sanded finish grades. Economic utilization of poorer quality material, which now forms the bulk of available timber, has also been enhanced.

The concept of rotary peeling of small logs as a cheaper raw material source and of laminating the material into structural lumber was examined by the Canadian Western Forest Products Laboratory staff as a possible solution to the problem of falling log sizes and qualities. It also promised to offset the additional costs due to the more stringent demands of close utilization made on industry by government. The laminating process makes possible the production of large, high grade structural components while utilizing small or poor quality logs.

In the United States, it was developed in anticipation of greater pressures from the environmentalists who advocate wilderness development, and might succeed in forcing the government to reduce the size of concessions allotted to the forest industries (Schaffer, et al. 1972). The socio-economic as well as forest inventory problems of developing nations provide an even greater incentive for exploring all avenues of improving raw material utilization.

As an example of serious inventory problems, Nigeria's situation can be cited. Forest land accounts for only 35 percent of total land area (Enabor 1973), and is covered by a heterogeneous mixture of species. British Columbia's forests depend on seven major species, all of which are suitable for timber production. Nearly 600 species attain merchantable size in Nigerian forests of which only about 24 are currently acceptable in the international timber market. The Nigerian forest industry does not face pressures from environmentalists at present but there is great competition for, and encroachment into, forest lands by the agricultural sector of the economy. It is therefore probable that, if the Nigerian forest industry is to survive it must learn and benefit from the North American experience by developing such products as LVL or Pres-Lam which make possible better raw material utilization.

1.2 Background, Objectives and Scope

As part of a course of directed studies, the author fabricated LVL from thick veneer of broadleaf maple (Acer macrophyllum Pursh.), using step-pressing as described by Bohlen (1972a). Suitable test specimens were prepared and stressed to failure in bending. It was found that some strength characteristics exceeded those of broadleaf maple solid lumber, while some were slightly lower. Some glue failure at the step joints was discovered. The findings brought into question the suitability of some hardwoods for LVL produced as "endless"[1] boards.

The original intention was to examine three tropical hardwoods of low, medium and high density, and determine their suitability for LVL. Efforts to obtain tropical species failed and therefore Canadian species were used. These included broadleaf maple (veneers saved from the earlier experiments), black cottonwood (Populus trichocarpa Torr. and Gray) and sugar maple (Acer saccharum Marsh). The Eastern Forest Products Laboratory supplied dry 0.273" (¼-inch nominal) sugar maple veneer. Also, some white spruce (Picea glauca Moench Voss) veneers, from previous laboratory studies, were available in limited quantities and were used as controls. Black cottonwood and sugar maple were, therefore, the main species studied.

---

[1]A term used to describe continuous long beams made by end jointing relatively short laminates.

The experiments were designed to determine adequate gluespreads, curing temperature and platen pressure. Temperature rise within boards in the press and in the stepped joints external to the platens were also measured in order to determine press-schedules.

The quality of the central glueline was studied with a standard plywood phenolic resin glue[2] and with the same glue modified for dryout resistance. Bonds produced with phenol-resorcinol resin were used as a standard.

1.2 Critical Points in the Continuous LVL Production Process

The laminating process described by Bohlen (1972a) included gluing of veneers that protruded from between the platens, during press closure, for six to 30 inches. In principle, the board section adjacent to the edge of the platens should promote a cantilever effect, thereby furnishing adequate pressure required for adhesion during pressing. Sections further away are subject to abnormally long (not less than 20 minutes) closed assembly time.

Either the glue should have a high dry-out tolerance or the veneer should have a low absorptive capacity for glue in order to ensure adequate bonds in the step joints. (Figures 1 and 2 show the step joints which stick out of the platens.) Also, the glue should not precure in the step

---

[2]Phenol-formaldehyde glue IB-337 was manufactured by Reichhold Chemicals (Canada) Limited.

joints at the temperatures prevailing close to the platen edge. Bohlen (1972a) reported that adequate bonds were formed in the Douglas-fir LVL with the glue specially modified by the manufacturer.

Because the veneers are usually shorter than the press platens, sections adjacent to the step joints are usually pressed twice (see figure 3).

While the process appears to be relatively simple, economical, and proven for Douglas-fir LVL, it is not known if it would be suitable for other species. It is also not known if the pressing regime used will have an adverse effect on the physical properties of the finished material in service so as to limit engineering applications.

2.0 LITERATURE REVIEW

2.1 Development and Special Advantages

Structural material laminated from thick-peeled veneers was reported during the second world war by Luxford (1944). The feasibility of commercial production of the new wood product was viewed with pessimism (Bohlen 1973) until recently. Intensified research and development are showing that, according to Bohlen, the "voices of gloom who declare such a material too expensive are not necessarily correct." The current production techniques derive largely from the pioneering work of Marra (1956) and McKean and Smith (1958) who developed techniques for rapidly laminating one-inch-thick lumber. Leicester and Bunker (1968), using ½- to two-inch-thick solid lumber laminations, demonstrated that the thinner the laminations the higher the fracture stress. Westman and Nemeth (1968) also used thin solid lumber (5/8-inch-thick) to compare single and 2-ply laminated tension values. The research reported by Koch (1964, 1965) and Murphey et al. (1967) involved laminating slicewood.[3] According to Koch (1967), in terms of veneer yield and utilization of bolts shorter than eight feet, rotary peeling is to be preferred to slicing. For this reason, most later workers concentrated on laminating rotary-peeled veneers.

---

[3] Slicewood is thin lumber cut from the side of a squared billet through an up and down, horizontal or rotary (in some German machines) movement of a heavy knife.

Koch (1967) and Koch and Woodson (1968) made very strong 42-ply beams from 1/6-inch rotary cut southern pine (Pinus spp.) veneers, using a phenol-resorcinol formaldehyde glue and a screw operated cold press. Hann et al. (1971) developed the Pres-Lam process for manufacturing red oak (Quercus sp.) laminated boards for pallet deck boards.

Bohlen (1972a) published the results of research done at the Western Forest Products Laboratory on production of Douglas fir LVL. An elaboration of the process, with a quality control programme of the wood product (Bohlen 1973) was presented at the IUFRO conference in Capetown, South Africa, later. He described the wood product as continuous wide planks, up to 48 inches wide, formed by gluing together in unidirectional multiple layers ¼-inch-thick rotary-peeled veneers with phenol-formaldehyde waterproof adhesive. Schaffer et al. (1972) improved the Pres-Lam technology and modified the schedules initially designed for red oak, to facilitate production of structural material from southern pines. According to these workers "Pres-Lam is an integrated processing system to convert logs into continuous thick laminated sheets more efficiently and rapidly than any processing schemes currently used." It employs the residual heat of drying ¼-to one-inch-thick rotary-peeled veneers to cure the phenol-resorcinol laminating glue in two to four minutes of pressing without additional heat.

Koch (1973) suggested a two-stage laminating process for rotary-peeled ¼-inch southern pine veneers. The first stage would involve hot laminating veneers into 3-ply beams with standard phenol-formaldehyde glue, probably as in the LVL system, while the second stage would involve cold laminating the 3-ply boards in pairs with phenol-resorcinol glue.

In the general summary of the Pres-Lam feasibility study, Schaffer et al. (1972) gave the special features of Veneer-Lumber laminated from rotary-peeled veneers. These include redistribution of strength-reducing defects, absence of juvenile wood from finished products, utilization of short bolts, possibility of producing wide, continuous beams, ease of preservative treatment through the access routes of lathe checks. Pres-Lam is characterized by a fast production speed from bolt to finished lumber of less than one hour. Bohlen (1972a) discussed the possibility of prefabrication of structural components of unconventional design. He cited the manufacture of a geodesic space frame from curved LVL by the architecture students of the University of B.C. Koch (1967) demonstrated the potential of producing superstrength lumber through densification and location of veneers by stiffness. He demonstrated the possibility of fabricating a seven-inch deep beam, and Bohlen (1972a) suggested the possibility of vertical laminating nominal two-inch LVL into large structural sizes like 9 x 48-inch x 80-feet.

Koch (1967), Koch and Woodson (1968), Moody (1972), Bohlen (1972a, 1973, 1974) agree that laminating thin veneers results in material with superior strength. Others such as Luxford (1944), Norton (1943), U.S. Forest Products Laboratory (1966) found no special strength improvement, while substantial reduction of some strength properties have been reported by Lutz et al. (1972), Echols and Currier (1973), Moody and Peters (1972). Koch (1973) reported that butt jointing did not significantly reduce strength provided laminae were thin and butt joints staggered.

2.2 Economic Feasibility

The development around 1930 of high-temperature-curing phenolic resin glues was a breakthrough in adhesives technology because it made possible cheap bonds more durable than the wood (Marra 1956). The high temperature requirement made these adhesives inapplicable to laminated beams because of the impracticality of forcing heat into any substantial depth in wood. Production of beams one inch thick and up, on a hot press may take 60 minutes or more to ensure complete polymerization of resin (Wood 1963). Development of radio frequency (RF) heating has reduced this problem, but according to Chugg (1964) and Wood (1963), the system is prohibitively costly and hence has not gained widespread acceptance. High initial cost of RF equipment demands large scale operation to ensure profitability

(Winlund 1947). Other factors of cost such as maintenance and requirement of high technical skill of operators were cited by Arneson (1947) and the quality of finished products, which was questionable as a result of arcing of some adhesives, was mentioned by Orth and Norton (1947).

Introduction of cold setting resorcinol glues in the 1940's eased the problem of high temperature curing but resorcinol glues were about five times as costly as the phenolics (Marra 1956) and currently are about six times as costly (Koch 1973). The amenability of resorcinol to modification with phenol-formaldehyde giving faster curing at low heat input has made these exterior glues gain substantial popularity in the industry. Most of the work done on laminating thick veneer has been with resorcinol or resorcinol-modified phenol-formaldehyde (Murphey et al. 1967, Koch 1967, Koch and Woodson 1968, Hann et al. 1971, Schaffer et al. 1972, Moody and Peters 1972, Echols and Currier 1973, and Koch 1973). All, except Hann et al. (1971) and Schaffer et al. (1972), Moody and Peters (1972), and Jokerst (1972) involved very long cold pressing times, thus adding to the manufacturing cost due to tie down of equipment and factory space. At room temperature (70°F) phenol-resorcinol formaldehyde will cure in 8 hours (Borden Chemicals 1970), at 180°F in seven minutes and at 220°F in three minutes.[4]

---

[4]Private communication with chemistry laboratory staff of Borden Chemicals (Canada) Limited, Vancouver, 1973.

Marra (1956), in embarking on research for developing the process for laminating 2 x 4's from 1 x 4-inch boards, set two targets, to ensure profitability. These were (i) ensuring usage of an exterior or boil-proof adhesive and, (ii) development of a high-speed, low-cost gluing operation which would maintain total gluing cost at between $10 and $20/Mfbm. The latter excluded use of cold-setting phenol or resorcinol adhesives. In his study the eventual use of hot-setting phenol formaldehyde glue reduced the glue cost from $12.50 to $2.50/Mfbm of 2 x 4's. Schaffer et al. (1972) recorded $44.50/Mfbm for phenol-resorcinol adhesive cost for 6-ply Pres-Lam. Koch (1973) gave an estimate of $7.00/Mfbm of lumber all but one of the six gluelines being of unmodified phenol-formaldehyde glue. Schaffer et al. (1972) estimated the selling price of Pres-Lam at between $150 and $200 and production cost at $126/Mfbm. Bohlen estimated LVL production cost to be $94.00/Mfbm while Koch (1973) gave his cost estimate as $136/Mfbm. While no direct comparison is possible between these three cost estimates, it could be assumed, on the basis of glue consumption alone, that Bohlen's LVL would probably be the most economically favourable.

2.3 Technical Feasibility

Technical feasibility of Laminated Veneer Lumber hinges on the curing temperature of the glue to be used.

the wood species involved, the rate at which they will be penetrated by heat to cure the central glueline and their gluability with regard to density, pH and extractive content. These conditions are fairly common to all gluing or laminating processes and involve wood surface preparation and application of glue, heat and pressure.

As with most solids, even when wood is properly planed, the surface is still rough and exhibits demonstrable topography at the microscopic level (Marian, Stumbo and Maxey 1958, Stumbo 1960, and Parker 1966). Surface roughness of rotary cut veneer is partly due to differences in the elastic behaviour of springwood-summerwood as well as lathe conditions at time of peeling (Marian and Stumbo 1962, Feihl 1960, and Feihl and Godin, 1970).

The peaks and troughs in the surface do not generally mesh but the peaks make intimate contact one with another, while the troughs remain as voids in the joint. Zisman (1963), Marian and Stumbo (1962), and Baier et al. (1968), demonstrated that under pressure and temperature, plastic and elastic deformations are induced at the asperities. According to Marian and Stumbo (1962), the deformations depend on the visco-elastic (rheological) properties of wood, extent of surface roughness, pressure, temperature and moisture content (Perkitney and Helinska

1961),[5] other physical properties (Bauman and Marian 1961), quality of veneers (Currier 1960), crystallinity of wood (Murphey 1963), and presence, absence or type of glue (Curry 1957). Various workers or organizations have specified acceptable ranges of pressing conditions for various wood species and panel products.

The American National Standards (1973) specifies a pressure range of 150 to 250 psi for glulam, the upper limit being recommended for dense hardwoods and the lower limit for softwoods. It is also recommended that non-planarity of laminates be avoided in order to facilitate contact.

Shelton (1969) described the experience of the plywood industry. He recalled that pressures used ranges from 100 to 300 psi (usually 175 to 225 psi) and temperatures from 220°F to 350°F (usually 275°F to 315°F). Carruthers (1969) simulated the British hardwood plywood industry practice in his study by employing pressures ranging from 150 to 300 psi, depending on species and density, for veneer moisture contents ranging from two to 18 percent. U.S. Forest Products Laboratory, Madison and Gamble Brothers (1944) recommended average gluing pressures of 100 to 300 psi for Oak and 150 to 200 psi for softwoods. Freeman (1959) used gluing pressures of 150, 200 and 300 psi, correlated with

---

[5] Original not seen. Cited from Palka (1964).

specific gravities of 0.36 to 0.45, 0.46 to 0.55 and 0.56 and above, respectively. Lutz (1955) recommended 250 to 275 for hickory while Truax (1929)[6] suggested pressures as high as 300 psi especially for cold pressing. In his study of factors influencing strength properties of Douglas-fir plywood normal to the glueline, Palka (1964) found that: (i) pressure highly significantly affected both compression and tensile properties of rotary peeled veneer, and only the former in case of sawn veneer blocks; (ii) optimum results were obtained at 200 psi gluing pressure, closely followed by 350 psi; (iii) a pressure of 50 psi was found to be inadequate. Redfern and Fawthrop (1945)[7] reported the inter-relationship of pressure and moisture content of veneer in Douglas-fir plywood hot-pressed with a liquid phenolic resin glue. Cheo (1946)[8] used three different glues--phenolic film, liquid phenolic and soybean--in a similar study.

Macdonald (1951) studied time, temperature, and pressure as major factors leading to compression of plywood and outlined the use of a pressure-control device which could cut down compression from 9 percent to from

---

[6] Original not seen. Cited from Olson and Blomquist (1953).

[7,8] Original not seen, cited from Currier (1960).

3 to 7 percent. Curry (1957) studied the compression and resin impregnation of plywood and found that compression takes place in bands adjacent to the gluelines and increased with number of plies. He also observed that because of alternate bands of weak and strong wood resulting from overcompression, the expected increase in strength might not be realized. Currier (1960) demonstrated the necessity for pressure control when pressing Douglas-fir white pocket veneer. He concluded that normal hot-pressing schedules led to overcompression of the white pockets in veneers while compression was minimized through gradual reduction after full initial pressure.

The manufacture, formulation and curing of phenol-formaldehyde and some modified phenolic resin adhesives were discussed by Parker and Taylor (1966). They described the curing as a cross-linking polymerization process which is accomplished by application of heat and pressure. A temperature range of 250 - 300°F, maintained at clamp times which depend on constitution of resin and wood species, was given. Chow et al. (1973), showed that acceptable wood failure for exterior phenolic resin-bonded plywood develop around 250°F. They analysed the data supplied by Canadian Forest Products Limited, and from the figures produced for seven, five and three-ply plywoods, the CSA 80 percent wood failure standard was attained at inner glueline temperatures 240, 250 and 260°F respectively.

The usual practice is not to completely cure the boards in the press but to attain a sufficient measure of cure which will hold the board together while curing completes during hot stacking. Jarvi (1967) discussed the various limitations to speed at which the temperature of the inner glueline of Douglas-fir plywood can be raised. He stated that the consensus in industry indicates that inner glueline should reach 220°F before pressure is released since experience shows that temperature will rise to about 250°F during hot stacking. Chow et al. (1973) cited some industry figures of 180, 210, 220°F and more but warned that to avoid failure the industry must ensure that proper temperature is attained during hot stacking. Carruthers (1959) investigated heat penetration in hardwood plywood using platen temperatures not exceeding 100°C (212°F). He found there could be considerable variation in heat penetration over the entire panel surface and at the edges owing to variation of thermal properties, moisture content and heat loss. For up to one inch panel thickness, heat loss could be compensated for by increasing calculated heating time by some factor. At platen temperatures above 100°C, his results apply only to the centre of large boards. He pointed out that theoretical calculation of heating time cannot replace actual measurement. MacLean (1943) developed mathematical formulae for computing rate of temperature change in wood panels heated between two plates of unequal temperature. From computed data, he developed curves from which heating times could be read directly or by extrapolation. In a more recent paper, MacLean (1955) reported extensive work done on temperature change in wood panels (plywood or solid lumber boards) heated between platens maintained at the same temperature. He developed curves for panels heated between platens at 225 to 325^{o}F. His work included examples of various panel sizes and pressing conditions. Within the limits of his experiments, heating times are undesirably long for panels thicker than one inch.

The required rate of gluespread is closely linked with adherent surface condition and wood species and it ultimately affects press time. Fischer and Bensend (1969) reported that rate of gluespread exhibited a linear response for shear and a parabolic response for wood failure values. The shear obtained in the boil test increased throughout the entire gluespread range of 60 to 100 pounds per thousand square feet of double glueline (60 to 100 lb/MDGL) tested. The authors pointed out that maximum shear and wood failure values occurred at 90 lb/MDGL in the dry and vacuum/pressure test, thus suggesting that boil tests masked undercure at higher than 90 lb/MDGL. Other disadvantages of high rate of gluespread were given as excessive squeeze-out and steam-blows. Cockerell and Bruce (1946) and Bergin (1969) reported that strength of all adhesives decrease in varying degrees, with an increase in glueline thickness. Northcott et al.

(1959) reported that large amounts of water introduced into the glueline-wood complex via high gluespreads interfere with normal phenolic resin condensation reaction. Cockerell and Bruce (1946) attributed the lower bond strength mainly to eccentricity of test specimens due to difference in glueline thickness but Fischer and Bensend (1969) suggested the strength decline is due to internal stresses developed within gluelines or interruption of the phenolic resin polymerization process as described by Northcott et al. (1959). Bergin[9] in an unpublished paper described ways to control gluespread. He also showed photomicrographs of normal, starved, glazed and crazed joints, the second and last resulting from inadequate gluespread. Using veneers peeled under laboratory conditions, Bohlen (1972a) found that the standard plywood gluespread of 30 lb/MSGL was adequate for Douglas-fir LVL. In a private discussion with Bergsen,[10] it was found that veneers produced in industry were usually rough and, in some instances, gluespreads as high as 42.5 lb/MSGL were used to counter the roughness.

2.4 Gluability

As part of his MF thesis at the University of B.C.,

---

[9]Glue Joint Failures and their Causes, by E. G. Bergin, Forest Products Laboratories Division, Department of Resources and Development, Ottawa.

[10]Proprietor of Truboard, the private company that produced Douglas-fir LVL in Vancouver in 1972-73.

Chunsi (1973) reviewed the literature on gluability of tropical hardwoods with reference to their physico-chemical characteristics and the influence of various laminating glues. He examined six Burmese hardwoods and found that species with medium to high density had high extractive contents but showed no direct relationship between the amount of extractives and gluability. He showed, barring the influence of specific gravity, a trend of increase in glue joint strength with increasing pH. Freeman (1959) reported that specific gravity is the dominant factor in the low density region, when urea resin glue was used, and throughout the entire density range tested (0.40 to 1.16) with resorcinol-phenol glue. He related the latter behaviour to wood/resorcinol joint strength which is generally limited by solid wood shear strength. This is also true of high temperature curing phenol-formaldehyde glue-wood joints (Marra 1956).

Cartensen (1961) attributed the development of a broad range of adhesives that will bond Douglas-fir excellently to the fact that Douglas-fir has been a favoured species and hence a lot of research has been done on its utilization for plywood and lumber. Using Douglas-fir as a standard, he showed the various modifications of glue application and bonding process that would ensure development of the same level of bond strength in various softwoods and hardwoods as is produced with Douglas-fir under standard gluing conditions. He concluded that, provided certain species characteristics such as accumulation of resinous materials on veneer surface and porosity due to low density are taken care of, and veneers are properly dried, all the species considered in his study could be glued equally well with practically any conventional plywood adhesive. He also discussed the potential of the hardwood plywood industry.

The gluability of 14 hardwoods and six softwoods of Eastern Canada were reported by Bergin (1953, 1964). He used two synthetic and two natural glues in the study, and his conclusion agreed with Cartensen (1961) that when gluing conditions are properly controlled, all the 20 species in his study could produce excellent bond strength. He classified the 20 species into four categories of gluability based on wood failure. He also showed that gluability of any one species may differ from that of other species within the same density range. Eickner (1942) investigated 11 hardwoods and four softwoods for gluability with casein and cold setting urea resin glues. He found no consistent difference between heartwood and sapwood, except in Hickory (<u>Carya</u> sp.). He concluded that the 15 species could be bonded to produce joints as strong in shear as the wood itself though, with casein glue, shear strength declined with increasing wood density. Bruce et al. (1944), in an unpublished paper, reported some strength data on birch plywood bonded with low temperature curing resin glues.

They also discussed resin glue behaviour as they vary in their rate of cure between wood species. He observed that resorcinol glues seemed to have a similar curing rate in birch, spruce and mahogany, while they cure more slowly in Douglas-fir, white oak, and possibly sweetgum. The trend for melamine glues was a similar rate on birch and sweetgum but a more rapid rate on Douglas-fir, white oak, mahogany and spruce. With phenolic resin glues, curing rate was said to be similar in birch, spruce and mahogany, slower on Douglas-fir, and slower still on white oak and sweetgum.

Most published papers dealing with LVL production are limited to one or a few aspects of the process. The work at the Western Forest Products Laboratory dealt specifically with Douglas-fir. While it demonstrated the potential for Douglas-fir, it did not quantify the bond quality at the step joints and the suitability of other species was not discussed. Pres-Lam structural material was specifically developed for southern pines. Very limited work has been reported on hardwoods and only the work of Hann et al. (1971) gave the feasibility of laminating poor quality red oak for nonstructural pallet deckboards. Most of the literature reported on glueline temperature rise dealt specifically with plywood. This study will therefore supply some of the much needed information on laminating ¼-inch-thick hardwood veneers, and specifically on the suitability of the laminating process described by Bohlen (1972a) for the species used in this study.

2.5 The Laminating Process

Bohlen (1972a) chose ¼-inch plies through a consideration of the thickest veneer possible to minimize the number of gluelines while still maintaining productivity related to lathe speed and veneer drying time. He clipped the veneers into 26 by 48-inch dimensions for ease of handling.

Veneers were laid up with "tight"[11] side of veneers towards the outside of the LVL. Balanced construction was maintained by arranging the veneers "loose" to "tight" side except the central glueline which was "loose" to "loose."

Using the finding of Fritz (1969)[12] that no interaction exists between stress concentrations at butt joints of adjacent laminations once such joints are further apart than 16 times the thickness of laminations, Bohlen decided that step joints should not be less than four inches apart. For a safety measure, he chose six inches for Douglas-fir LVL in his study.

He used the normal production mix of phenol-formaldehyde plywood glue, a gluespread of 30 lb/MSGL and a press

---

[11] "Tight" side of veneer is that on which the pressure bar rested during peeling and "loose" side is the opposite surface.

[12] Original not seen. Cited from Bohlen (1972a).

time of 20 minutes at a platen temperature of 300°F.

The layup consisted of arranging the veneers in "stair" fashion, with each step being six inches apart. The forward indexing was arranged such that the edge of the topmost lamination coincided with the edge of the upper platen. In this case, five plies were sticking out of the press and the lower face of four of them had been gluespread. Prior to press opening, the next series of gluespread veneers were placed tightly against the steps sticking out of press. In all cases the bottom ply was not gluespread. In the next press cycle, the assembly was indexed forward by 48 inches thus creating a new series of steps sticking out of the press. The last press cycle involved closing up the steps with veneers cut to size so that no new steps were created.

3.0 MATERIALS AND METHODS

3.1 Veneer

The four wood species used in this study are:

(i) Broadleaf maple - peeled at the WFPL

(ii) Sugar maple - " " " EFPL

(iii) Black cottonwood- " " " WFPL

(iv) White spruce - " " " WFPL

3.1.1 Broadleaf Maple

The broadleaf maple (BMP) veneers were in assorted sizes from six to 15 inches wide by 20 to 48 inches long. They were selected from the veneers peeled from #3 to cull grade bolts.[13] The qualities of dry veneers are tabulated below:

Items of Veneer Quality	Mean	Standard Deviation	Range
Veneer thickness (in.)	0.282	0.016	0.197-0.304
Veneer roughness (in.)	0.035	-	0.010-0.045
Depth of lathe check (%)	85	15	20-99
Mean moisture content (%)	6	0.6	1.9-8.4

3.1.2 Sugar Maple

The sugar maple (SMP) veneers were peeled to nominal

---

13 The B.C. fir log grading rules were applied in the absence of any grading rule for broadleaf maple.

¼-inch by the staff of the Eastern Forest Products Laboratory, Ottawa.[14] The peeling parameters are given in Appendix I(a). The qualities of green veneers are given in Appendices I(a) and I(b), for the preliminary and final peelings, respectively. The drying schedule given in Appendix I(c), was used to dry the green veneers, at the EFPL, from approximately 90 to two percent moisture content.

The veneers were wrapped in polyethylene sheets prior to shipment, and all the parcels were intact on delivery. Hence transit conditions did not seriously affect the moisture content of the veneers.

3.1.3 Black Cottonwood

Four 55-inch long black cottonwood (BCW) bolts were obtained from one tree growing at the University of British Columbia Research Forest. The bolts ranged from 14 to 17-inch large end diameter and 13 to 16-inch small end diameter. The bolts were transported to the WFPL three days after the tree was felled. They were kept wet with water sprinklers for another four days after which they were manually debarked prior to peeling.

Earlier peeling studies by Feihl and Godin (1966) had shown that optimum cutting temperature for Aspen poplar

---

[14] Feil and Godin (1973), Forest Products Laboratory departmental correspondence file 361-3-1-1, and Telex (see Appendix I(a).

is slightly above freezing point and that good veneer can be cut at room temperature (70°F). The BCW bolts were therefore peeled cold, using the peeling parameters given in Appendix II.

All bolts peeled easily to a five-inch core. Sixty-four full width (25-inch) sheets; 22 narrows (seven to fifteen inches wide); and six "fishtails" (five to ten inches wide by 20 to 39 inches long) were produced. The veneers were graded according to CSA standard 0153-1963 which covers "poplars" growing in Canada. The frequency of the different grades in the black cottonwood veneers produced is presented in Table 1.

To obtain the green moisture content of the veneers two four-inch strips, 54 inches long, were randomly clipped, one from sapwood and the other from heartwood, of each bolt. The strips were wrapped up in polyethylene plastic sheets for about 30 minutes to minimize moisture loss while the green chain was being cleared. Each strip was then sawn into three 18-inch pieces, weighed, and oven-dried. The average green moisture content of the wood zones and average for all bolts are presented in Table 2.

Poplars generally have a high tendency to retain pockets of high moisture content in dried material (Farmer 1972). To eliminate this, the author decided to dry the veneers as close to oven-dry weight as possible. The Forest Products Laboratory four feet by six feet drying kiln, which has a continuous weighing device, was used. The veneers were dried in two full charges and a third which was 33 percent BCW and 67 percent air-dried Douglas-fir veneers which were used to fill up the kiln so as to avoid the problem of short circuiting and improper air distribution that would result from operating the kiln below capacity.

Half-inch-thick stickers were used between veneers and the top veneers were weighted to limit movement and edge waviness during drying. The six "fishtails" were sawn to 20-inch lengths and were located in pairs at three levels in the first charge and two "narrows" were sawn into six 18-inch pieces and located in the same levels in the second charge. These were used to check the moisture contents of each charge by oven drying in a smaller oven. The kiln schedule used for the three charges is shown in Appendix III. Since each kiln charge was to be dried until the weight was constant, a mild drying schedule of 220^{o}F was used. All kiln charges were dried to constant weight but samples showed the average moisture content to be from three to five percent.

All full size veneers were squared to 25 by 53 inches and the narrows were squared to 52-inch lengths by as close to their original widths as possible. All veneers were wrapped up in polythene sheets prior to the LVL study.

3.1.4 White Spruce

Fifteen pieces of 20 by 52-inch ¼-inch white spruce (WSP) veneers, produced for peeling studies by the veneer peeling section of the WFPL, were used in a limited aspect of this study. The veneers had been stickered in the laboratory for about two months to air dry. Further drying the spruce veneers was not attempted because the veneers had attained an EMC of about seven percent, and further drying could result in over drying with consequent surface inactivation. It has been reported that WSP is susceptible to surface inactivation (Chow 1969). To avoid veneers with serious surface contamination, the upper and lower five pieces of veneer in the stack were avoided, and the veneers were removed from the stacks just prior to the grading and LVL manufacture.

From the foregoing, it is evident that the manufacture and drying history of the veneers of different species used in this study differ. Comparison will be made only where these differences do not make such comparisons meaningless.

3.2 Glues

Utilization of low grade wood material is the most attractive aspect of LVL. Since such poor quality materials are often difficult to glue owing to defects such as cross-grain, end grain at knots and accumulating of resins and other physico-chemical characteristics, it is of utmost importance that adequate bonding be ensured. Resin glues capable of producing exterior bonds were, therefore, considered for this study. Three glues were tried in various aspects of this study. They include Reichhold Chemicals' phenolic resins IB-337 Plyophen and IB-334 Plyophen, and Borden Chemicals' Cascophen (2600-CR 40), and are described below.

3.2.1 IB-337 Plyophen

Reichhold Chemicals' IB-337 Plyophen (hereafter called PF IB-337) phenolic resin produces high quality exterior adhesive bonds for the plywood industry. It was used successfully in the development of Douglas-fir LVL at the Western Forest Products Laboratory. It is characterized by moderate to good tolerance to long assembly times, a feature used to advantage in producing continuous LVL, and fast rates of cure.

The glue was supplied ready-mixed by the manufacturer. The glue mix, and mixing sequence for a five-gallon bucket of glue are given in Appendix IV(a).

Viscosity of glue measured with a Brookfield LVF Viscosimeter on No. 3 spindle (at glue lab.) was:

4,000 cps at 6 rpm, and

1,720 cps at 60 rpm.

On No. SC4-34/14 spindle (at WFPL) viscosity was:

4,600 cps at 6 rpm, and

3,590 cps at 12 rpm.

The difference was due to inbuilt differences in viscosimeters rather than change in degree of polymerization of the glue because further tests one week later did not show any change in viscosity or DP. The mixed glue was stored in a cold room at 34°F prior to use. The pH was 12.6.

3.2.2 IB-334 Plyophen

This resin is also water soluble and produces high quality exterior plywood bonds. The manufacturer claims that, when used according to their instructions, IB-334 (PF IB-334 hereafter) "is abnormally tolerant to conditions of long assembly times and high ambient and stock temperatures encountered . . . during the summer months." This glue was explored for possible improvement over the bond produced with PF IB-337.

The glue was also supplied ready-mixed and the mix and mixing sequence for a five gallon pail are shown in Appendix IV(b).

Viscosity measured on delivery at the WFPL laboratory was 7000 cps at 6 rpm using #SC4-34/13 spindle. The pH was also 12.6. The viscosity also remained unchanged after three weeks storage in a 34°F cold room.

3.2.3 Cascophen 904-003-Catalyst 400-040 (2600-CR40)

Cascophen 904-003-Catalyst 400-040 is a modified phenol-resorcinol resin glue (MPRG) for use in wood laminating and general assembly gluing. According to the manufacturer, it gives a completely waterproof exterior adhesive bond and passes the tests required by the Canadian Standards Association specification for Phenol and Resorcinol resin adhesives for wood, CSA 0112.7-1960 (Class 1, Type I and II and Class 2 Type II).

This more expensive glue was used to determine the full potential of the bond strength that could be produced with rotary-peeled ¼-inch veneers.

3.3 Experimental Procedure

3.3.1 Aspects of the Study

The experiments were done in four main stages: determination of adequate gluing conditions for (1) broadleaf maple, and (2) for sugar maple and black cottonwood veneers; (3) investigating the quality of bonds developed in the step joints of boards produced by simulating the last step in Bohlen's continuous LVL manufacturing process, and (4) the phenol-resorcinol bond quality test. The continuous LVL boards were manufactured from black cottonwood, sugar maple and white spruce veneers.

3.3.2 Experimental Design

3.3.2.1 Small panel tests

The design of the experiments for determining press schedules, using small panels,[15] is presented in Table 3.

---

[15]Size of panels are given under panel construction and conditioning.

In all cases, it was assumed that the factors tested were responsible for the variation in the strength and related properties. This assumption was made on the basis that other gluing conditions were held relatively constant for all panels.

The general model for a two factor analysis of variance (ANOVA) with interaction is:

$$Yijk = \mu + \tau_i + \beta_j + (\tau\beta)ij + Eijk$$

where τ and β are the two factors, $(\tau\beta)ij$, the interaction term and Eijk the error term. The statistical assumptions are: $Eijk \sim NID(0, \sigma^2)$

$$i = 1, - - - - k$$

$$j = 1, - - - - n$$

$$\sum_{i=1}^{k} \tau i = 0$$

$$\sum_{j=1}^{n} \beta j = 0$$

$$\sum_{i=1}^{k} \sum_{j=1}^{n} (\tau\beta)ij = 0$$

Only when the interaction term is not significant can Duncan's Multiple Range Test be carried out. Whenever the interaction terms were significant, the means for the various treatment combinations only were discussed.

The factor names and levels are presented in Table 4. Individual factors are further discussed under the subheading Testing Procedure (3.3.5).

Besides the ANOVA and Duncan's Multiple Range Test (DMRT) where applicable, mean of observations for individual treatment combinations would be discussed.

3.3.2.2. Continuous LVL tests

These were designed to test suitability of the continuous process described by Bohlen. Mean values of the variables, would be evaluated according to American National Standards specification on glued laminated timber: Voluntary Product Standard P.S. 56 - 73. Standard deviation and coefficient of variation of the variables would also be discussed.

The quality response test was designed to show graphically the quality of the central glueline along the whole length of the continuous LVL. The graphs would show the transition between the sections.

Delamination tests would show the quality of all gluelines according to CSA O177 - 1965. Besides the average delamination, performance of each board along its whole length would also be discussed.

3.3.3 Panel Construction and Conditioning

3.3.3.1 Veneers for small panels

The broadleaf maple veneers were very poor (see section 3.1.1). However, those selected for panel construction were free of knots larger than ¼-inch across the grain, excessive grain deviation, knot holes and other unsound defects. Veneers were not planed but those showing observable thickness variation were excluded. Cluster knots and isolated bird's eye were permitted.

Characteristics of sugar maple and black cottonwood veneers, for small panels, are presented in the first two rows of Table 5. The figures are mean values calculated from sample measurements. The measurements were taken on four by four-inch specimens cut from full size veneers (Figure 3). Test-weight (M) and oven-dry weight (M_1) of each specimen were taken and moisture content (MC) was calculated from the equation:

$$MC\ (\%) = \frac{M - M_1}{M_1} \times 100$$

The percent depth of lathe check and roughness (Northcott and Walser, 1965), were estimated. Length and breadth of each specimen were measured with dial calipers calibrated to 0.001 inch. Thickness was measured with a pressure operated veneer thickness measurer developed at the WFPL, Vancouver. Myronuk (1972) described the semi-automatic model of the veneer thickness measuring system. Specific gravity of each specimen was calculated using test-weight and test-volume.

3.3.3.2 Gluing of small panels

In all cases, six veneers were assembled with their loose side toward the inside of the assembly. Glue was brushed on to the lower surface of each of the five upper plies. Gluespread, based on lb/MSGL, was predetermined and the amount to be deposited on each of the five plies was kept constant by weighing.

The small panels constructed for the various tests are presented by number, in Figure 4. Pressing conditions other than those being tested are presented in column 7 of the same figure. Broadleaf maple panels were 12 by 12 inches while those of black cottonwood and sugar maple were 12 by eight inches. All panels were conditioned to laboratory conditions for seven days prior to machining.

In all cases, temperatures of central and outer gluelines were taken. Copper-constantan thermocouples from a two-channel potentiometer recorder were used. When the central glueline temperatures specified in the design were attained the press was immediately opened. Further rise in temperature was not recorded. The panels were hot-stacked for 24 hours before they were stickered for the last six days of conditioning.

The control panels for temperature measurement were not glued.

The test for effect of double-pressing was designed to simulate the condition in which some parts of LVL are pressed once and others twice. It takes approximately 20 minutes to raise CGLT of assembled six-ply sugar maple LVL to 240°F, and about three minutes to lay up gluespread veneers and index the assembly forward into the press. The portion pressed twice was simulated by pressing during two 20 minute press cycles with a three minute interval between press cycles.

Sugar maple and black cottonwood veneers laminated with MPRG were conditioned in the 12 percent equilibrium moisture content (EMC) chamber for three months. The veneers attained an average MC of 8.4 and 12.7 percent, respectively. Spreads below 37.5 lb/MSGL were difficult to brush on to sugar maple veneers and even 37.5 lb/MSGL spread was difficult to brush on to black cottonwood, owing to the low viscosity of the glue.

The glue requires a minimum clamp time of seven minutes with a CGLT of 180°F, or three minutes at 220°F. Because the CGLT continued to rise after attaining 180°F, the boards were clamped for five more minutes after this CGLT was attained. Total clamp time was 15 minutes.

3.3.3.3. Quantity and characteristics of veneers used for the continuous LVL production

Two full lengths of veneer were used to simulate the last two press cycles in the continuous LVL production process. This means that 12 veneer sheets per board were used. Full lengths of BCW, SMP and WSP veneers were 52, 42, and 50 inches, respectively. Samples of 4-inch by 4-inch test specimens were used to measure veneer characteristics which were determined as described for small panels. Specimens were cut as shown in figure 5 and the mean veneer characteristics are presented in Table 5.

3.3.3.4 Gluing of continuous LVL

Panels were constructed in two batches. The first batch consisted of one panel each of sugar maple, black cottonwood and white spruce LVL glued with PF IB-337. The second batch consisted of one panel each of black cottonwood and sugar maple LVL and both were laminated with PF IB-334. The continuous boards were 16 inches wide, and their lengths were determined by the original length of veneers (figures 5 and 6).

Veneers for the starter board were cut as shown in figure 7. In order to avoid end crushing of the starter board, a mid-segment consisting of veneers of equal lengths was introduced into the assembly such that the edge of the topmost veneer coincided with the edge of the upper platen. Six steps therefore stuck out of the platens as shown in figures 1 and 2. At the end of the first press cycle, the five steps were closed up with veneers already cut to size and spread with glue. The board was then indexed forward into the press with the end of the topmost ply coinciding with the edge of the platen as shown by the end board in figure 3.

In the continuous board manufacture, a mechanical gluespreader with rubber rolls was used to apply glue to veneers. Proper contact of butt joints was ensured and the assembly was indexed into the press manually. Platen pressures used were 275 psi for sugar maple, and 100 psi for black cottonwood and white spruce. The press cycle for sugar maple and white spruce LVL was determined by the time for CGLT to reach 240°F. For black cottonwood LVL, the press cycle was fixed at 22 minutes. A longer press cycle was considered undesirable in terms of production economics.

3.3.4 Specimen Preparation

3.3.4.1 Shear blocks from small panels

Twenty block shear specimens were cut from each small panel of broadleaf maple LVL except for that used for adequate gluespread test at 42.5 lb/MSGL from which, owing to highly defective portions of one of the central plys, only ten shear blocks were obtained. Blocks were cut according to CSA 0177-1965. While testing the cyclic (vacuum/pressure) soak (CVPS) specimens, it was observed that specimens swelled tangentially and some exceeded the width of the shearing head of the machine. For this reason block shear specimens from one of the sugar maple panels were reduced in width to approximately 1.9 in. from 2 in. A few specimens still swelled in excess of the width of the shearing head. Subsequent specimens were made 1.5 in. wide. Sample size for the small panel tests are shown in Table 6.

3.3.4.2 Shear blocks from continuous LVL boards

The mid-segment in the continuous boards were 42, 32, and 34 inches, for sugar maple, black cottonwood and white spruce, respectively. A 24-inch segment of these, adjacent to the end-board joints, was pressed twice. Therefore the remaining 18, 8 and 10-inch segments[15] were pressed only once (see figure 1, and the last two segments of figure 3 for platen overlap, i.e. portion pressed twice C5). Each continuous board was divided into sections: 1, pressed only once (the last four inches of the topmost ply of the starter-board inclusive); 2, pressed twice (24 inches in all cases); and 3, pressed once (the end board which was 30 inches in all cases).

Four 1.5-inch and four 2-inch strips were sawn from each board for block shear and delamination specimens, respectively. Two 1.5-inch strips were randomly selected for each of dry and CVPS tests respectively, two 2-inch strips for delamination test; and only in case of PF IB-334 bonded LVL boards, the last two were used for boil test.

In order to test the bond quality of the whole strip, two-inch long block shear specimens were cut and coded consecutively from the last four inches of the top ply of the

---

[15] These lengths were estimated, using the topmost plies only.

starter board. In some instances, the last block of section 1 and/or section 2 was shorter than two inches. Because specimen length has significant effect on shear strength (Strickler 1968), such substandard blocks were discarded. But for the width of 1.5 in., all block shear specimens were also cut according to CSA 0177-1965.

Delamination and boil test specimens were cut into two-inch cubes and were coded exactly as for block shear specimens. Subsize specimens were discarded.

3.3.5 Testing Procedure

3.3.5.1 Dry shear test

Test specimens were conditioned in the laboratory for three days after preparation. The central glueline was then sheared in compression loading according to CSA 0177-1965 for glued-laminated timber. However, because of equipment breakdown, blocks from PF IB-337-glued continuous LVL were tested three weeks after machining. A Tinius Olsen 20,000 lb. testing machine, fitted with a shearing head was used.

The maximum failing load in shear and % wood failure were recorded for each block. Each specimen was weighed after the testing and oven drying in order to establish the moisture content at time of test.

3.3.5.2 Cold soak

In the final draft of a quality control program established for a local LVL manufacturer in B.C., Bohlen

(1972b) specified a 24-hour cold-soak test (after DIN 68705) or a (vacuum/pressure) soak test for shorter duration. The 24-hour cold soak only was used in the broadleaf maple tests, where specimens were held submerged in water at 70 to 75°F for 24 hours and sheared wet afterwards. Also, failing load and % wood failure were recorded.

3.3.5.3 Cyclic (vacuum/pressure) soak test

The test specimens were held submerged in water in a retort at 70 to 75°F. A vacuum of at least 25 inches of mercury was drawn by water vacuum for two hours, followed immediately by application of 75 to 80 psi for two hours. Specimens were removed from the retort, dried for 14 hours in an oven at 60° ± 5°F at an air speed of 450 fpm. The vacuum/pressure cycle was repeated and then the specimens were tested wet. This test is between the vacuum-pressure-soak recommended by Bohlen (1972b) and the delamination test of CSA 0177-1965.

The latter was modified for use in this study in order to cut down length of test period. Since only the central glueline would be tested, it was assumed that the delamination tests would be more informative because they would test all gluelines. Hence the delamination test was carried out according to CSA 0177-1965.

Also, the oven available at the time the shear test was being carried out has a forced air circulation of 450 fpm instead of the 200 to 300 fpm recommended in CSA 0177-

1965. If the test was not modified, the specimens would be subjected to excessive drying stresses.

3.3.5.4 Delamination test

The delamination test was carried out according to CSA 0177-1965, but length of specimens was changed in order to test board quality with two-inch blocks cut consecutively as in the strength response test.

Specimens were put in a retort where they were held immersed in water at room temperature of 70 to 75°F. Samples were separated for all end-grain surfaces to be exposed to water. A vacuum of at least 25 inches of mercury was drawn and held for two hours. The vacuum was then released and a pressure of 75 ± 5 psi was applied for two hours. The vacuum/pressure cycle was repeated and then the specimens were dried for 88 hours in air at 80 ± 5°F and 25 to 30% relative humidity with the air moving at 200 to 300 fpm. The entire soaking-drying cycle was repeated twice to comprise a total test period of 12 days.

Following the final drying period, the total length of open glue joints on the end-grain surfaces of the specimens were measured to the nearest 1/16-inch and expressed, for the two end-grain surfaces as a percentage of the entire length of gluelines exposed on these surfaces. Gluelines at knots or knotty areas were excluded from estimation of delamination.

3.3.5.5 Boil test

Specimens were held submerged in boiling water for four hours, then dried in an oven at 145° ± 5°F for 20 hours, held submerged again in boiling water for another four hours and then cooled in water at 70 to 75°F. The specimens were not tested in shear but percentage delamination was measured as described for the delamination test above.

3.3.5.6 Shear strength adjustment

The moisture contents at time of test were generally low except for the blocks from the PF IB-337 bonded continuous LVL blocks which were sheared three weeks after machining. All dry shear strength values for all species except broadleaf maple were adjusted to their seven percent moisture content equivalents.

The USDA Forest Service (1955) devised exponential formulae for accurate adjustment of strength properties of wood at different moisture contents to their equivalent at a common moisture content level. Approximate values were also given for situations where high accuracy was not expected. A three percent average increase (or decrease) in shear strength was given for a one percent decrease (or increase) in moisture content. The American National Standards (1973) gave 3.7 percent for structural glued laminated timber. Since it is known that lathe checks weaken the plies in LVL, a condition absent in laminated timber, the laminae of which are generally planed and solid, an approximate adjustment factor of three percent was adopted in this study. The wet shear data were not adjusted.

4.0 RESULTS

4.1 Small Panel Tests

4.1.1 Glueline Temperature of Broadleaf Maple, Black Cottonwood and Sugar Maple LVL

Temperature rise of broadleaf maple LVL at a spread of 42.5 lb/MSGL, platen pressure of 200 psi, and temperature of 300°F, and CGLT of 233°F, is shown in figure 8. The three central glueline temperatures considered in these studies are marked by horizontal lines on the graph. Temperature in the CGL of broadleaf maple LVL as affected by size and temperature of press platens and gluespreads are presented in Table 7. A similar study for black cottonwood and sugar maple is presented in Table 8.

4.1.2 Adequate Gluing Conditions for Broadleaf Maple LVL

The ANOVA tables and statistically ranked means for three variables--maximum failing load in shear, shear strength and wood failure developed at gluespreads 27.5-, 30-, and 37.5 lb/MSGL are presented in Table 9. The ANOVA table and ranked means for the four levels of gluespread are presented for wood failure in the last row of Table 9. Mean, standard deviation and coefficient of variation of each of the three variables at the different treatment combinations are presented in Tables 10 and 11.

Effect of platen temperature and aging on the quality of central glueline bonds and the statistically ranked means under different treatments are presented in Table 12. The mean, standard deviation and coefficient of variation of the three variables are presented in Table 13 for the four treatment combinations.

Table 14 contains ANOVA tables and statistically ranked means of variables obtained from specimens tested for adequate curing temperature. Table 15 contains the mean values for treatment combinations.

The effect of pressure and aging on shear strength, wood failure and thickness of LVL panels are presented in Table 16.

4.1.3 Adequate Gluing Conditions for Black Cottonwood

Dry shear strength at test, adjusted shear strength and wood failure were the three variables used in determining the adequate gluing conditions for black cottonwood and sugar maple (Table 17).

For adequate gluespread, ANOVA tables, and statistically ranked means are presented in Table 18. The mean values of variables at various treatment combinations are presented in Table 18.

Tables 19 and 20 contain ANOVA tables with statistically ranked means, and mean values for treatment combinations, involved in the study of adequate pressure for black cottonwood.

4.1.4 Adequate Gluing Conditions for Sugar Maple LVL

Results for adequate gluespread and adequate pressure tests are presented in Tables 21, 22 and 23, 24, respectively. Variables, gluespread levels, agings and tests are as for Tables 17, 18, 19 and 20.

For effect of double-pressing, five variables were considered. Tables 25 and 26 contain ANOVA tables with statistically ranked means, mean and variability of strength and related properties (variables), at the different treatment combinations, respectively.

4.1.5 Performance of MPRG in Sugar Maple and Black Cottonwood LVL

For the adequate gluespread test analysis of variance tables with statistical ranking are presented in Table 27. Mean and variability of strength properties under the different treatment combinations are presented in Table 28.

To investigate bond quality of black cottonwood LVL laminated with MPRG, ANOVA test was carried out for dry shear strength and wood failure. The results are presented in Table 29. Mean and variability at the various treatment combinations are presented in Table 30.

4.2 Continuous LVL Tests

4.2.1 Mean Values for Continuous LVL Sections

Mean and variability of each of the three sections of the continuous LVL board are presented in Table 31. The various combinations of species, aging, glue and section are shown.

4.2.2 Glueline Temperature of Continuous LVL

Temperature rise curves for the three critical points in the LVL board during continuous production are presented in figure 9.

Temperature distribution within LVL during the press schedule and the average rise at the various points within the boards, are presented in Table 32. The wood species, platen pressure and glue combinations are shown on the table.

4.2.3 Strength Quality Response to Continuous Laminating Process

Dry and adjusted shear strength and wood failure along the length of continuous boards are presented graphically in figures 10 to 19. The three sections of board are identified. The effects of aging are also shown. Trends are shown for different wood species/glue combinations.

4.2.4 Delamination Test

Average delamination in each of the three sections for wood species/glue combinations are shown in Tables 33 and 34. Results in Table 33 were obtained from specimens tested by cyclic vacuum/pressure/dry delamination of LVL while those in Table 34 were obtained from boil/dry/boil test of PF IB-334-bonded LVL.

5.0 DISCUSSION

5.1 Small Panel Tests

5.1.1 Press Schedule for Broadleaf Maple

Bohlen (1972a) used a 20-minute press time, 200 psi pressure and 30 lb/MSGL of glue in his Doublas-fir LVL study. Using similar pressing conditions of 200 psi and 300°F platen pressure and temperature, respectively, the same gluespread of 30 lb/MSGL, and same glue, PF IB-337, BMP LVL reached a CGLT of 233°F in 32 minutes. This pressing time was for 16 by 16 in. panels rather than 54 by 54 in. panels. The CGLT, while using gluespread of 42.5 lb/MSGL, reached 240°F in 25 minutes when the large press at platen temperature 350°F was used.

The longer press time with BMP LVL was expected because BMP is denser than Douglas-fir. Although conductivity of BMP is higher than that of Douglas-fir (MacLean 1941), its rate of temperature rise is decreased by its higher specific heat. According to MacLean (1930, 1932) diffusivity,[16] which is a measure of rate of change of temperature can be expressed by the equation

$$h^2 = \frac{K}{ce},$$

where: h^2 is the diffusivity, K the thermal conductivity; c, the density and e, the specific heat. Consequently, within

---

[16] Diffusivity is in inch-second-degree, thermal conductivity, in Btu/hr/ft²/°F/in. and specific heat in Btu.

certain limits, the denser wood should have a lower rate of change of temperature and hence a longer press time than a less dense wood.

The veneers with zero gluespread heated faster than the gluespread ones. Although MacLean (1955) concluded that glue does not appreciably alter the conductivity of plywood panels, the presence of extra material to heat generally increases time to raise CGLT. Data presented in Table 7 confirm that the higher the platen temperature, the lower the press time required to reach a specified CGLT. Table 7 also shows that the higher the gluespread, the longer the press time.

5.1.2 Adequate Gluespreads for Broadleaf Maple LVL

The ANOVA of maximum load in shear, shear strength and wood failure developed at spreads 27.5-, 30- and 37.5 lb/MSGL under dry and 24 hour cold soak agings show the following (see Table 9):

(a) There was no significant difference between maximum load at spread 27.5 and 30 lb/MSGL, but value at spread 42.5 lb/MSGL was significantly higher than for the lower spreads. The same is true for shear strength. The three spread levels showed significant differences in wood failure.

In all cases, the 24-hour cold soak significantly reduced the three strength properties.

The ANOVA table in the last row of Table 9 showed no significant difference between wood failure at spreads 37.5- and 42.5 lb/MSGL. This analysis, done with sub-samples of 5, was less sensitive than that carried out with samples of 10 because as shown by the latter, the wood failure at spreads of 27.5- and 30 lb/MSGL differed. Larger samples might possibly show significant difference between the two higher spreads. In essence, the strength properties developed with a spread of 42.5 lb/MSGL would be higher than those developed with the three lower spreads.

The American National Standard A 190.1-1973 (PS 56-73) specifies a minimum of 80 percent average wood failure for wet-use adhesives used with all species and for dry-use adhesives used with softwoods and non-dense hardwoods. A minimum of 90 percent of clear lumber shear strength parallel to grain was specified for laminated timber.

Tables 10 and 11 show that specimens with 27.5- and 30 lb/MSGL gluespread failed both in dry and wet shear and those with 37.5 lb/MSGL passed only in dry shear. Table 11 shows that bonds produced at 42.5 lb/MSGL spread passed at both dry and cold soak.

The average strength values showed a general trend of increasing strength with increasing gluespread (Tables 10 and 11). This agrees with the finding of Fischer and Bensend (1969) in their study of southern pine, which is a porous softwood, that shear strength continued to rise, and maximum gluespread of 90 lb/MSGL (higher than maximum gluespread in this study) gave maximum wood failure.

The cold soak test reduced maximum load by 74, 66, 66 and 66 percent for spreads of 27.5, 30, 37.5 and 42.5 lb/MSGL, respectively, shear strength by 75, 68, 70 and 68 percent, respectively, and wood failure by 68, 47, 24 and 11 percent, respectively. It should be noted that part of the reduction was due to presence of water. However, high reduction in strength was not expected because CGLT was raised to 233°F before the press was opened, and hence proper curing of glue was expected. This CGLT was higher than the 220°F reported for the plywood industry (Jarvi 1967; Chow et al. 1973, and Shelton 1969). This corroborates the warning of Chow et al. (1973) that the industry should ensure that CGLT reached the proper temperature prior to hot stacking if the CGLT is to reach adequate curing temperature. Saturation of specimens with water (Chunsi 1973) and presence of lathe checks (Bohlen 1972a, and Schaffer et al. 1972) and possibly, undercure of glueline were responsible for the substantial strength reduction.

Although average wood failure at 42.5 lb/MSGL spread was 85 percent it was considered quite low although it passed the 80 percent wood failure specification of the American National Standard PS 56-73. It was considered quite low because of the presence of lathe checks which usually increase wood failure.

5.1.3 Effect of Platen Temperature

The ANOVA (Table 12) showed that panels heated to CGLT of 233°F using 300°F and 400°F platens did not show any significant difference in either maximum load, shear strength or wood failure. This showed that platen temperature did not have any significant effect on CGL of LVL but the temperature to which the CGL was heated. In essence, it is the degree of cure of the CGL that matters, not the platen condition used.

The significant difference in the aging test showed that the CGL was weakened by aging.

Mean dry strength values (Table 13) showed slightly higher values for panels pressed at 300°F than for those pressed with 400°F platens, except for the dry wood failure which was 96 percent in either case. The aged specimens showed higher values in panels heated with 400°F platens than in those heated with 300°F platens. At the two platen temperatures, averages of maximum load were 2500 and 2114 lb., shear strength, 575 and 477 psi, respectively, while average wood failure of panels were 83 to 85 percent for the two platen temperatures, respectively.

These differences are quite large though not significant at 0.05 level as shown above.

5.1.4 Adequate Curing Temperature

Panels heated to CGLT 233°, 240° and 300°F were tested dry, cold soaked and cyclic (vacuum/pressure) soaked and analysed for difference of means (Table 14). The platen temperatures used were ignored, on the basis of the test above.

Maximum load and shear strength showed no significant difference between panels at CGLT 1 and 2. Similarly they showed no significant difference between panels at CGLT 2 and 3. That is, only panels at CGLT 1 and 3 were significantly different.

The maximum load and shear strength were not significantly different after 24-hour cold soak and cyclic (vacuum/pressure) soak, though they were significantly higher when tested dry than after the two accelerated agings.

These results show than at an 0.05 level of significance CGLT3 (300°F) does not produce a better bond than CGLT2 (240°F). Similarly, the 24-hour cold soak and the cyclic (vacuum/pressure) soak do not differ significantly in their aging effect on shear specimens.

Wood failure showed the effects of CGLT more clearly because while there was no significant difference between CGLT of 240 and 300°F, it showed that either of them produced significantly higher wood failure than CGLT of 233°F. Maximum load and shear strength did not show significant difference between CGLT 1 and 2.

This better estimate of bond durability obtained with wood failure agrees with the conclusion of Northcott and Colbeck (1960), and Northcott et al. (1963), that within limits, percent wood failure was a potentially good estimator of plywood durability. In an earlier work, Northcott (1955) had postulated that there was poorer correlation between breaking load and service life than between percent wood failure and service life.

The average wood failure values presented in Table 15 were highest at CGLT 240°F irrespective of aging and were lowest at CGLT 233°F. These results, including the ANOVA, justify the acceptance of 240°F as an adequate curing temperature to be attained in the press to ensure adequate cure of these phenolic resins during hot stacking of LVL. This 240°F minimum was adopted in the small panel tests.

5.1.5 Effect of Platen Pressures

Pressures of 250 and 275 psi showed considerable increase in shear strength and wood failure over the values for panels pressed at 200 psi (Table 16). Net thickness of specimens made at 200, 250 and 275 psi are 1.548, 1.351 and 1.296 inches, respectively. The latter two are evidently lower than the nominal 2-inch thickness required for an LVL joist or stud. While specimens made at 200 psi showed an increase in thickness of 5.8 and 7.2 percent during cold soak and cyclic aging, respectively, those made at 250 psi increased by 16.1 and 20.0 percent, respectively and those made at 275 psi swelled by 21.7 and 24.4 percent, respectively. Broadleaf maple LVL pressed at 250 and 275 psi therefore, showed severe dimensional movement, which was probably due to over compression during manufacture.

For dry-use conditions and in structural uses where thickness is not limiting, using these higher platen pressures for broadleaf maple LVL would be advantageous. They would be highly limited in wet use situations.

The broadleaf maple LVL study proved the following general gluing conditions: that gluespread of 42.5 lb/MSGL gives better results than lower gluespreads, CGLT and not platen temperature determines CGL bond strength, and CGLT of 240°F is preferable to either 233 or 300°F, while using PF IB-337.

Specifically, broadleaf maple LVL at a spread of 42.5 lb/MSGL would require a press time of about 25 minutes to get CGL to 240°F when using a 54-inch by 54-inch press heated to 350°F and maintained at 200 psi. A small 16 by 16-inch press at 300°F and 200 psi would take about 40 minutes. Also, a press pressure of 200 psi would be preferred to either of 250 or 275 psi.

5.1.6 Black Cottonwood and Sugar Maple Studies

As shown in Table 5, the peeling characteristics of black cottonwood and sugar maple veneers were much better than corresponding values for broadleaf maple veneers (page 26). If peeling characteristics are the main determining factors for using high gluespreads, then black cottonwood and sugar maple would require lower spreads.

5.1.6.1 Press schedules for black cottonwood and sugar maple LVL

The black cottonwood LVL panels took 27.5, 31 and 35 minutes, at gluespreads of 30, 37.5 and 42.5 for the CGL to heat up to 240°F. Platen size of 16 by 16 inches and temperature of 350°F were used. At the time the 240°F CGLT was reached the outer glueline attained 299, 300 and 309°F at the three gluespreads. The non-glued panels reached 240 ± 1°F within 15 to 18 minutes and the outer glueline reached 288 to 295°F within the same period. These show the same trend of press time with gluespread as shown by broadleaf maple. Also, by the time CGL was heated to 240°F, the OGL had reached temperatures which preclude undercure. Sugar maple LVL also showed the same trend, the CGLT reaching 240°F in 17.3 to 20.25 minutes for gluespreads ranging from zero to 42.5 lb/MSGL.

The press times presented in Table 8 are, strictly speaking, not comparable. This is because the initial temperature of the assemblies differed in the black cottonwood and sugar maple LVL. A factor X, calculated by dividing change in temperature of CGL over the pressing period by the press time, is considered more comparable. In all species studied, the higher the gluespread, the lower was factor X and the higher the platen temperature (see Table 7), the higher was factor X. The nearer the glueline to the platen, the higher is the factor X. Over a long press time, the gradient between factor X of the central and outer gluelines diminished. This was shown by the data for the double-pressed panels in Table 8. The effect of pressure on press time was slight. The CGL of sugar maple LVL panels pressed at 275 psi attained 240°F, 1.5 minutes faster than that for panels pressed at 250 psi. There was no difference in press time of black cottonwood LVL pressed at 69 and 100 psi, respectively.

Other factors such as the slight differences in thickness of boards, presence or absence of knots and knot holes in the assemblies may also have had an effect on press time. Investigation of such factors were beyond the scope of this study.

5.1.7 Adequate Gluespread for Black Cottonwood LVL

Analysis of variance (Table 17) showed that each of shear strength, adjusted shear strength and wood failure was significantly different at spreads of 30, 37.5 and 42.5 lb/MSGL, consequently showing that spread 42.5 lb/MSGL was superior to all others. The cyclic (vacuum/pressure) soak also significantly reduced the three strength characteristics of LVL.

The strength values for individual spread/aging combination (Table 18) showed progressive increase from the lowest to the highest gluespreads studied. The same trend was observed both in the dry and cyclic (vacuum/pressure) soak specimens. Dry shear specimens showed wood failure of 42, 88, and 95 percent, respectively, while the aged specimens showed wood failure of 18, 71, and 87 percent, respectively. Only the 42.5 lb/MSGL specimens passed the minimum 80 percent requirement of the American National Standards PS 56-73.

Variability of the strength characteristics decreased from the lowest to the highest spreads studied and was higher in the cyclic (vacuum/pressure) soak than in the dry specimens. The gradient of variability between the two agings also decreased with increasing spread level. This lower variability suggests that as bond improved, glueline characteristics became more uniform.

5.1.8 Adequate Platen Pressure for Black Cottonwood LVL

Analysis of variance showed that strength characteristics (shear strength and wood failure) of panels pressed at 100 psi press pressure were significantly higher than for those pressed at 69 psi (Table 19). The platen pressure/aging combinations (Table 20) showed wood failure of 97 compared to 87 percent for panels pressed at 100 psi and 69 psi, respectively after aging. The dry test wood failures were 99 and 95 percent, respectively. This shows that the superiority of bonds produced at 100 psi over that produced at 69 psi was more pronounced after aging.

Dry test shear strengths were 1228 and 1097 psi and adjusted shear strengths were 1156 and 1034 psi, respectively, for the two pressure levels, while the cyclic (vacuum/pressure) soak specimens showed shear strengths of 566 and 450 psi, respectively.

The improved strength values must have resulted from the more intimate mating of the wood surfaces caused by higher pressure. Average thickness of black cottonwood LVL pressed at 69 psi and tested dry was 1.509 inches. It was 1.456 inches at 100 psi. The cyclic aged equivalents had mean thickness of 1.568 and 1.506 inches respectively. These represent thickness increases of 3.9 and 3.2 percent. Thickness of black cottonwood LVL panels produced at platen pressure of 100 psi was not substantially lower than that for panels produced at 69 psi. Thickness in either case was quite close to the nominal 2-inch dimension for stud or joist lumber. Dimensional movement during aging was not excessive.

Shear strength value for small clear specimens of solid sawn black cottonwood published by Kennedy (1965) for shear parallel to grain in tangential plane is 1157 psi for air dry (12 percent MC) condition and 770 psi at green condition. The air dry shear strength, adjusted to the seven percent MC equivalent, using the approximate conversion factor of three for every percent moisture change as suggested by the USDA forest service (1955), becomes 1331 psi. The shear value of black cottonwood LVL similarly adjusted becomes 1156 psi which equals 87 percent of the solid lumber equivalent. The shear strength of cyclic (vacuum/pressure) soak LVL specimens was 566 psi or 74 percent of published green figures (Table 36).

These shear strength values of black cottonwood LVL are quite high percentage-wise, bearing in mind that the veneers were of relatively poor quality compared with the small clear specimens used in Kennedy's study. Schaffer et al. (1972) reported Pres-Lam shear strength which was 67 percent of solid sawn controls.

5.1.9 Adequate Gluespread for Sugar Maple LVL

There was significant interaction between spread and aging in the ANOVA of dry test shear strength (Table 21). No such interaction occurred in ANOVA of wood failure which showed significant difference between spreads 30, 37.5 and 42.5 lb/MSGL, and between values at dry test and after cyclic (vacuum/pressure) soak aging.

Adjusted shear strength at spread/dry test combinations showed significant difference between the three combinations.

Strength values at the spread/aging combinations progressively increased with increasing gluespread irrespective of aging (Table 22). The wood failures recorded at the different spread levels were quite comparable with those produced by black cottonwood LVL. As expected, shear strengths at which these wood failures were produced were much higher in sugar maple LVL than in black cottonwood LVL (see Tables 18 and 21). Variability decreased with gluespread irrespective of aging.

In the light of the same trend in strength properties in both black cottonwood and sugar maple LVL, it was not understood why the interaction term should be so highly significant in sugar maple (for shear strength) while not significant in black cottonwood LVL. Possibly because of the tigher peel, and lower porosity (of grain) of the sugar maple veneers, more of the glue remained in the glueline than with poplar. This would increase the thickness of the glueline and if under the gluing conditions there was undercure, the thicker the glueline, the higher would be the percentage of undercure, and hence the lack of water-proofness of glueline. Also, the thicker the glueline the higher the tendency to develop micro cracks which would lead to glueline failure when stressed. This would result in high interaction between gluespread and aging. Very low pressure would also have the same effect on glueline thickness.

5.1.10 Adequate Platen Pressure for Sugar Maple LVL

The results of both wood failure and shear strength show significant interaction of pressure and aging (Table 23).

The adjusted shear strength showed significantly higher values at 275 psi pressure than at 250 psi. The higher pressure improved both the shear strength and wood failure irrespective of the aging. Variability of dry strength increased with pressure contrary to expectation, but the aged samples had lower variability at the higher pressure. The latter was true of both dry and aged samples of sugar maple LVL (Table 24).

5.1.11 Small Panel Study, Summary and Comments

These tests have shown that good quality LVL can be produced from black cottonwood and sugar maple ¼-inch veneers. Gluing conditions were: maximum gluespread of 42.5 lb/MSGL of phenol-formaldehyde glue IB-337, CGLT of 240°F attained in the press, 100 psi and 275 psi for the two species, respectively, and platen temperature of 350°F. This high gluespread would introduce substantial moisture into the glueline. Table 36 shows that the strength of CGL produced under these conditions compares favourably with clear solid lumber except for broadleaf maple LVL. At the average condition of veneers given in Table 5, and the glue mixes given in appendices IV(a) and IV(b), and using the formula developed by Freas and Selbo (1947),[17] PF IB-337 would increase moisture content of black cottonwood sugar maple LVL lay-up by 0.93 and 0.53 percent, respectively. In the light of the long press time, high

---

[17] Increase in moisture content (percent) is:

$$\frac{W/100 \times G \times (L-1)}{\frac{T \times L}{12} \times 1000 \times S \times 62.5}\ 100 = \frac{0.000192\ WG}{TS}\ \frac{L-1}{L}$$

where:
W = pounds of water in 100 lb. of mixed glue;
G = pounds of mixed glue used per thousand square feet of glue-joint area;
L = number of laminations;
L - 1 = number of gluelines in glued assembly;
T = average lamination thickness (in inches);
S = specific gravity of wood (dry).

platen temperature and low initial moisture content veneers, this additional moisture would offer no disadvantage and even would offer a little help in reducing the tendency of laminations to oven-dry during pressing. Glue PF IB-334 added 1.25 and 0.71 percent, respectively, to the black cottonwood and sugar maple glued LVL assembly.

The long press time makes the economic feasibility of this wood product questionable except it could be drastically reduced. This is further discussed below.

5.1.12 Adequate Gluespread of Phenol-Resorcinol Glue with Sugar Maple

The ANOVA of wood failure (Table 27) showed significant difference between panels at spreads of 37.5 and 42.5 lb/MSGL. Aging did not reduce wood failure significantly at the 0.05 level. This is an expected improvement over the phenolic resins used in this study.

Shear strength showed significant interaction between gluespread and aging. This also happened with PF IB-337-bonded sugar maple LVL (Table 21). This interaction thus appears to be a factor inherent in sugar maple and probably not with the glue used. Adjusted shear strength at the two spread levels were significantly different at the 0.05 level.

The dry shear strengths developed were higher at

37.5 lb/MSGL gluespread than at 42.5 lb/MSGL, but after aging, the shear strength was higher at 42.5 lb/MSGL than at 37.5 lb/MSGL spread (Table 28). Under both dry and cyclic (vacuum/pressure) soak, wood failure was higher at 42.5 than at 37.5 lb/MSGL spreads. From this and other cases noted above, where the superiority of the bond at higher gluespreads showed more clearly after aging, it can be concluded that dry shear strength values tend to mask the actual quality of bond strength.

In MPRG-bonded sugar maple LVL, shear strengths developed at spreads of 37.5 and 42.5 lb/MSGL were decreased by 56 and 44 percent, respectively, and wood failure, by 2.8 and 0 percent, by cyclic (vacuum/pressure) soak. This aging reduced bond strength of PF IB-337-bonded sugar maple LVL by 59 and 4.5 percent in shear strength and wood failure, respectively. This decrease is higher than 44 and 0 percent given for MPRG-bonded sugar maple at 42.5 lb/MSGL gluespread reported above.

Chunsi (1973) recorded a shear strength reduction of 37 percent for laminated timber of In (Dipterocarpus tuberculatus Roxb.) having a specific gravity of 0.67 which is similar to that of sugar maple. Since he used solid planed lumber, the difference may be due to lathe checks and surface roughness of the ¼-inch veneers used.

The sugar maple LVL bonded with phenol-resorcinol glue (MPRG) and pressed at 275 psi and with a gluespread of 42.5 lb/MSGL, developed higher wood failure than its PF IB-337 bonded counterpart, and samples were less variable (Tables 24 and 28). These also agreed with the findings of Chunsi (1973). The wood failure developed was also not significantly reduced by cyclic (vacuum/pressure) soak, unlike that developed with PF IB-337.

5.1.13 Bond Strength with Black Cottonwood

As with sugar maple LVL, the wood failures at the two agings were very high, here 99.9 and 99.7 respectively. Dry test wood failure was not significantly reduced by aging (Table 29). The wood failure values were slightly higher than in PF IB-337-bonded black cottonwood LVL (Table 20). The average shear and wood failure values (Table 30) showed some improvement over PF IB-337 performance in the aged samples. The MPRG-bonded LVL developed 581 psi shear strength and 99.7 percent wood failure, while PF IB-337 bonded LVL developed 566 psi shear strength and 97.3 percent wood failure. As in the sugar maple LVL, dry test samples scored higher adjusted shear strength in PF IB-337-bonded than in MPRG-bonded black cottonwood LVL, whereas the reverse was true after the aging test.

Cyclic (vacuum/pressure) soak decreased the dry shear strength and wood failure by 41 and 0.2 percent, respectively. These compare favourably with the corresponding 54 and 1.9 percent reduction calculated from Table 20, for panels pressed at 100 psi in PF IB-337 bonded LVL.

5.1.14 Effect of Double-Pressing

Of the five variables tested in eight combinations, only in one variable was the interaction term not significant (Table 25). In the test, ANOVA for moisture content of samples at aging 1, the specimens showed significantly different moisture content between panels pressed for 20 minutes only (press time 1) and those pressed in two 20-minute press cycles with a three minute interval (press time 2). It did not differ significantly between glues. Adjusted shear strength at the two pressing times differed significantly for each of the glues.

Thickness of LVL at aging 1 showed non-significant F-values for any of pressing time, glue type and their interaction term. Hence, thickness of panels did not significantly differ irrespective of treatment/glue.

Strength values of samples glued with PF IB-337 were substantially lower for panels double-pressed than for those pressed once whereas the reverse was true for those glued with PF IB-334. This decrease in strength at high temperature agrees with wood failure values obtained for broadleaf maple LVL at CGLT of 300°F, which were slightly lower than values at CGLT of 240°F (Table 15). This strength reduction is unusual.

Moisture content of double-pressed panels was lower than that of single pressed panels. After cyclic (vacuum/pressure) soak, the double-pressed panels had higher moisture content than those single-pressed (Table 26). This is rather unusual because densification and heat stabilization should reduce moisture pick-up of the double-pressed panels.

A comparison of glues at pressing time of 20 minutes shows that PF IB-337-glued panels developed higher shear strengths and wood failure than PF IB-334-glued panels. This was expected because PF IB-337 was the glue originally modified for LVL production whereas PF IB-334 was tried only because of its higher dryout tolerance. The latter glue may, therefore, have not developed full bonds within the specified press time. This agrees with the manufacturer's advice[18] that PF IB-334 has a slower rate of cure than PF IB-337.

Depending on the wood used, quality of glueline may or may not be substantially affected by prolonged heating though differences in moisture content may cause adverse hygroscopicity problems. Thickness is not substantially altered if the same pressure is applied throughout the press cycles. When single- and double-pressed bands occur in a continuous board, some built-in defects may result.

5.2 Continuous LVL Study

5.2.1 Average Strength Characteristics of Board Sections

The CGL quality of continuous LVL produced by the

---

[18]Private communication with W.C. Ainslie (Wood Laboratory Manager, Reichhold Chemicals Ltd., Port Moody, Canada, 9th August 1973 (Appendix V).

process described by Bohlen was evaluated on the basis of whether or not the three sections passed the American National Standard P.S. 56-73, and variations of the thickness and moisture content of board sections were examined. The adjusted value of shear parallel to grain published by Kennedy (1965) was used in place of shear strength parallel to grain as determined according to ASTM D 2555-70, specified in P.S. 56-73. Adjusted shear strength of LVL less than 90 percent of the adjusted published equivalent (Table 35) was considered failed.

Published figures for white spruce were 670 and 985 psi, for green and air dry shear strength parallel to grain, respectively (Kennedy 1965). The air dry (approximately 12 percent MC) was adjusted to 1132 psi at approximately seven percent. From adjusted shear strength and wood failure figures presented in Table 32, and information on solid lumber in Table 35, Table 36 was prepared and it shows the following:

(i) Irrespective of glue or aging, continuous sugar maple LVL boards failed the specification for laminated timbers. Sections 1 and 2 passed the wood failure specification while they failed the shear strength specification. Section 3 performed poorly in all treatments. The failure of sections 1 and 2 in shear may be attributed to peeling characteristics such as lathe checks and roughness of mating surfaces. These have been stated in the literature to reduce shear strength though they have a tendency to increase wood failure.

(ii) Sections 1 and 2 of PF IB-337-bonded black cottonwood LVL passed while section 3 failed the dry test specifications. The aged specimens showed a similar result for the sections. The dry test with PF IB-334-bonded LVL passed in all three sections, but section 3 failed the wet test.

(iii) White spruce LVL passed the specifications irrespective of treatment, except section 1 which developed 74 percent wood failure after aging. This low wood failure was observed to be due to allowable defects in the veneers of the two central plies.

Because of complete delamination of the outer glue-line in some section 3 specimens (Table 31), it was not possible to estimate thickness and moisture content for that section in PF IB-337-bonded sugar maple LVL. There was no difference between thickness of dry test specimens from sections 1 and 2, and section 1 was less than two percent thicker than section 2 after cyclic (vacuum/pressure) soak. Moisture content of sections 1 and 2 did not differ significantly irrespective of aging.

In all wood species/aging/glue combinations, except in black cottonwood/dry test/PF IB-337, the trend was towards a slightly lower thickness in section 2 than the two other sections which were approximately equal. If thicknesses differed appreciably at time of manufacture, they were almost fully recovered after the conditioning.

The differences in thickness and moisture content of sections are not of such magnitude as could affect continuous LVL adversely in service. The strength and related characteristics considered showed consistently higher variability in section 3 than in sections 1 and 2, irrespective of aging. There was no consistent trend between sections 1 and 2 within species. White spruce LVL was the most variable in shear strength and wood failure in sections 1 and 2. Conversely, it was the least variable in section 3.

5.2.2 Strength Quality Response to the Continuous Board Laminating Process

The average strength characteristics discussed above showed the overall quality of sections without locating individual observations as they occurred in the beam. The object of this quality response test was to examine quality of bonds along the length of continuous LVL board. Defects could, therefore, be related to the continuous LVL production process.

5.2.2.1 Glueline temperature along length of boards

Recorder channels (thermocouple points in LVL) 1 and 2 monitored the temperature of section 1 central and outer gluelines respectively, and 5 and 8 monitored those of the last two inches of section 2. In all, except PF IB-337-

bonded black cottonwood and sugar maple, CGLT at point 8 was slightly lower than that at point 1 (see Table 33). A lower temperature at point 8 was expected because of heat loss at edge of platens, as reported by Carruthers (1959). The temperature rise of three critical points in the continuous board is presented in figure 9. Points 5 and 8 were not critical because that segment of board would be double pressed and hence full cure was assured. Points 1 and 2 were critical because they would determine the press time. It was mandatory to have temperature at points 7, 3, 6 and 4 (see figure 2) as low as possible because that segment might be under substandard pressure. If so, at high temperature, glue would precure or dry out and fail to flow or transfer. Sections further than points 6 and 4 would suffer prolonged closed assembly time, and while the glue might not precure, it would suffer moisture loss and hence improper bonding as Troughton and Chow (1972) demonstrated with plywood.

Figure 9 shows that up till about 226°F (i.e. during the first 15 minutes of press time) CGL of black cottonwood LVL showed the fastest rate of temperature pick up. From then on temperature rise was slow. Temperature of central glueline, one inch outside platen, was lower than its outer glueline equivalent in white spruce and sugar maple. The better performance of white spruce in section 3 is understandable because it scored the lowest temperatures at pounts 7, 3, 6 and 4 except for PF IB-334 bonded sugar maple which recorded a lower temperature than did white spruce LVL at point 4 (refer to figure 7 and Table 32).

The lower central glueline temperature of white spruce LVL suggested temperature to be the main cause of failure of section 3. The central glueline temperature of black cottonwood was higher in section 3 than that of sugar maple and the sugar maple LVL still performed more poorly than did black cottonwood LVL. Also, temperature in points 7 and 6 were lower in LVL boards bonded with PF IB-337 than in those bonded with PF IB-334. Nevertheless, the latter produced better bonds in section 3. These suggest that factors, other than temperature, were responsible for failure of section 3. Porosity of veneers and effect of additives in the glues are probably two of such factors.

5.2.2.2 Graphical illustration of bond quality of central glueline

In all cases, the most serious strength failure occurred at the beginning of section 3. This further suggested that high temperature was more critical than pressure.

The last 18 inches of the central glueline of section 3 should pass because it did not experience long assembly time. In all figures except 11 and 13 (wood failure of PF IB-337-bonded black cottonwood and same of PF IB-334 black cottonwood), this last segment was also highly variable.

Figures 16 and 17 showed significant improvement of shear strength and wood failure, respectively, of PF IB-334-bonded sugar maple LVL over those of PF IB-337-bonded LVL (figures 14, 15). The same was true of black cottonwood LVL in figures 10, 11 and 12, 13. This is probably due to presence of fillers which reduced dry out.

The variability of white spruce LVL is depicted in figures 18 and 19. While the average figures were reasonably high, variability along the length was very high. The first 12 inches of section 3 also showed definite evidence of some failure.

The graphs showed that all the continuous LVL boards produced were markedly variable along their length. Even sections 1 and 2, which developed high strength values in the central gluelines, were also markedly variable. The shear strength of PF IB-334-glued black cottonwood LVL (figure 12) showed a marked drop in strength along the board from section 1 through section 2. The trend after cyclic (vacuum/pressure) soak showed section 1 fairly uniform and same with section 2 which was also shown to be definitely lower than section 1. This drop in strength is probably due to wood deterioration in section 2. In the other figures, section 2 showed generally higher average values than section 1.

This test proved to be more sensitive than the average values. Not only are all boards shown to be highly variable, but even white spruce was shown to have developed weaker bonds at the step joints which protruded from the press.

5.2.2.3 Delamination test

5.2.2.3.1 Cyclic vacuum/pressure delamination (CSA 0177-1965)

The shear strength test showed the quality of the central glueline only. The delamination test was to show the quality of all gluelines. As stated above, the temperatures of the outer glueline at points 3 and 4 were higher than those of the central glueline at points 7 and 6, respectively, in almost all cases. This caused the outer glueline and the glueline between it and central glueline (hereafter called mGL) to be more susceptible to dryout or precure than the central glueline. Resistance to delamination would therefore be a better estimate of bond quality of all gluelines.

The average delamination figures presented in Table 33 showed that only PF IB-337-bonded sugar maple failed the maximum 8 percent delamination specified for hardwoods. None of the samples failed in section 2 and only sugar maple LVL failed in section 3, irrespective of glue used. White spruce LVL showed no delamination in any of the three sections.

Section 3 of PF IB-337-bonded black cottonwood LVL appeared to pass the test by scoring an average of 7 percent delamination. Performance of consecutive specimens showed that only the first four of the 13 specimens failed, scoring from 11 to 34 percent delamination. Also in three cases, some of the delamination occurred in mGL and in seven cases, some of the delamination occurred in central glueline. In PF IB-334 bonded black cottonwood LVL, only the first two specimens of section 3 failed, each scoring 32 and 35 percent delamination respectively. Each of the gluelines showed some measure of delamination.

Sugar maple LVL (PF IB-337-bonded) showed large scale delamination. Six of the ten specimens in section 1 failed, most of the failure being attributed to large knots and very rough spots around knots in the central glueline. Ten of the 15 recorded cases of delamination occurred in the central glueline. Only once did delamination occur in the outer glueline, while it occurred four times in the mGL.

Section 2 was relatively good but two specimens failed. The first specimen in section 3 recorded 55 percent delamination, the next four completely delaminated in the central glueline, the next two scored 30 and 27 percent, respectively, with all delamination being in mGL. The next specimen completely delaminated, and the last four scored 23, 27, 21 and 14 percent, respectively, and most of the delamination occurred in the OGL followed by CGL.

In sections 1 and 2 of PF IB-334-bonded sugar maple, delamination was negligible. In section 3, there was no complete delamination of any specimen but delamination was high in the first part of section 3. The recorded delaminations were 34, 46, 22, 11, 7, 0, 10, 14, 15, 1 4, 0, 0 percent, respectively, beginning from the platen end of section 3. Eighteen out of the 25 recorded cases of delamination occurred in mGL, three in the outer glueline and four in the central glueline.

These test results showed that the location of delamination is more important than the average. Therefore, both black cottonwood and sugar maple LVL (irrespective of glue used) failed the delamination test.

Table 34 shows average boil test delaminations for black cottonwood and sugar maple LVL which are lower than figures recorded for cyclic (vacuum/pressure/dry) delamination in Table 33. In the black cottonwood LVL figures, only the first two specimens failed in section 3, scoring 23 and 14 percent delamination, respectively. This shows that the first four inches of section 3 failed.

Sugar maple LVL showed a more severe failure than black cottonwood LVL but in both cases failure was relatively less severe than in the cyclic vacuum/pressure/dry delamination.

These agreed with the finding of Fischer and Bensend (1969) that the boil test is a less sensitive test of bond quality. This is due to the tendency of boil test to complete curing of undercured bonds which the vacuum/pressure test would detect.

Failure of section 3 of the LVL board makes the continuous LVL production process, described by Bohlen (1972a) and modified for species studied in this thesis, not technically feasible. The process was quite adequate for white spruce, though further work is required to reduce the variability of white spruce LVL beams.

A possibility for hardwoods is to use a cooling system (either a water jacket or dry ice) around the stepped joints protruding from the platens to minimize the temperature rise of this section of board. Development of glues with better assembly time tolerance would represent a major breakthrough in the development of this wood product.

The small panels had proved that adequate bonds could be produced with these species. Beams up to or longer than 16 feet could be produced, using 16-foot platen (or longer) presses. In such a case, a beam like that shown in figure 3 could be assembled and pressed in one press cycle. Such a beam would ensure all the advantages of uniformity of moisture content and strength, characteristic of laminated beams. Multiplaten arrangements are also possible which would increase daily production and minimize unit cost. Such multiplaten arrangements would involve some mechanized layup, charging and discharging of press. An 8-opening 16-foot platen press currently costs about $250,000.00 and would represent the main item of cost in an operation coupled to a larger mill complex. A listing and current cost of the machinery for an independent operation is presented in appendix VI. An economic analysis of such a production operation is outside the scope of this thesis.

6.0 CONCLUSION

Veneers used in this study were obtained from wood species grown in Canada. Trees were not obtained by any special sampling design, and bolts were free only of sound and unsound defects that would seriously hinder peeling. Results do not, therefore, necessarily reflect the characteristics of the species as a whole. Conclusions based on stated experiments, sample sizes and observations of sample behaviour can, however, be drawn.

A simple experimental design that would incorporate all possible treatment combinations was not considered feasible because of incomplete information on glue cure, heat penetration of wood species available, and optimum press schedules for the wood product under test. Experiments were therefore conducted successively, and factors which were not considered useful from a production point of view were eliminated. Some of the factors not tested, such as lower gluespreads for black cottonwood LVL at 100 psi, and for sugar maple LVL at 275 psi and glue PF IB-334 for optimum gluespread, could furnish useful information in a more extensive project.

Presence of glue decreased rate of temperature rise of the central glueline, in all species tested and this effect was proportional to gluespread. When using platen temperature of 350°F and gluespread of 42.5 lb/MSGL, press times of 19, 20 and 22 minutes were found suitable for continuous LVL of white spruce, sugar maple and black cottonwood, respectively.

Glueline shear strength and wood failure increased with increasing gluespread and pressure in broadleaf maple, black cottonwood and sugar maple LVL.

The central glueline temperature attained, and not the platen temperature used to attain it, was the main factor that determined central glueline bond quality.

There was no significant difference between central glueline strength quality of broadleaf maple LVL produced at a central glueline temperature of 240°F and that produced at 300°F.

Small LVL panels produced at a gluespread of 42.5 lb/MSGL, central glueline temperature of 240°F, and pressures of 200 psi, for broadleaf maple; 275 psi for sugar maple; and 100 psi for black cottonwood, produced wood failures which passed the American National Standards specification P.S. 56-73.

Small sugar maple LVL panels, constructed to simulate the double pressing which occurs in continuous LVL production, showed no significant differences in thickness between single-pressed and double-pressed panels, but a significant difference in moisture contents. There was a significant reduction in strength of double-pressed phenol-formaldehyde glue IB-337-bonded LVK, but a significant increase in strength of that bonded with the same glue modified for dry-out resistance.

There was considerable variation between the three sections within the continuous LVL boards in all species considered.

The average strength values of sections, the strength quality response plotted into graphs and the delamination tests showed that the step joints which protruded from platens during a press cycle in both black cottonwood and sugar maple continuous LVL failed. Therefore the species would be unsuitable for continuous LVL production with the manufacturing process described by Bohlen (1972a) and modified in this study.

The phenol-formaldehyde glue modified for dry-out resistance (IB-334) produced better bonds in the step joints than did the unmodified PF IB-337 which was originally formulated for Douglas-fir LVL.

White spruce produced LVL of reasonable quality but would require further and more detailed study to minimize the variability within the board.

Phenol-resorcinol glue produced stronger and less variable bonds than did phenol-formaldehyde glues in sugar maple and black cottonwood LVL.

7.0 RECOMMENDATIONS

The main features of the continuous LVL production process are: utilization of conventional plywood machinery, operational simplicity, labour intensiveness and the many advantages of wide endless boards. I recommend: (1) the use of a cooling system for the step joints, coupled with formulation of a better adhesive or (2) the use of a single-step system employing a long press in order to extend the potential of this wood product to the utilization of hardwoods.

8.0 LITERATURE CITED

American National Standards. 1973. "Structural Glued laminated timber voluntary product standard P.S. 56-73." American National Standard A 190, 1-1973.

Arneson, G.N. 1947. Possible uses of radio frequency heating in the plywood industry. Proc. Conf. Radio Frequency and Its Applications in Gluing Wood. University of Washington, Seattle, Wash., Bull. No. 2, pp 21-23.

Baier, R.E., E.G. Shafrin, and W.A. Zisman, 1968. Adhesion mechanisms that assist or impede it. Science 162 (3860): 1360-1368.

Baumann, H. and J. E. Marian. 1961. Gluing pressure in wood as a function of physical factors. Holz als Roh - Und Werkstoff 19(11): 441-446.

Bergin, E.G. 1969. The strength and durability of thick glue lines. Dept. Fish and Forest, Canada Forest Serv. Publ. No. 1260.

________, 1953(a). The gluing characteristics of various eastern Canadian wood species. Reprinted from Canadian Woodworker, December, 1953

________, 1953(b). The significance of wood failure in glued joints. Reprints from Canadian Woodworker, March, 1953.

________, 1964. Gluability of various eastern Canadian wood species. Forest Prod. Res. Branch, Contrib. No. P-76. Reprint, Canadian Wood Prod. Industries, Oct.-Nov. 1964.

Bohlen, J.C. 1974. Tensile strength of Douglas-fir Laminated Veneer Lumber. Forest Prod. J. 24(1): 54-58.

________, 1973. Dimension lumber from laminations of thick rotary peeled wood veneer. Reprint Proc. UIFRO Div. 5, held in Capetown, South Africa, Sept. and Oct. 1973.

Bohlen, 1972(a). LVL Laminated Veneer Lumber. Development and economics. Forest Prod. J. 22(1): 18-26.

________, 1972(b). LVL (Laminated Veneer-Lumber) quality control procedures manual. Fifth draft. Western Forest Prod. Lab., Canada Forest Serv. Dept. of the Environment, Vancouver, B.C.

Borden Chemicals, 1970. Laminating Douglas-fir with Cascophen 904-003-catalyst 400-040 adhesive (2600-CR40). Trade leaflet TD 904-003. The Borden Chemical Company (Canada) Limited, New Westminster, B.C.

Bruce, H.D., W.Z. Olson, J.M. Black, and A.H. Ranch, 1944. Gluing with low temperature setting phenol-resorcinol and melamine glues. Unpublished report, Project L-157, USDA Forest Serv. Madison, Wis.

Bryant, B.S. 1968. Studies in wood adhesion-interaction of wood surface and adhesive variables. Forest Prod. J. 18(6): 57-62.

Canadian Standards Association, 1965. Qualification code for manufacturers of structural glued laminated timber. CSA 0177-1965. Ottawa, Ont. 22 pp.

Carruthers, J.F.S. 1959. Heat penetration in the pressing of wood. DSIR Forest Prod. Res. London: H.M.S.O. Bull. No. 44.

Cartensen, J.P. 1961. Gluing characteristics of softwood veneers and secondary Western hardwood. Forest Prod. J. 11(7): 313-315.

Chow, S-Z, 1969. Color-intensity differences as indicators of surface inactivation with white spruce veneer. Canada Dept. Fish. and Forest. FPL Info. Rept. VP-X-104, 13 pp.

________, G.E. Troughten, W.V. Hancock, and H.N. Mukai, 1973. Quality control in veneer drying and plywood gluing. Canada Forest Serv. Western Forest Prod. Lab., Info. Rept. VP-X-104, 13 pp.

Chugg, W.A. 1964. Glulam. The theory and practice of the manufacture of glued laminated timber structures. Ernest Benn Ltd., London, 423 pp.

Chunsi, K.S. 1973. The gluability of certain hardwoods from Burma. MF thesis, Faculty of Forestry, University of British Columbia.

Cockrell, R.A. and H.D. Bruce. 1946. Effect of thickness of glueline on strength and durability of glued wood joists. USDA Forest Serv. Rept. No. R1616, US FPL Madison, Wis.

Currier, R.A., 1960. Compression of white pocket veneer in hot-pressed Douglas-fir plywood. Forestr Prod. J. 10(8): 409-415.

Curry , W.J. 1957. The strength properties of plywood Part 3: Influence of the adhesive. DSIR, Forest Prod. Res. Bull. No. 39, HMSO, London.

Dobie, J., 1970. Trends in Forest research use and forest products manufacturing in British Columbia. Canada Forest Serv. Western Forest Prod. Lab. Info. Rept. VP-X-75. 9 pp.

Echols, R.M., and R. A. Currier, 1973. Comparative properties of Douglas-fir boards made from parallel-laminated veneers vs solid wood. Forest Prod. J. 23(2): 45-47.

Eickner, H.W. 1942. The gluing characteristics of 15 species of wood with cold setting urea-resin glues. USDA Forest Serv. Mimeo No. 1342. Forest Prod. Lab., Madison, Wis.

Enabor, E.E. 1973. The prospects of forest industries development in Nigeria. Journal of the Geographical Association of Nigeria 16(1): 51-65.

Farmer, R.H. (ed.) 1972. Handbook of hardwoods, 2nd ed. Buiding Research Establishment. Princes Risborough Forest Prod. Lab. Aylesbury, Buckinghamshire.

Feihl, O. 1960. Wear, play and heat distortion in veneer lathes. Canadian Wood Worker. Dec. 1960.

________ and V. Godin, 1970. Peeling defects in veneer, their causes and control. Canada Dept. Forest. Rural Develop. Publ. No. 1280.

________, 1966. Veneer and plywood from aspen poplar. Canada Dept. Forest. Rural Develop. Publ. No. 1157.

Fischer, C., and D. W. Bensend. 1969. Gluing of southern pine veneer with blood modified phenolic resin glues. Forest Prod. J. 19(5): 32-37.

Freeman, H.A. 1959. Relation between physical and chemical properties of wood and adhesion. Forest Prod. J. 9(12): 451-458.

Fritz, D.W. 1969. The photoelastic coating method applied to stress analysis of wood. Master's degree thesis, Oregon State Univ. Corvalis (original not seen, cited from Bohlen, 1972a).

Government of B.C. 1972. The sawmilling industry of British Columbia. Dept. Ind. Develop. Trade and Comm. Parliament Buildings, Victoria, B.C.

Hann, R.A., R.W. Jokerst, R.S. Kurtenacker, C.C. Peters, and J. L. Tschernitz, 1971. Rapid production of pallet deckboards from low-grade logs. USDA Forest Prod. Lab. Madison, Wis.

Hse, C.V. 1968. Gluability of Southern pine early wood and late wood. Forest Prod. J. 18(12): 32-36.

Jarvi, R.A. 1967. Exterior glues for plywood. Forest Prod. J. 17(1): 37-42.

Jokerst, R.W. 1972. Feasibility of producing a high-yield laminated structural product: residual heat of drying accelerates adhesives cure. USDA Forest Serv. Res. Pap. FPL179 Forest Prod. Lab. Madison, Wis.

Kennedy, E.I. 1965. Strength and related properties of woods grown in Canada. Canada Dept. Forest Rural Develop. Publ. No. 1104.

Koch, P. 1973. Structural lumber laminated from ¼-inch of uniform high strength. Forest Prod. J. 18(10): 45-51.

________, 1967. Super-strength beams laminated from rotary cut Southern pine veneer. Forest Prod. J. 17(6): 42-48.

________, 1964. Techniques for drying thick southern pine veneer. Forest Prod. J. 14(9): 382-386.

________, and G. W. Woodson, 1968. Laminating butt-jointed log-run Southern pine veneers into long beams of uniform high strength. Forest Prod. J. 18(10): 45-51.

________, and B. Bohannan, 1965. Beam strength as affected by placement of laminae. Forest Prod. J. 15(7): 289-295.

Leicester, R.H., and P.C. Bunker, 1969. Fracture at butt joints in laminated pine. Forest Prod. J. 19(2): 59-60.

Lutz, J.F. 1972. Veneer species that grow in the United States. USDA Forest Serv. Res. Pap. FPL 167, Forest Prod. Lab. Madison, Wis.

Luxford, R.F., 1944. Strength of glued laminated Sitka spruce made up of rotary cut veneer. USDA Forest Serv. Rept. No. 1512, Forest Prod. Lab., Madison, Wis.

Macdonald, M.D. 1951. Compression of Douglas-fir veneer during processing. The Timberman 52(4): 98-100; 52(5): 86-92.

MacLean, J.D. 1955. The rate of temperature change in wood panels heated between hot plates. USDA Forest Serv. Rept. No. 1299, Forest Prod. Lab. Madison, Wis.

________, 1943. Method of computing the rate of temperature change in wood and plywood panels when the two opposite surfaces are maintained at different temperature. USDA Forest Serv. Mimeo No. R1406, Forest Prod. Lab. Madison, Wis.

________, 1941. Thermal conductivity of wood. Reprinted from ASHVE, Journal Section, Heating Piping and Air Conditioning.

________, 1932. Studies of heat conduction in wood - Part II. Results of steaming green sawed southern pine timbers. Proc. AWPA, 1932, pp. 303-329.

________, 1930. Studies of heat conduction in wood. Results of steaming green round southern pine timbers. Proc. AWPA, 1930, pp. 197-217.

Marian, J.E., and D.A. Stumbo, 1962. Adhesion in wood. Physical Factors. Holzforschung 16(5): 134-142.

________, and C.W. Maxey, 1958. Surface texture of wood as related to glue joint strength. Forest Prod. J. 8(12): 345-351.

Marra, G.G., 1959. Development of a method for rapid laminating of lumber without the use of high frequency heat. Forest Prod. J. 6(3): 97-104.

McKean, H.B. and W. J. Smith, 1958. Pilot planting laminated 2 by 4's. Forest Prod. J. 8(8): 19A-22A.

Moody, R.C., 1972. Tensile strength of lumber laminated from 1/8-inch-thick veneers. USDA Forest Serv. Res. Pap. FDL 181 Forest Prod. Lab. Madison, Wis.

________, and C.C. Peters. 1972. Feasibility of producing of high yield laminated structural product: strength property of rotary knife cut laminated southern pine. USDA Forest Serv. Res. Pap. FDL 178, Forest Prod. Lab. Madison, Wis.

Murphey, W.K., 1963. Cell wall crystallinity as a function of tensile strain. Forest Prod. J. 13(14): 151-155.

Northcott, P.L., 1955. Bond strength as indicated by wood failure or mechanical test. Forest Prod. J. 5(2): 118-123.

________, and D.C. Walser., 1965. Veneer roughness scale. Canada Dept. Forest. Rural Develop. Forest Prod. Res. Contrib. No. P-115, 3 pp.

________, W.V. Hancock and H.G.M. Colbeck, 1963. Evidence of need for wood failure standard. Adhesion S.T.P. No. 360 of the ASTM. 13 pp.

________, and H.G.M. Colbeck, 1960. Prediction of plywood bond durability. Forest Prod. J. 10(8): 403-408.

________, W.V. Hancock, and K.C. Shen. 1959. Undercure... case hardening in plywood. Forest Prod. J. 9(12): 442-450.

Olson, W.Z., and R.J. Blomquist, 1953. Gluing techniques for beech. Beech utilization series No. 5. North Eastern Technical Committee on the utilization of beech, in co-operation with North Eastern Forest Experiment Station, USDA, Forest Serv.

Orth, G.O., and A.J. Norton, 1947. Personnel factors in high frequency gluing. Proc. Conf. Radio Frequency and its Applications in Gluing Wood. Univ. of Washington, Seattle, Wash. Bull. No. 2, pp. 21-23.

Palka, L.C., 1964. Factors influencing the strength properties of Douglas-fir plywood normal to glueline. M.F. thesis, Faculty of Forestry, University of British Columbia.

Parker, R.S.R., and P. Taylor, 1966. Adhesion and adhesives. Pergamom Press Inc. 44-01 21st street, Long Island City, New York 11101.

Perkitny, T., and L. Helinska, 1961. Uber den Einfluss gloichzeitiger, Temperatur-und Feuchtigkctsanderung auf die Verformungen des Holzes. Holz als Roh Werkstoff 19(7): 259-269. (cited from Palka, 1964).

Schaffer, E.L., Jokerst, R.W., R.C. Moody, C.C. Peters, J.L. Tschernitz, and J.J. Zahn., 1972. Feasibility of producing a high-yield laminated structural product: General summary. USDA Forest Serv. Res. Pap. FPL 175, Forest Prod. Lab. Madison, Wis.

Shelton, F.J., 1969. Plywood adheasives--developments and trends. Forest Prod. J. 19(1): 9-12.

Stumbo, D.A. 1960. Surface texture measurements for quality and production control. Forest Prod. J. 10(2): 122-124.

Troughton, G.E., and S.-Z. Chow, 1972. A study on the cause for variation in plywood bond quality with open assembly time. Forest Prod. J. 22(3): 55-58.

Truax, T.R. 1929. The gluing of wood. USDA Forest Serv. Tech. Bull. No. 1500. Forest Prod. Lab. Madison, Wis. (original not seen, cited from Olson and Blomquist 1953).

USDA Forest Service, 1955. Wood handbook. Agric. Handbk. 72, Forest Prod. Lab. Madison, Wis.

US Forest Products Laboratory, 1966. Basic properties of yellow-birch laminates modified with phenol and urea resins. U.S. Forest Serv. Res. Note FPL-0140 (original not seen, cited from Moody, 1972).

________, and Gamble Brothers, Inc. 1944. Manual on the laminating of resin glues. USDA Forest Prod. Serv. Mimeo No. R1437, Forest Prod. Lab. Madison, Wis.

Westman, E.F., and L.J. Nemeth., 1968. Single ply vs. 2-ply laminated tension values. Forest Prod. J. 18(8) 41-42.

Winlund, . 1947. High frequency gluing - fact or fantasy. Proc. Conf. on Radio Frequency and its Application in Gluing Wood. College of Forestry, Univ. of Washington, Seattle, Wash. Bull. No. 2, pp. 6-17.

Wood, A.D., 1963. Plywoods of the world, their development manufacture and application. W & A.K. Johnson and G.W. Bacon, Ltd. Edinburgh and London, 489 pp.

Zisman, W.A., 1963. Influence of constitution on adhesion. Ind. and Eng. Chem. 55(10): 19-38.

9.0 TABLES

TABLE 1

Frequency of grades of black cottonwood ¼-inch veneers peeled for the study

Veneer size[b]	GRADES[a]					
	A	BB	B	C	C-	Total
	FREQUENCY					
Full size	1	8	18	20	17	64
Narrows	5	-	15	2	-	22
Fishtails	4	-	2	-	-	6
Total	10	8	35	22	17	92

[a]According to CSA standard 0153-1963 for popular plywood veneers.

[b]Full size is 25 by 54 inches. Narrows are from seven to 15 inches wide by 54 inches. Fishtails are from five to ten inches wide by 20 to 39 inches long.

TABLE 2

Average green moisture content of black cottonwood ¼ inch veneers[a]

Bolt No.	Sapwood[b]	Heartwood[c]	Bolt average
1	178.5	164.4	171.4
2	190.9	212.7	201.8
3	160.6	144.2	152.4
4	210.4	143.0	176.7
All bolts average	185.1	166.1	176[c]

[a] Veneers were wrapped in polythene plastic sheets, after about five minutes exposure, to check (minimize) moisture control.

[b] Each woodzone figure is an average of three moisture content values.

[c] Rounded to the nearest one percent moisture content.

TABLE 3

Design of small-panel experiments

Veneer Wood Species	Test	Variable	Experiment	Design	Analysis
Broadleaf Maple	Adequate Gluespread	1 Maximum failing load in shear (lb); 2 Shear strength (psi); 3 Wood failure (%)	4 x 2 Factorial (crossed)	i Completely randomized; ii Linear model[a] is Yijk=μ+Si+Aj+(SA)ij+Eijk----1	ANOVA with interactions
"	Effect of platen temperature	1 Maximum failing load in shear (lb); 2 Shear strength (psi); 3 Wood failure (%)	2 x 2 Factorial (crossed)	i Completely randomized; ii Linear model[b] is Yijk= μ + Pi+Aj+(PA)ij+Eijk--2	"
"	Adequate curing temperature	1 Maximum failing load in shear (lb); 2 Shear strength (psi); 3 Wood failure (%)	3 x 3 Factorial (crossed)	i Completely randomized; ii Linear model[c] is Yijk=μ +Ci+Aj+(CA)ij+Eijk---3	"
"	Effect of platen pressure	1 Maximum failing load in shear (lb); 2 Shear strength (psi); 3 Wood failure (%)	—	—	Mean and standard deviation
Black Cottonwood and Sugar Maple	Adequate gluespread	1 Shear strength (psi); 3 Wood failure (%)	3 x 2 Factorial	i Completely randomized; ii Linear model[d] is same as in equation 1	ANOVA with interactions
		2 Adjusted shear strength (psi)	Single factor	i Completely randomized; ii Linear model is Yijk=μ+Sj+Eij------------4	One-way ANOVA
"	Adequate pressure	1 Shear strength (psi); 3 Wood failure (%)	2 x 2 Factorial (crossed)	i Completely randomized; ii Linear model[e] is same as in equation 2	ANOVA with interactions
		2 Adjusted shear strength (psi)	Single factor	i Completely randomized; ii Linear model[f] is same as in equation 4	One-way ANOVA
Sugar Maple	Effect of double pressing	1 Shear strength (psi); 3 Wood failure (%); 4 LVL thickness (in); 5 Moisture content (%)	2 x 2 Factorial (crossed)	i Completely randomized; ii Linear model[g] is Yijk=μ +Pi+Gj+(PG)ij+Eijk--5	ANOVA with interactions
		2 Adjusted shear strength (psi)	Single factor	i Completely randomized; ii Linear model[h] same as in equation 5	One-way ANOVA
"	Adequate gluespread with modified phenol-resorcinol glue (MPRG)	1 Shear strength (psi); 3 Wood failure (%)	2 x 2 Factorial (crossed)	i Completely randomized; ii Linear model[i] is the same[k] as in equation 1	ANOVA with interactions
		2 Adjusted shear strength (psi)	Single factor	i Completely randomized; ii Linear model[j] is the same as in equation 4	One-way ANOVA
Black Cottonwood	Bond quality with MPRG	1 Shear strength (psi); 2 Wood failure (%)	Single factor	i Completely randomized; ii Linear model[k] is same as in equation 4	One-way ANOVA

TABLE 3 - Continued

---

[a]In equation 1, S = gluespread, A = aging, i.e. dry or cyclic (vacuum/pressure) soak; E = error; i = 1,2,3,4; j = 1,2; k = 1,2 - - - 10

[b]In equation 2, P = platen temperature; A = aging; E = error, and i = 1,2; j = 1,2, and k = 1,2 - - - 15.

[c]In equation 3, C = central glueline temperature; A = aging; E = error; i = 1,2,3; j = 1,2,3, and k = 1, 2, - - - 15.

[d]Model notation is the same as for equation 1, but i = 1,2,3 and k = 1,2, - - - 15.

[e]In equation 4, S = effect of the jth treatment (i.e. gluespread by dry test), E = error; j = 1,2,3 (treatments); i = 1,2 - - - 15 (observations per treatment).

[f]Model notation is the same as in equation 2, except that P = platen pressure, and k = 1,2 - - - 15.

[g]Model notation is the same as in equation 4, except that S = pressure by dry test and j = 1,2.

[h]In equation 5, G = glue type (PF IB-337 or PF IB-334); P = press time, E = error; j = 1,2; i = 1,2, and k = 1,2 - - - 15.

[i]Model notation is the same as in equation 4, except that S = glue type by dry test, and j = 1,2.

[j]Model notation is the same as in equation 1, except that i = 1,2 and k = 1,2 - - - 15.

[k]Model notation is same as in equation 4, except that j = 1,2.

[l]Model notation is same as in equation 4, except that S is effect of aging on the ith observation.

TABLE 4

Factors examined in the small panel experiments

Veneer wood species	Test	FACTOR A	comment	B	Comment
Broadleaf maple	Adequate gluespread	Gluespread 1 27.5 lb/MSGL 2 30 " " 3 37.5 " " 4 42.5 " "	chosen to cover plywood and LVL manufacturing practice	Aging 1 Dry (laboratory condition) 2 24-hour cold soak	Recommended by Bohlen for LVL
"	Effect of platen temperature	Platen Temperature 1 300°F 2 400°F	two extremes chosen arbitrarily	Aging 1 Dry (laboratory condition) 2 24-hour cold soak	"
"	Adequate curing temperature	Central glueline Temperature[a] 1 233°F 2 240°F 3 300°F	curing range of many phenolic glues	Aging 1 Dry (laboratory condition) 2 24-hour cold soak 3 Cyclic (vacuum/pressure) soak	" modified test for quality of central glue-line bond
Black cottonwood	Adequate gluespread	Gluespread 1 30 lb/MSGL 2 37.5 lb/MSGL 3 42.5 lb/MSGL	chosen to cover plywood and LVL manufacturing practice	Aging 1 Dry (laboratory condition) 2 Cyclic (vacuum/pressure) soak	modified test for quality of central glueline bond
"	Adequate pressure	Platen pressure 1 69 psi 2 100 psi	within range specified for low density hardwoods P.S. 56-73[b]	Aging 1 Dry (laboratory condition) 2 Cyclic (vacuum/pressure) soak	"
Sugar maple	Adequate pressure	Platen pressure 1 250 psi 2 275 psi	upper limit recommended for dense hardwoods[b] tried because its within ranges reported in literature	Aging 1 Dry (laboratory condition) 2 Cyclic (vacuum/pressure) soak	"
" "	Effect of double-pressing	Pressing time 1 single (20 minutes) 2 double (40 minutes)	to simulate Bohlen's LVL production process	Glue type 1 PF IB-337[c] 2 PF IB-334[d]	to observe effect of glue formulation
" "	Adequate gluespread with MPRG	Gluespread 1 37.5 lb/MSGL 2 42.5 lb/MSGL	lower spreads rapidly absorbed into veneers	Aging 1 Dry (laboratory condition) 2 Cyclic (vacuum/pressure) soak	"

[a] Temperature attained in press. Rise in temperature during hot stacking was not measured.

[b] American National Standards, Voluntary Products Standards P.S. 56-1965.

[c] Phenolic resin glue manufactured by Reichhold Chemicals (Canada) Limited.

[d] Phenolic resin glue modified for dryout tolerance (also a Reichhold product).

TABLE 5

Some characteristics of the ¼-inch veneers used in this study

Test	Veneer wood species	Glue to be used in test	Moisture content (%)		Specific gravity[a]		Veneer thickness (in)		% depth of late check		Veneer roughness (in x 10^{-3})	
			Mean	SD[b]	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Small panel	Sugar maple	IB-337	3.5	0.02	0.652	0.0016	0.265	0.005	53	10	15	6
"	Black cottonwood	"	5.1	0.02	0.375	0.0016	0.268	0.009	65	19	20	9
Continuous LVL	Sugar maple	"	3.4	0.03	0.662	0.0040	0.264	0.005	55	10	15	6
"	" "	IB-334	3.5	0.02	0.656	0.0015	0.267	0.013	52	12	15	6
"	Black cottonwood	IB-337	5.3	0.02	0.370	0.0024	0.268	0.009	72	22	15	7
"	" "	IB-334	5.2	0.02	0.369	0.0023	0.269	0.010	66	20	20	8
"	White spruce	IB-337	6.8	0.03	0.376	0.0120	0.268	0.012	30	19	20	7

[a]Specific gravity based on oven dry weight and test volume.

[b]Standard deviation.

TABLE 6

Shear block samples for the small panel tests

TEST	AGING			
	Dry	Coldsoak	Cyclic (Vac/press) soak	Total
Broadleaf Maple				
Adequate gluespread	5/spread of 42.5 lb/MSGL 10 spread of 27.5, 30 & 37.5 lb/MSGL	5/spread of 42.5 lb/MSGL 10/spread of 27.5, 30 & 37.5 lb/MSGL	-	10 60
Effect of platen temperature	5/platen temperature	5/platen temperature	-	20
Adequate curing temperature	5/CGL temperature	5/CGL temperature	5/CGL temperature	45
Other pressures (250 and 275 psi)	5/pressure	5/pressure	10 pressure	40
Black Cottonwood				
Adequate gluespread	15/spread	-	15/spread	90
Adequate pressure	15/aging	-	15/aging	60
Sugar Maple				
Adequate gluespread	15/spread	-	15/spread	90
Adequate pressure	15/pressure	-	15/pressure	60
Effect of presstime	15/presstime	-	15/presstime	60
Adequate gluespread ofMPRG glue on sugar maple	15/spread	-	15/spread	60
Testing black cottonwood forMPRG glue bond strength	15	-	15	30

TABLE 7

Central glueline temperature rise of phenolic glue IB-337 bonded broadleaf maple LVL

Press size	Small (16 in. x 16 in.)						Small (16 in. x 16 in.)						Large (54 in. x 54 in.)
Platen temperature (°F)	300						400						350
Gluespread (lb/MSGL)	0	0	30	37.5	42.5	42.5	0	0	42.5	42.5	42.5	42.5	42.5
Initial central glueline temperature[a] (°F)	75	75	75	75	75	75	75	75	75	75	75	97	75
Final temperature of central glueline (°F)	233	240	233	233	233	240	233	240	233	240	300	297	240
Time to final temperature (min.)	26	34	32	33	36	40	20	24	27	30	48	39	25
Total temperature change (°F)	158	165	158	158	158	165	158	165	158	165	225	200	165
Factor X[b] (°F/min.)	6.1	4.9	4.9	4.8	4.4	4.1	7.9	6.9	5.9	5.5	4.7	5.1	6.6

[a]Glueline was held at 200 psi platen pressure, and each LVL panel was 12 inches by 12 inches.

[b]Factor X was calculated by dividing change in CGLT by time of change.

TABLE 8

Glueline temperature in 6-ply Laminated-Veneer-Lumber at various levels of gluespread

Species	Platen pressure (psi)	Glue-spread (lb/MSGL)	Glue-line	Initial temperature (°F)[a]	Final temperature (°F)[b]	Total change in temperature	Time to final temperature (min)	Factor X[c] (°F min)	Phenol-formaldehyde gluebrand
Cottonwood Sapwood	69	0	CGL[d]	78	241	163	18	9.06	-
		0	OGL[e]	98	295	197	18	10.94	-
Heartwood	69	0	CGL	77	240	163	15.25	10.69	-
		0	OGL	105	288	183	15.25	12.00	-
Random	69	30	CGL	77	240	163	27.5	5.93	IB-337
		30	OGL	81	299	218	27.5	7.93	"
"	69	37.5	CGL	78	240	162	31	5.23	"
		37.5	OGL	82	300	218	31	7.03	"
"	69	42.5	CGL	78	240	162	35	4.63	"
		42.5	OGL	83	309	226	35	6.46	"
"	100	42.5	CGL	77	240	163	35	4.66	"
Sugar maple	250	0	CGL	78	240	162	17.33	9.35	IB-337
		0	OGL	99	299	200	17.33	11.54	"
"	250	30	CGL	78	240	162	19	8.53	"
		30	OGL	85	298	214	19	11.26	"
"	250	37.5	CGL	75	240	165	20	8.25	"
		37.5	OGL	82	295	213	20	10.65	"
"	250	42.5	CGL	79	240	161	20.25	7.95	"
		42.5	OGL	84	297	213	20.25	10.52	"
"	275	42.5	CGL	76	240	164	19	8.63	"
		42.5	OGL	80	295	215	19	11.32	"
"	275	42.5	CGL	75	240	165	20	8.25	IB-334
		42.5	OGL	76	289	213	20	10.65	"
"	275	42.5	CGL	76	285	209	43[f]	4.86	IB-337
		42.5	OGL	80	328	248	43[f]	5.77	"
"	275	42.5	CGL	75	285	210	43[f]	4.88	IB-334
		42.5	OGL	76	326	250	43[f]	5.81	"

[a] Temperature when full pressure was attained.

[b] Final temperature of outer glueline was that attained when CGL reached 240°F.

[c] Factor X was calculated by dividing the change in CGLT by time of change.

[d] CGL is central glueline.

[e] OGL is outer glueline.

[f] Two 20 minute pressing plus a 3 minute interval without pressure.

TABLE 9

Testing broadleaf maple LVL for adequate gluespread

Analysis of Variance Table

Variable	Source	DF	SS	MS	F	Comment	Statistically ranked means[a]
Max. load (lb)	Spread[b]	2	21159000.00	10580000.00	24.22	**	(1) 1429.2 (2) 1639.9 (3) 2802.6
	Aging[c]	1	49755000.00	49755000.00	113.88	**	2845.8 1008.9
	Sp x Ag	2	814240.00	407120.00	0.93	NS	
	Error	53	23155000.00	436890.00			
	Total	58	94884000.00				
Dry shear strength (psi)	Spread	2	1462100.00	731030.00	23.90	**	353.6 397.8 710.4
	Aging	1	3468500.00	3468500.00	113.40	**	721.9 236.9
	Sp x Ag	2	83168.00	41584.00	1.36	NS	
	Error	53	1621100.00	30588.00			
	Total	58	6634900.00				
Wood failure (%)	Spread	2	26238.00	13119.00	58.42	**	27.0 38.0 76.6
	Aging	1	10536.00	10536.00	46.92	**	59.8 33.1
	Sp x Ag	2	-644.41	-322.20	-1.43	NS	
	Error	53	11901.00	224.55			
	Total	58	48031.00				
Wood failure (%)[+]	Spread	3	32773.00	10924.00	56.93	**	(1) 25.0 (2) 36.0 (3) 83.5 (4) 90.5
	Aging	1	4202.50	4202.50	21.90	**	69.0 48.5
	Sp x Ag	3	322.50	107.50	0.56	NS	
	Error	32	6140.00	191.87			
	Total	39	43438.00				

[a]Means underscored with a common line are not significantly different at 0.05 level. Numbers in parentheses refer to either gluespread level or aging.

[b]Spreads 1, 2, 3, and 4 are 27.5-, 30-, 37.5 and 42.5 lb/MSGL respectively.

[c]Aging 1 and 2 are dry test and 24-hour cold-soak, respectively.

[+]Refers to analyses carried out with samples of 5 species for each gluespread level.

[**]Significant at 0.01 level.

[NS]Not significant.

TABLE 10

Mean and variability of three strength properties of broadleaf maple LVL tested for adequate gluespread

Spread (lb/MSGL)	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
27.5	Dry test	Max. load (lb)	10	2235.8	511.34	22.9
		Shear str. (psi)	10	564.5	120.16	21.3
		Wood failure (%)	10	40.0	20.28	52.2
27.5	24-hour cold soak	Max. load (lb)	10	622.5	380.46	61.1
		Shear str. (psi)	10	142.8	79.75	55.8
		Wood failure (%)	10	14.0	9.37	66.9
30	Dry test	Max. load (lb)	10	2370.5	1096.83	46.3
		Shear str. (psi)	10	577.3	255.07	44.2
		Wood failure (%)	10	49.0	11.97	24.4
30	24-hour cold soak	Max. load (lb)	10	905.2	447.61	49.2
		Shear str. (psi)	10	208.3	95.18	45.7
		Wood failure (%)	10	27.0	18.44	68.3
37.5	Dry test	Max. load (lb)	10	3931.0	833.26	21.2
		Shear str. (psi)	10	1013.9	292.29	28.8
		Wood failure (%)	10	91.0	7.62	8.4
37.5	24-hour cold soak	Max. load (lb)	10	1548.9	278.38	18.0
		Shear str. (psi)	10	373.2	85.15	22.8
		Wood failure (%)	10	61.0	17.81	29.2

TABLE 11

Mean and variability of three strength properties of Broadleaf maple LVL tested for adequate gluespreads

Spread	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation[a]
27.5	Dry test	Max.load(lb)	5	1951.6	476.00	24.4
		Dry shear str.(psi)	5	469.5	169.89	36.2
		Wood failure (%)	5	38.0	23.61	62.1
27.5	24-hour cold soak	Max.load (lb)	5	501.0	222.02	44.3
		Dry shear str.(psi)	5	115.1	44.34	38.5
		Wood failure (%)	5	12.0	9.75	81.2
30	Dry test	Max. load (lb)	5	2752.0	1344.70	48.9
		Dry shear str.(psi)	5	678.3	295.32	43.5
		Wood failure (%)	5	47.0	12.04	25.6
30	24-hour cold soak	Max. load (lb)	5	948.8	448.60	47.3
		Dry shear str.(psi)	5	216.0	94.25	43.6
		Wood failure (%)	5	25.0	19.04	76.2
37.5	Dry test	Max. load (lb)	5	4467.0	603.20	13.5
		Dry shear str.(psi)	5	1209.7	265.39	21.9
		Wood failure (%)	5	95.0	6.12	6.4
37.5	24-hour cold soak	Max. load (lb)	5	1539.4	235.25	15.3
		Dry shear str.(psi)	5	368.1	65.70	17.8
		Wood failure (%)	5	72.0	15.25	21.2
42.5	Dry-test	Max. load (lb)	5	6223.0	1362.24	21.9
		Dry shear str.(psi)	5	1490.8	317.63	21.3
		Wood failure (%)	5	96.0	6.52	6.8
42.5	24-hour cold soak	Max. load (lb)	5	2114.0	696.65	33.0
		Dry shear str.(psi)	5	477.1	157.86	33.1
		Wood failure (%)	5	85.0	7.91	9.3

[a]Subsamples of 5 were selected randomly from samples in spreads 1 to 3 and were tested with the samples of 5 obtained from spread panel.

TABLE 12

Testing Broadleaf maple LVL for effect of platen temperature

Analysis of variance table

Variable	Source	DF	SS	MS	F	Comment	Statistically ranked means[a] (1)	(2)
Max. load (lb)	Platen temp[b]	1	281.25	281.25	0.00	NS	4168.5	4176.0
	Aging[c]	1	69583000.00	69583000.00	79.35	**	6037.5	2307.0
	Plat.T x Ag	1	716310.00	716310.00	0.82	NS		
	Error	16	14030000.00	876900.00				
	Total	19	84330000.00					
Dry shear strength (psi)	Platen temp	1	1111.50	1111.50	0.03	NS	984.0	969.1
	Aging	1	4055000.00	4055000.00	108.94	**	1426.8	526.3
	Plat.T x Ag	1	63924.00	63924.00	1.72	NS		
	Error	16	595540.00	37221.00				
	Total	19	4715500.00					
Wood failure (%)	Platen temp	1	7.20	7.20	0.07	NS	90.5	89.3
	Aging	1	720.00	720.00	7.32	**	95.9	83.9
	Plat.T x Ag	1	5.00	5.00	0.05	NS		
	Error	16	1573.60	98.35				
	Total	19	2305.80					

[a]Means underscored with a common line are not significantly different at 0.05 level. Numbers in parentheses refer to platen temperature and aging levels.

[b]Platen temperature 1 is 300°F and 2 is 400°F.

[c]Agings 1 and 2 are dry test and 24-hour cold soak, respectively.

TABLE 13

Mean and variability of three strength properties of broadleaf maple LVL tested for effect of platen temperature

Platen temp. (^{o}F)	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
300	Dry test	Max. load (lb)	5	6223.0	1362.24	21.9
		Shear str. (psi)	5	1490.8	317.63	21.3
		Wood failure (%)	5	96.0	6.52	6.8
300	24-hour cold soak	Max. load (lb)	5	2114.0	696.65	33.0
		Shear str. (psi)	5	477.1	157.86	33.1
		Wood failure (%)	5	85.0	7.91	9.3
400	Dry test	Max. load (lb)	5	5852.0	918.35	15.7
		Shear str. (psi)	5	1362.8	74.58	5.5
		Wood failure (%)	5	96.0	1.30	1.4
400	24-hour cold soak	Max. load (lb)	5	2500.0	568.54	22.7
		Shear str. (psi)	5	575.3	132.39	23.0
		Wood failure (%)	5	83.0	16.93	20.4

TABLE 14

Testing broadleaf maple LVL for adequate curing temperature

Analysis of variance table

Variable	Source	DF	SS	MS	F	Comment	Statistically ranked means[a] (1)	(2)	(3)
Dry shear strength (psi)	CGL Temp[b]	2	210070.00	105040.00	5.39	*	853.4	934.1	1020.7
	Aging[c]	2	10080000.00	5039800.00	258.44	**	1605.2	615.9	587.2
	CGL T x Ag	4	78648.00	19662.00	1.01	NS			
	Error	36	702040.00	19501.00					
	Total	44	11070000.00						
Wood failure (%)	CGL Temp	2	1456.10	728.07	12.43	**	85.9	98.6	97.1
	Aging	2	474.53	237.27	4.05	*	98.0	93.5	90.1
	CGL T x Ag	4	390.13	97.53	1.67	NS			
	Error	36	2108.40	58.57					
	Total	44	4429.20						
Max. load (lb)	CGL Temp	2	3403800.00	1701900.00	5.03	*	3579.3	3833.6	4246.7
	Aging	2	152920000.00	76471000.00	226.05	**	6493.0	2630.6	2536.1
	CGL T x Ag	4	1284100.00	321030.00	0.95	NS			
	Error	36	12177000.00	338250.34					
	Total	44	169790000.00						

[a]Means underscored with a common line are not significantly different at 0.05 level. Numbers in parentheses refer to glueline temperature and aging levels, respectively.

[b]Central glueline temperature 1 is 233°F; central glueline temperature 2 is 240°F; central glueline temperature 3 is 300°F.

[c]Agings 1, 2 and 3 are dry test, 24-hour cold soak and cyclic (vac/press) soak, respectively.

TABLE 15

Mean and variability of three strength properties of broadleaf maple LVL tested for adequate curing temperature

CGL Temp	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation
233	Dry-test	Max. load (lb)	5	5852.0	918.36	15.7
		Dry shear (psi)	5	1439.2	217.03	15.1
		Wood failure (%)	5	95.8	1.30	1.4
233	24-hour cold soak	Max. load (lb)	5	2500.0	568.54	22.7
		Dry shear (psi)	5	575.3	132.39	23.0
		Wood failure (%)	5	82.8	16.93	20.4
233	Cyclic (vac/press) soak	Max. load (lb)	5	2386.0	357.90	15.0
		Dry shear (psi)	5	545.7	79.12	14.5
		Wood failure (%)	5	79.0	12.94	16.4
240	Dry-test	Max. load (lb)	5	6567.0	805.56	12.3
		Dry shear (psi)	5	1639.1	197.75	12.1
		Wood failure (%)	5	99.4	0.90	0.9
240	24-hour cold soak	Max. load (lb)	5	2492.8	319.40	12.8
		Dry shear (psi)	5	594.1	77.16	13.0
		Wood failure (%)	5	99.2	0.84	0.8
240	Cyclic (vac/press) soak	Max. load (lb)	5	2441.0	374.42	15.3
		Dry shear (psi)	5	569.2	92.90	16.3
		Wood failure (%)	5	97.2	4.38	4.5
300	Dry-test	Max. load (lb)	5	7060.0	786.13	11.1
		Dry shear (psi)	5	1737.3	194.65	11.2
		Wood failure (%)	5	98.8	1.79	1.8
300	24-hour cold soak	Max. load (lb)	5	2899.0	391.88	13.5
		Dry shear (psi)	5	678.3	89.57	13.2
		Wood failure (%)	5	98.6	2.19	2.2
300	Cyclic (vac/press) soak	Max. load (lb)	5	2781.2	294.70	10.6
		Dry shear (psi)	5	646.6	70.90	11.0
		Wood failure (%)	5	94.0	6.52	6.9

TABLE 16

Effect of pressure on certain characteristics of broadleaf maple LVL

Pressure	Aging	Variable	Mean	SD	CV	Sample size
200	Dry test	Shear strength (psi)	1639.1	197.75	12.1	5
"	" "	Wood failure (%)	99.4	0.90	0.9	5
"	" "	LVL thickness (in)	1.548	0.11	0.7	5
"	24-hour cold soak	Shear strength (psi)	594.1	77.5	13.0	5
"	" "	Wood failure (%)	99.2	0.84	0.8	5
"	" "	LVL thickness (in)	1.637	0.006	0.4	5
"	Cyclic (vac/press) soak	Shear strength (psi)	569.2	92.90	16.3	5
"	" "	Wood failure (%)	97.2	4.38	4.5	5
"	" "	LVL thickness (in)	1.660	0.009	0.5	5
250	Dry test	Shear strength (psi)	1965.3	357.9	18.2	5
"	" "	Wood failure (%)	100	0	0	5
"	" "	LVL thickness (in)	1.351	0.007	0.5	5
"	24-hour cold soak	Shear strength (psi)	743.8	142.8	19.2	5
"	" "	Wood failure (%)	100	0	0	5
"	" "	LVL thickness (in)	1.568	0.009	0.6	5
"	Cyclic (Vac/press) soak	Shear strength (psi)	713.4	75.3	10.6	10
"	" "	Wood failure (%)	100	0	0	10
"	" "	LVL thickness (in)	1.622	0.012	0.7	10
275	Dry test	Shear strength (psi)	2000.3	198.2	9.9	5
"	" "	Wood failure (%)	100	0	0	5
"	" "	LVL thickness (in)	1.296	0.010	0.8	5
"	24-hour cold soak	Shear strength (psi)	710.4	78.4	11.0	5
"	" "	Wood failure (%)	100	0	0	5
"	" "	LVL thickness (in)	1.577	0.010	0.6	5
"	Cyclic (vac/press) soak	Shear strength (psi)	632.4	66.4	10.5	10
"	" "	Wood failure (%)	100	0	0	10
"	" "	LVL thickness (in)	1.612	0.008	0.5	10

TABLE 17

Testing black cottonwood for adequate gluespread of phenolic resin glue IB-337[a]

Analysis of variance table

Variable	Source	DF	SS	MF	F	Comment	Statistically ranked means[b] (1)	(2)	(3)
Dry shear str. (psi)	Spread[c]	2	3101400.00	1550700.00	94.26	**	323.4	602.1	733.9
	Aging[d]	1	8010800.00	8010800.00	486.93	**	864.8	268.1	
	Sp x Ag[e]	2	42696.00	21348.00	1.30	NS			
	Error	84	1381900.00	16452.00					
	Total	89	12537000.00						
Wood failure (%)	Spread	2	64099.00	32050.00	135.92	**	29.6	79.7	91.1
	Aging	1	6117.40	6117.40	25.94	**	75.0	58.6	
	Sp x Ag	2	990.96	495.48	2.10	NS			
	Error	84	19807.00	235.80					
	Total	89	91014.00						
Adj. shear strength (psi)	Spread	2	1762300.00	881160.00	36.34	**	555.7	864.1	1033.7
	Error	42	1018400.00	24248.00					
	Total	44	2780700.00						

[a]IB-337 is a phenol-formaldehyde resin manufactured by Reichhold Chemicals (Canada) Limited, Vancouver, B.C.

[b]Means underscored with a common line are not significantly different. Numbers in parentheses refer to spread or aging. Same numbers refer to both spread and aging.

[c]Spread 1 is 30 lb/MSGL; spread 2 is 37.5 lb/MSGL; spread 3 is 42.5 lb/MSGL.

[d]Aging 1 is dry test under laboratory condition; 2 is cyclic (vacuum/pressure) soak.

[e]Interaction term.

**Significant at 0.01 or highly significant. NS Not significant.

TABLE 18

Mean and variability of some strength properties of black cottonwood LVL[a] at different levels of gluespread[b]

Spread (lb/MSGL)	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
30	Dry test	Dry shear str. (psi)	15	593.7	160.99	27.1
		Adj. shear str. (psi)	15	555.7	153.33	27.6
		Wood failure (%)	15	41.7	25.34	60.7
30	Cyclic (vac/press) soak	Dry shear str. (psi)	15	53.1	39.89	75.2
		Wood failure (%)	15	17.5	15.53	88.6
37.5	Dry test	Dry shear str. (psi)	15	903.4	169.08	18.7
		Adj. shear str. (psi)	15	864.1	167.41	19.4
		Wood failure (%)	15	88.3	14.54	16.5
37.5	Cyclic (vac/press) soak	Dry shear str. (psi)	15	300.7	101.81	33.9
		Wood failure (%)	15	71.1	12.06	17.0
42.5	Dry test	Dry shear str. (psi)	15	1097.3	160.56	14.6
		Adj. shear str. (psi)	15	1033.7	145.63	14.1
		Wood failure (%)	15	95.1	5.62	5.9
42.5	Cyclic (vac/press) soak	Dry shear str. (psi)	15	450.5	80.44	17.9
		Wood failure (%)	15	87.1	11.95	13.7

[a]Laminated Veneer Lumber

[b]Gluespread of phenol-formaldehyde resin glue IB-337 manufactured by Reichhold Chemicals (Canada) Limited, Vancouver, B.C.

TABLE 19

Testing black cottonwood LVL for effect of pressing[a] at 69 and 100 psi respectively

Analysis of variance table

Variable	Source	DF	SS	MF	F	Comment	Statistically ranked means[b] (1)	(2)
Dry shear str. (psi)	Pressure[c]	1	225460.00	225460.00	19.43	**	773.9	896.5
	Aging[d]	1	6421000.00	6421000.00	553.46	**	1162.3	508.0
	Pr x Ag[e]	1	83627.00	83627.00	0.07	NS		
	Error	56	649690.00	11602.00				
	Total	59	7297000.00					
Wood failure (%)	Pressure	1	777.60	777.60	14.12	**	91.1	98.3
	Aging	1	365.07	365.07	6.63	*	97.1	92.2
	Pr x Ag	1	141.07	141.07	2.56	NS		
	Error	56	3083.60	55.06				
	Total	59	4367.30					
Adj. shear strength (psi)	Pressure	1	111870.00	111870.00	7.28	*	1033.7	1155.9
	Error	28	430770.00	15360.00				
	Total	29	541940.00					

[a] Glue spread was 42.5 lb/MSGL and central gluelines were heated to 240°F with 350°F platens.

[b] Means underscored with a common line are not significant at 0.05 level.

[c] Pressure 1 is 69 psi and pressure 2 is 100 psi.

[d] Aging 1 is dry test at laboratory condition; aging 2 is cyclic (vacuum/pressure) soak.

[e] Interaction term.

TABLE 20

Mean and variability of some strength properties of black cottonwood LVL[a] at two levels of platen pressure[b]

Platen pressure (psi)	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
69	Dry test	Dry shear str. (psi)	15	1097.3	160.56	14.6
		Adj. shear str. (psi)	15	1033.7	145.63	14.1
		Wood failure (%)	15	95.1	5.63	5.9
69	Cyclic (vac/press) soak	Dry shear str. (psi)	15	450.5	80.44	17.9
		Wood failure (%)	15	87.1	11.95	13.7
100	Dry test	Dry shear str. (psi)	15	1227.3	100.06	8.2
		Adj. shear str. (psi)	15	1155.9	97.53	8.4
		Wood failure (%)	15	99.2	0.86	0.9
100	Cyclic (vac/press) soak	Dry shear str. (psi)	15	565.6	64.38	11.4
		Wood failure (%)	15	97.3	6.72	6.9

[a] Laminated Veneer Lumber

[b] Platen size is 16 inches by 16 inches; LVL boards were 8 inches by 12 inches.

TABLE 21

Testing sugar maple LVL for adequate gluespread of phenolic resin glue IB-337[a]

Analysis of variance table

Variable	Source	DF	SS	MF	F	Comment	Statistically ranked means[b] (1)	(2)	(3)
Dry shear str.(psi)	Spread[c]	2	28811000.00	14405000.00	153.03	NU[d]			
	Aging[e]	1	45624000.00	45624000.00	484.66	NU			
	Sp x Ag	2	1162000.00	581000.00	6.17	**			
	Error	84	7907400.00	94136.00					
	Total	89	83504000.00						
Wood failure (%)	Spread	2	50683.00	25342.00	135.91	**	34.3	74.0	90.9
	Aging	1	9589.30	9589.30	51.43	**			
	Sp x Ag	2	232.16	116.08	0.62	NS			
	Error	84	15663.00	186.46					
	Total	89	76167.00						
Adj. shear str. (psi)	Spread	2	16965000.00	8482600.00	59.99	**	1191.4	1856.8	2692.2
	Error	42	5938500.00	141390.00					
	Total	44	22904000.00						

[a]IB-337 is a phenol-formaldehyde resin manufactured by Reichhold Chemicals (Canada) Limited, Vancouver, B.C.

[b]Means underscored with a common line are not significantly different at 0.05 level. Numbers in parentheses refer to spread and aging.

[c]Spread 1 is 30 lb/MSGL; spread 2 is 37.5 lb/MSGL; spread 3 is 42.5 lb/MSGL.

[d]F-value not useful because interaction is significant.

[e]Aging 1 is dry test under laboratory condition; aging 2 is cyclic (vac/press) soak.

**Significant at 0.01, i.e. highly significant.

TABLE 22

Mean and variability of some strength properties of sugar maple LVL[a] at different levels of gluespread[b]

Spread (lb/MSGL	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
30	Dry test	Dry shear str. (psi)	15	1307.2	470.78	36.0
		Adj. shear str. (psi)	15	1191.4	430.54	36.7
		Wood failure (%)	15	46.5	22.56	48.5
30	Cyclic (vac/press) soak	Dry shear str. (psi)	15	145.0	86.02	59.3
		Wood failure (%)	15	22.0	9.29	42.2
37.5	Dry test	Dry shear str. (psi)	15	1999.5	492.11	24.6
		Adj. shear str. (psi)	15	1856.8	447.66	24.1
		Wood failure (%)	15	84.4	14.39	17.0
37.5	Cyclic (vac/press) soak	Dry shear str. (psi)	15	606.1	195.35	32.2
		Wood failure (%)	15	63.7	13.56	21.3
42.5	Dry test	Dry shear str. (psi)	15	2964.0	200.94	6.8
		Adj. shear str. (psi)	15	2962.2	179.82	6.7
		Wood failure (%)	15	99.2	1.47	1.5
42.5	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1247.7	122.77	9.8
		Wood failure (%)	15	82.5	11.43	13.8

[a] Laminated Veneer Lumber

[b] Glue used was phenol-formaldehyde resin glue IB-337 manufactured by Reichhold Chemicals (Canada) Limited, Vancouver, B.C.

TABLE 23

Testing sugar maple LVL for effect of pressing[a] at 250 and 275 psi, respectively

Analysis of variance table

Variable	Source	DF	SS	MF	F	Comment	Statistically ranked means[b] (1)	(2)
Dry shear str. (psi)	Pressure[c]	1	960890.00	960890.00	22.42	NU[d]		
	Aging[e]	1	51317000.00	51317000.00	1197.24	NU		
	Pr x Ag[f]	1	266530.00	266530.00	6.22	*		
	Error	56	2400300.00	42863.00				
	Total	59	54945000.00					
Wood failure (%)	Pressure	1	442.82	442.82	10.76	NU		
	Aging	1	1653.80	1653.80	40.20	NU		
	Pr x Ag	1	570.42	570.42	13.87	**		
	Error	56	2303.60	41.14				
	Total	59	4970.60					
Adj. shear str. (psi)	Pressure	1	747970.00	747970.00	12.78	**	2692.2	3008.0
	Error	28	1638700.00	58524.00				
	Total	29	2386600.00					

[a]Gluespread 3 was applied to all boards and central glueline was heated to $240 \pm 1^{\circ}F$ before removing pressure.

[b]Means not underscored with a common line are significantly different at 0.05 level. When interaction is significant, Duncan's Multiple Range Test is not carried out.

[c]Pressures 1 and 2 were 250 and 275 psi, respectively.

[d]F-value not useful because interaction term is significant level.

[e]Aging 1 and 2 were dry tested under laboratory conditions, and cyclic (vacuum/pressed) soak, respectively.

[f]Interaction term.

*Significant at 0.05 level. **Significant at 0.01 level, i.e. highly significant.

TABLE 24

Mean and variability of some strength properties of sugar maple LVL[a] at two levels of platen[b] pressure

Platen pressure (psi)	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
250	Dry test	Dry shear str. (psi)	15	2964.0	200.94	6.8
		Adj. shear str.(psi)	15	2692.2	179.82	6.7
		Wood failure (%)	15	99.2	1.47	1.5
250	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1247.7	122.77	9.8
		Wood failure (%)	15	82.5	11.43	13.8
275	Dry test	Dry shear str. (psi)	15	3350.4	323.35	9.7
		Adj. shear str. (psi)	15	3008.0	231.04	9.7
		Wood failure (%)	15	98.5	2.70	2.7
275	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1367.5	106.94	7.8
		Wood failure (%)	15	94.1	4.96	5.3

[a] Laminated Veneer Lumber

[b] Platen size is 16 inches by 16 inches.

TABLE 25

Effect of pressing time and glue on some strength and related properties of sugar maple LVL[a]

Analysis of variance table

Phenolic resin glue	Aging	Variable	Source	DF	SS	MS	F	Comment	Statistically ranked means[b] (1)	(2)
IB-337 & IB-334	Dry test	Dry shear str (psi)	Press time[c]	1	156470.00	156470.00	2.49	NU		
			Glue[d]	1	3292900.00	3292900.00	52.49	NU		
			Pr.T x Gl[e]	1	6244200.00	6244200.00	99.53	**		
			Error	56	3513200.00	62736.00				
			Total	59	13207000.00					
"	"	Wood failure (%)	Press time	1	228.15	228.15	11.57	NU		
			Glue	1	120.42	120.42	6.11	NU		
			Pr.T x Gl	1	126.15	126.15	6.40	*		
			Error	56	1104.10	19.72				
			Total	59	1578.80					
"	"	LVL thickness (in)	Press time	1	16667×10^{-10}	16667×10^{-10}	0.04	NS		
			Glue	1	77067×10^{-9}	77067×10^{-9}	1.94	NS		
			Pr.T x Gl	1	6×10^{-7}	6×10^{-7}	0.02	NS		
			Error	56	223×10^{-5}	39821×10^{-9}				
			Total	59						
"	"	Moisture content (%)	Press time	1	15647×10^{-3}	15647×10^{-3}	190.82	**	3.53	2.51
			Glue	1	58907×10^{-6}	58907×10^{-6}	0.72	NS	<u>3.05</u>	<u>2.99</u>
			Pr.T x Gl	1	50460×10^{-6}	50460×10^{-6}	0.62	NS		
			Error	56	45919×10^{-4}	81999×10^{-6}				
			Total	59	20348×10^{-3}					
IB-337	"	Adj. shear str.[f] (psi)	Press time	1	4313800.00	4313800.00	86.33	**	3008.0	2249.6
			Error	28	1399100.00	49968.00				
			Total	29	5712900.00					
IB-334	Dry test	Adj. shear str.(psi)	Press time	1	1237900.00	1237900.00	24.63	**		
			Error	28	1407100.00	50253.00				
			Total	29	2645000.00					
IB-337 & IB-334	Cyclic (vac/press) soak	Dry shear str.(psi)	Press time	1	3904.30	3904.30	0.24	NU		
			Glue	1	601.67	601.67	0.04	NU		
			Pr.T x Gl	1	363790.00	363790.00	22.61	**		
			Error	56	900840.00	16086.00				
			Total	59	1269100.00					
"	"	Wood failure (%)	Press time	1	742.02	742.02	9.46	NU		
			Glue	1	93.75	93.75	1.20	NU		
			Pr.T x Gl	1	3360.00	3360.00	42.83	**		
			Error	56	4392.80	78.44				
			Total	59	8588.60					
"	"	LVL thickness (in)	Press time	1	68267×10^{-9}	68267×10^{-9}	0.96	NU		
			Glue	1	86400×10^{-9}	86400×10^{-9}	1.22	NU		
			Pr T x Gl	1	38507×10^{-8}	38507×10^{-8}	5.42	*		
			Error	56	39812×10^{-7}	71903×10^{-9}				
			Total	59	45209×10^{-7}					
"	"	Moisture content (%)	Press time	1	665.07	665.07	299.83	NU		
			Glue	1	181.45	181.45	81.80	NU		
			Pr.T x Gl	1	20.28	20.28	9.14	**		
			Error	56	124.22	2.22				
			Total	59	991.01					

[a]Gluespread was 42.5 lb/MSGL and LVL boards were pressed at 275 psi.

[b]Means underscored with a common line are not significantly different at 0.05 level. Those not underscored at all differ significantly at 0.05 level. Numbers in parentheses refer to pressing time and glue type.

[c]Pressing time 2 is two 20-minute cycles with a three-minute interval. This pressing time was used to simulate the portion of the continuous LVL that is usually pressed twice.

[d]IB-337 is a laminating phenol-formaldehyde resin manufactured by the Reichhold Chemicals (Canada) Ltd., Vancouver, B.C.; IB-334 is a modification of IB-337 for dryout tolerance.

[e]Interaction term.

[f]Glueline shear strength adjusted to its 7% MC value (psi). This variable was not available for the cyclic (vacuum/pressure) soak. Hence simple analysis of variance test was used.

[NU]F-value not useful because interaction term is significant.

**Significant at 0.01 level, i.e. highly significant.

*Significant at 0.05 level.

TABLE 26

Mean and variability of some strength and related properties of sugar maple LVL as affected by press time[a] and type of glue[b]

Press time (min)	Phenolic resin glue	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
20	IB-337	Dry test	Dry shear str. (psi)	15	3350.70	323.00	9.6
			Adj. shear str. (psi)	15	3008.00	291.04	9.7
			Wood failure (%)	15	98.50	2.70	2.7
			LVL thickness (in)	15	1.55	0.07	0.4
			Moisture content (%)	15	3.59	0.14	4.0
20	"	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1367.50	106.94	7.8
			Wood failure (%)	15	94.10	4.96	5.3
			LVL thickness (in)	15	1.66	0.01	0.6
			Moisture content (%)	15	95.68	1.41	1.5
40	"	Dry test	Dry shear str. (psi)	15	2603.30	147.10	5.7
			Adj. shear str. (psi)	15	2249.60	123.37	5.5
			Wood failure (%)	15	99.50	1.41	1.4
			LVL thickness (in)	15	1.55	0.05	0.5
			Moisture content (%)	15	2.51	0.22	8.9
40	"	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1227.90	167.28	13.6
			Wood failure (%)	15	86.20	11.69	13.6
			LVL thickness (in)	15	1.65	0.04	0.5
			Moisture content (%)	15	101.17	2.19	2.2
20	IB-334	Dry test	Dry shear str. (psi)	15	2236.90	303.87	13.6
			Adj. shear str. (psi)	15	1999.60	268.12	13.4
			Wood failure (%)	15	92.70	8.31	9.0
			LVL thickness (in)	15	1.55	0.01	0.5
			Moisture content (%)	15	3.47	0.30	8.6
20	"	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1205.40	132.25	11.0
			Wood failure (%)	15	76.70	12.05	15.7
			LVL thickness (in)	15	1.65	0.01	0.5
			Moisture content (%)	15	91.04	0.67	0.7
20	"	Dry test	Dry shear str. (psi)	15	2780.00	180.63	6.5
			Adj. shear str. (psi)	15	2405.90	169.16	7.0
			Wood failure (%)	15	99.50	0.74	0.7
			LVL thickness (in)	15	1.55	0.00	0.0
			Moisture content (%)	15	2.51	0.41	16.4
20	"	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1377.30	86.22	6.3
			Wood failure (%)	15	98.70	2.72	2.8
			LVL thickness (in)	15	1.66	0.01	0.6
			Moisture content (%)	15	98.86	1.30	1.3

[a]Pressing time of 40 minutes consists of two 20-minute press cycles with an interval of three minutes in between. This is to simulate the portion of continuous board pressed twice, with the three minute interval between press cycles.

[b]Phenol-formaldehyde resin IB-337 and IB-334 were used, the latter being a modification of the former for dryout resistance.

TABLE 27

Testing sugar maple LVL for adequate gluespread with phenol-resorcinol glue[a]

Analysis of variance table

Variable[b]	Source	DF	SS	MS	F	Comment	Statistically ranked means[c] (1)	(2)	(3)
Dry shear strength (psi)	Spread	1	512450.00	512450.00	14.25	NU			
	Aging	1	23982000.00	23982000.00	666.97	NU			
	Sp x Ag	1	939750.00	939750.00	26.14	**			
	Error	56	2013600.00	35957.00					
	Total	59	27448000.00						
Wood failure (%)	Spread	1	138.02	138.02	6.48	*		96.5	99.5
	Aging	1	28.02	28.02	1.31	NS	<u>98.7</u>	<u>97.3</u>	
	Sp x Ag	1	25.35	25.35	1.19	NS			
	Error	56	1193.60	21.31					
	Total	59	1385.00						
Adjusted shear str. (psi)	Spread	1	1558200.00	1558200.00	27.18	**		2692.1	2236.3
	Error	28	1605000.00	57323.00					
	Total	29	3163200.00						

[a]Gluespreads 2 and 3, are 37.5 and 42.5 lb/MSGL, respectively; agings 1 and 2 were dry test and cyclic (vacuum/pressure) soak.

[b]Variable 2 is glueline shear strength adjusted to its 7% MC value.

[c]Means underscored with a common line are not significantly different at 0.05 level. Those not underscored at all are significantly different at 0.05 level. Numbers in parentheses refer to gluespreads or aging.

**Significant at 0.01 level, i.e. highly significant;

*Significant at 0.05 level.

[NS]Not significant. [NU]F-value not useful because interaction term is significant.

TABLE 28

Mean and variability of some strength properties of phenol-resorcinol-bonded sugar maple LVL at two levels of gluespread

Spread (lb/MSGL)[a]	Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
37.5	Dry test	Dry shear str. (psi)	15	2724.3	309.64	11.4
		Adj. shear str. (psi)	15	2692.1	320.92	11.9
		Wood failure (%)	15	97.8	4.00	4.1
37.5	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1209.5	169.19	13.0
		Wood failure (%)	15	95.1	8.17	8.6
42.5	Dry test	Dry shear str. (psi)	15	2289.1	91.37	4.0
		Adj. shear str. (psi)	15	2236.3	107.94	4.8
		Wood failure (%)	15	99.5	1.13	1.1
42.5	Cyclic (vac/press) soak	Dry shear str. (psi)	15	1275.0	104.73	8.2
		Wood failure (%)	15	99.5	1.13	1.1

[a] Gluespreads lower than 37.5 were difficult to spread with brush, hence were not included in this test.

TABLE 29

Testing black cottonwood LVL for bond quality with phenol-resorcinol glue[a]

Analysis of variance table

Variable	Source	DF	SS	MS	F	Comment	Statistically ranked means[b] (1)	(2)
Dry shear str. (psi)	Aging	1	1225700.00	1225700.00	223.87	**	985.3	581.1
	Error	28	153310.00	5473.30				
	Total	29	1379000.00					
Wood failure (%)	Aging	1	0.30	0.30	0.49	NS	99.9	99.7
	Error	28	17.07	0.61				
	Total	29	17.37					

[a] The only spread used was 42.5 lb/MSGL. Central glueline was heated to 216 ± 2°F using platen temperature and pressure of 350°F and psi, respectively.

[b] Means underscored with a common line are not significantly different at 0.05 level whereas those not underscored differ. Numbers in parentheses refer to the aging.

** Significant at 0.01 level.

NS Not significant.

TABLE 30

Mean and variability of three strength properties of phenol-resorcinol-bonded black cottonwood LVL

Aging	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
Dry test	Dry shear str. (psi)	15	985.3	66.12	6.7
	Adj. shear str. (psi)	15	966.1	73.51	7.6
	Wood failure (%)	15	99.9	0.35	0.4
Cyclic (vac/press) soak	Dry shear str. (psi)	15	581.1	81.11	14.0
	Wood failure (%)	15	99.7	1.05	1.1

TABLE 31

Mean and variability of some strength and related properties of the three sections of continuous LVL

Wood species	Aging	Phenolic glue	Section[a]	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
Sugar maple	Dry test	IB-337	1	Dry shear str.(psi)	9	2138.60	205.05	9.6
				Adj.shear str.(psi)	9	2040.80	194.05	9.5
				Wood failure (%)	9	95.00	3.28	3.5
				LVL thickness (in)	9	1.58	0.00	0.0
				Moisture content(%)	9	5.48	0.45	8.2
"	" "	"	2	Dry shear str.(psi)	12	2326.40	243.38	10.5
				Adj.shear str.(psi)	12	2204.10	239.63	10.9
				Wood failure (%)	12	93.80	7.35	7.8
				LVL thickness (in)	12	1.58	0.00	0.8
				Moisture content(%)	12	5.24	0.29	5.5
"	" "	"	3	Dry shear str.(psi)	14	1065.20	931.80	87.5
				Adj.shear str.(psi)	14	1023.10	895.36	87.5
				Wood failure (%)	14	44.60	35.11	78.7
				LVL thickness (in)	-	-	-	-
				Moisture content (%)	-	-	-	-
"	Cyclic (vac/press) soak	"	1	Dry shear str.(psi)	9	1159.90	79.33	6.8
				Wood failure (%)	9	89.70	8.38	9.3
				LVL thickness (in)	9	1.68	0.01	0.5
				Moisture content(%)	9	103.90	3.61	3.5
"	" "	"	2	Dry shear str.(psi)	11	1193.50	147.71	12.4
				Wood failure (%)	11	86.70	5.88	6.8
				LVL thickness (in)	11	1.66	0.02	1.5
				Moisture content(%)	11	105.24	1.09	1.0
"	" "	"	3	Dry shear str.(psi)	15	594.10	380.00	64.0
				Wood failure (%)	15	43.50	29.00	67.5
				LVL thickness (in)	-	-	-	-
				Moisture content(%)	-	-	-	-
"	Dry test	IB-334	1	Dry shear str.(psi)	7	1834.10	187.57	10.2
				Adj.shear str.(psi)	7	1657.90	144.57	8.7
				Wood failure (%)	7	89.10	13.07	14.7
				LVL thickness (in)	7	1.56	0.00	0.2
				Moisture content(%)	7	3.34	0.26	7.6
"	" "	"	2	Dry shear str.(psi)	11	1973.20	202.76	10.3
				Adj.shear str.(psi)	11	1705.20	175.57	10.3
				Wood failure (%)	11	97.30	5.06	5.2
				LVL thickness (in)	11	1.56	0.00	0.2
				Moisture content(%)	11	2.48	0.63	25.3
"	" "	"	3	Dry shear str.(psi)	13	1805.50	328.87	18.2
				Adj.shear str.(psi)	13	1620.00	300.49	18.5
				Wood failure (%)	13	82.20	13.54	16.5
				LVL thickness (in)	13	1.56	0.02	1.0
				Moisture content(%)	13	3.59	0.20	5.5
"	Cyclic (vac/press) soak	"	1	Dry shear str.(psi)	7	924.10	143.49	15.5
				Wood failure (%)	7	82.60	9.16	11.1
				LVL thickness (in)	7	1.66	0.00	0.0
				Moisture content(%)	6	96.15	-	-
"	" "	"	2	Dry shear str.(psi)	11	1077.10	90.89	8.4
				Wood failure (%)	11	88.40	10.25	11.6
				LVL thickness (in)	11	1.66	0.01	0.3
				Moisture content(%)	11	100.70	1.68	1.7
"	" "	"	3	Dry shear str.(psi)	13	635.80	247.66	38.9
				Wood failure (%)	13	61.20	26.99	44.1
				LVL thickness (in)	13	1.67	0.01	0.5
				Moisture content(%)	13	105.26	1.66	1.6
Black cotton-wood	Dry test	IB-337	1	Dry shear str.(psi)	7	1079.40	137.41	12.7
				Adj.shear str.(psi)	7	1063.20	136.28	12.8
				Wood failure (%)	7	97.60	0.90	0.9
				LVL thickness (in)	7	1.48	0.03	2.1
				Moisture content(%)	7	6.50	0.07	1.0
"	" "	"	2	Dry shear str.(psi)	11	924.70	132.70	14.4
				Adj.shear str.(psi)	11	897.90	128.99	14.4
				Wood failure (%)	11	98.20	2.27	2.3
				LVL thickness (in)	11	1.48	0.00	0.3
				Moisture content(%)	11	6.00	0.15	2.4
"	" "	"	3	Dry shear str.(psi)	13	750.30	350.88	46.8
				Adj.shear str.(psi)	13	743.60	347.88	46.8
				Wood failure (%)	13	71.60	35.94	50.2
				LVL thickness (in)	13	1.49	0.02	1.2
				Moisture content(%)	13	6.70	0.12	1.7
"	Cyclic (vac/press) soak	"	1	Dry shear str.(psi)	5	532.00	51.30	9.6
				Wood failure (%)	5	88.00	7.52	8.5
				LVL thickness (in)	5	1.58	0.00	0.0
				Moisture content(%)	5	221.21	3.82	1.7
"	" "	"	2	Dry shear str.(psi)	11	618.30	67.60	10.9
				Wood failure (%)	11	93.20	5.49	5.9
				LVL thickness (in)	11	1.57	0.01	0.6
				Moisture content(%)	11	220.61	5.56	2.5
"	" "	"	3	Dry shear str.(psi)	14	363.20	248.12	68.3
				Wood failure (%)	14	58.90	39.19	66.6
				LVL thickness (in)	14	-	-	-
				Moisture content(%)	14	218.56	10.16	4.7

TABLE 31 - Continued

Wood species	Aging	Phenolic glue	Section	Variable	Sample size	Mean	Standard deviation	Coefficient of variation (%)
Black cottonwood	Dry test	IB-334	1	Dry shear str.(psi)	7	1335.90	106.83	8.0
				Adj.shear str.(psi)	7	1297.10	102.85	7.9
				Wood failure (%)	7	98.10	0.69	0.7
				LVL thickness (in)	7	1.49	0.01	0.8
				Moisture content(%)	7	5.79	1.66	11.4
"	"	"	2	Dry shear str.(psi)	9	1040.90	78.08	7.5
				Adj.shear str.(psi)	9	963.30	72.47	7.5
				Wood failure (%)	9	99.70	0.71	0.7
				LVL thickness (in)	9	1.47	0.01	0.3
				Moisture content(%)	9	4.52	0.15	3.3
"	"	"	3	Dry shear str.(psi)	13	896.70	280.81	31.3
				Adj.shear str.(psi)	13	875.20	273.64	31.3
				Wood failure (%)	13	88.10	24.63	28.0
				LVL thickness (in)	13	1.48	0.01	0.5
				Moisture content(%)	13	6.21	0.12	1.9
"	Cyclic (vac/press) soak	"	1	Dry shear str.(psi)	7	710.30	28.67	4.0
				Wood failure (%)	7	80.70	9.14	11.3
				LVL thickness (in)	7	1.58	0.00	0.0
				Moisture content(%)	7	209.69	4.48	2.1
"	"	"	2	Dry shear str.(psi)	9	535.60	46.96	8.8
				Wood failure (%)	9	90.90	9.70	10.7
				LVL thickness (in)	9	1.58	0.01	0.6
				Moisture content(%)	9	209.09	4.57	2.2
"	"	"	3	Dry shear str.(psi)	13	337.80	132.78	39.3
				Wood failure (%)	13	78.90	18.35	23.2
				LVL thickness (in)	13	1.59	0.12	1.0
				Moisture content(%)	13	214.72	4.93	2.3
White spruce	Dry test	"	1	Dry shear str.(psi)	6	990.00	153.77	15.5
				Adj.shear str.(psi)	6	1041.50	162.21	15.6
				Wood failure (%)	6	89.20	6.88	7.7
				LVL thickness (in)	6	1.50	0.01	0.3
				Moisture content(%)	6	8.73	0.09	1.0
"	"	"	2	Dry shear str.(psi)	12	1147.00	218.36	19.0
				Adj.shear str.(psi)	12	1177.00	218.94	18.6
				Wood failure (%)	12	94.20	8.96	9.5
				LVL thickness (in)	12	1.48	0.02	1.2
				Moisture content(%)	12	7.91	0.24	3.1
"	"	"	3	Dry shear str.(psi)	12	1019.40	139.75	13.7
				Adj.shear str.(psi)	12	1065.70	147.19	13.8
				Wood failure (%)	12	92.20	7.07	7.7
				LVL thickness (in)	12	1.49	0.00	0.0
				Moisture content(%)	12	8.51	0.12	1.4
"	Cyclic (vac/press) soak	"	1	Dry shear str.(psi)	6	553.20	165.65	29.9
				Wood failure (%)	6	74.00	15.49	20.9
				LVL thickness (in)	6	1.57	0.02	0.1
				Moisture content(%)	6	187.17	7.18	3.8
"	"	"	2	Dry shear str.(psi)	12	783.90	129.46	16.5
				Wood failure (%)	12	87.50	11.14	12.7
				LVL thickness (in)	12	1.57	0.02	1.2
				Moisture content(%)	12	177.57	6.89	3.0
"	"	"	3	Dry shear str.(psi)	12	685.9	170.07	24.8
				Wood failure (%)	12	83.2	12.16	14.6
				LVL thickness (in)	12	1.586	0.010	0.6
				Moisture content(%)	12	177.57	6.890	3.9

[a]Sections 1, 2 and 3 correspond to segments of continuous LVL which were (a) single-pressed portion of the starter board, (b) double pressed 24-inch portion of continuous LVL and (c) section containing end joints which protruded out of platens for the duration of one press cycle.

TABLE 32

Glueline temperature in continuous LVL at various points along the board[a]

Species	Platen pressure (psi)	Recorder Channel (points)	Initial temperature (°F)[b]	Final temperature (°F)[c]	Total change in temperature (°F)	Time to final temperature (min)[d]	Factor X[e] (°F/min)	Phenol-formaldehyde glue brand
Black Cottonwood	100	1	84	230	146	22	6.64	IB-337
		2	133	294	161	22	7.32	"
		3	89	210	121	22	5.50	"
		4	83	182	99	22	4.50	"
		5	144	282	138	21	6.57	"
		6	77	207	130	21	6.19	"
		7	78	226	148	21	7.05	"
		8	79	232	153	21	7.29	"
Sugar maple	275	1	81	240	149	19	7.84	"
		2	107	295	188	19	9.89	"
		3	88	226	138	19	7.26	"
		4	88	139	51	19	2.68	"
		5	132	294	162	18	9.00	"
		6	80	136	56	18	3.11	"
		7	81	191	110	18	6.11	"
		8	81	246	165	18	9.17	"
White spruce	100	1	74	240	166	19	8.74	"
		3	82	166	84	19	4.42	"
		4	77	135	58	19	3.05	"
		5	119	253	134	18	7.44	"
		6	69	108	39	18	2.17	"
		7	69	135	66	18	3.67	"
		8	69	210	141	18	7.83	"
Black Cottonwood	100	1	78	226	148	22	6.73	IB-334
		2	90	272	182	22	8.27	"
		3	88	239	151	22	6.86	"
		4	73	211	138	22	6.27	"
		5	136	281	145	21	6.90	"
		6	73	217	144	21	6.86	"
		7	73	219	146	21	6.95	"
		8	74	221	147	21	7.00	"
Sugar maple	275	1	82	240	158	17	9.29	"
		2	108	288	180	17	10.59	"
		3	86	219	133	17	7.82	"
		4	84	129	45	17	2.65	"
		5	141	286	145	16	9.06	"
		6	77	162	85	16	5.31	"
		7	77	202	125	16	7.81	"
		8	78	233	155	16	9.69	"

[a]Four pairs of points in the glueline were chosen to monitor temperature of central glueline (CGL) and outer glueline (OGL) of the continuous board. Points 1 and 2 were CGL and OGL of LVL and were located at the geometric centre of platens. They were also within "starter board." Points 8 and 5 were CGL and OGL located two inches from platen edge, and hence were within section 2. Points 7 and 3 were CGL and OGL one inch outside platen, while 6 and 4 were CGL and OGL two inches outside platen.

[b]Temperature when platens attained full pressure except in channels 5 - 8 where the initial temperature was monitored one minute later owing to instrument limitation.

[c]Final temperature of CGL was 240°F except in black cottonwood.

[d]Period over which temperature was monitored.

[e]Factor X was calculated by dividing the change in CGLT by time of change.

TABLE 33

Cyclic vacuum/pressure/dry delamination of LVL

Wood species	Glue	Continuous LVL Board Section 1	2	3	Remarks
		Delamination (%)			
Black cotton-wood	IB-337	0	0.6	7	Five specimens failed in section 3.
Sugar maple	"	9.3	2.8	58	Six, two, and all 12 specimens failed in sections 1, 2 and 3, respectively.
White spruce	"	0	0	0	No delamination
Black cotton-wood	IB-334	0	0	4.8	Only the first two specimens failed, scoring 32 and 35% respectively.
Sugar maple	"	1.8	1.2	24.3	Only one specimen failed in section 2, while seven failed in section 3.

TABLE 34

Boil/dry/boil delamination of PF IB-334 bonded LVL

Wood species	Continuous LVL Board Section 1	2	3	Remarks
	Delamination (%)			
Black cottonwood	0	0	2.8	Only the first two specimens in section 3 failed, scoring 23 and 14%, respectively
Sugar maple	0	0	27.5	Ten specimens failed in section 3.

TABLE 35

Comparison of shear strength of phenolic glue IB-337-bonded LVL with published data on solid sawn lumber[a]

	Shear strength of LVL (psi)			Shear strength of solid sawn lumber (psi)			Shear strength of LVL as % of solid lumber	
	Dry test[b]	Adjusted to 7% MC value[c]	Green	Published Air dry[d]	Published Green	Air dry adjusted to 7% MC value	Adjusted shear strength	Green shear strength
Broadleaf maple	1639 (--)	-	594	1765	1265	2030	-	47
Black cottonwood	1227 (5.05)	1156	566	1157	770	1331	87	74
Sugar maple	3350 (3.59)	3008	1368	2424	1615	2788	108	85

[a] Strength and related properties of woods grown in Canada (Kennedy, 1965). Kennedy's study involved large samples of specimens from several trees sampled over a large geographic region whereas the LVL was made from small samples of specimens from a few trees obtained from a single location.

[b] Figures in parentheses refer to average moisture content at test. These figures were not used for the adjustment to 7% MC value. Adjustment was done for each specimen.

[c] Air dry condition was given as approximately 12% moisture content.

[d] Approximate adjustment was done using a conversion factor of 3% for increase or decrease in shear strength for each decrease or increase of moisture content from observed to adjusted moisture content (USDA Forest Service, 1955).

TABLE 36

Performance of continuous LVL central glueline according to PS 56 - 73

Wood Species	Aging	Glue	Section	Adjusted shear strength of LVL as percent of solid lumber equivalent[a]	Wood failure	Comment[b]
Sugar maple	Dry test	PF IB-337	1[c]	73	95	Failed +
"	"	"	2	79	94	Failed +
"	"	"	3	37	44	Failed
"	Cyclic(vac/ press) soak	"	1	72	90	Failed +
"	"	"	2	74	87	Failed +
"	"	"	3	37	44	Failed
"	Dry test	PF IB-334	1	59	89	Failed +
"	"	"	2	61	97	Failed +
"	"	"	3	58	82	Failed +
"	Cyclic(vac/ press) soak	"	1	57	83	Failed +
"	"	"	2	67	88	Failed +
"	"	"	3	39	61	Failed
Black cotton-wood	Dry test	PF IB-337	1	107	98	Passed
"	"	"	2	91	98	Passed
"	"	"	3	75	72	Failed
"	Cyclic (Vac/ press) soak	"	1	95	88	Passed
"	"	"	2	110	93	Passed
"	"	"	3	65	59	Failed
"	Dry test	PF IB-334	1	131	98	Passed
"	"	"	2	97	100	Passed
"	"	"	3	88	88	Passed
"	Cyclic (Vac/ press) soak	"	1	127	81	Passed
"	"	"	2	96	91	Passed
"	"	"	3	63	79	Failed
White Spruce	Dry test	PF IB-337	1	92	89	Passed
"	"	"	2	104	94	Passed
"	"	"	3	94	92	Passed
"	Cyclic (Vac/ Press) soak	"	1	83	74	Failed +
"	"	"	2	117	88	Passed
"	"	"	3	102	83	Passed

[a] Shear strength parallel to grain published by Kennedy (1965) adjusted to their 7% MC equivalent. Shear strength after cyclic (vacuum/ pressure) soak was regarded as being equivalent to the green values.

[b] Failed + denotes that a section failed either of the specification for shear strength and that for wood failure.

[c] Section 1 corresponds to segment of LVL starter board which was single-pressed, section 2 was double-pressed and section 3 was the segment containing the step-joints which protruded out of platens during one press cycle.

10 FIGURES

DENTED ARROWS POINT TO GLUED SURFACE. THE SAME SURFACE IS GLUED IN THE THREE SEGMENTS. VENEERS OF MIDSEGMENT ARE 32, 42 and 34 INCHES FOR BLACK COTTONWOOD, SUGAR MAPLE AND WHITE SPRUCE, RESPECTIVELY.

(Not drawn to scale)

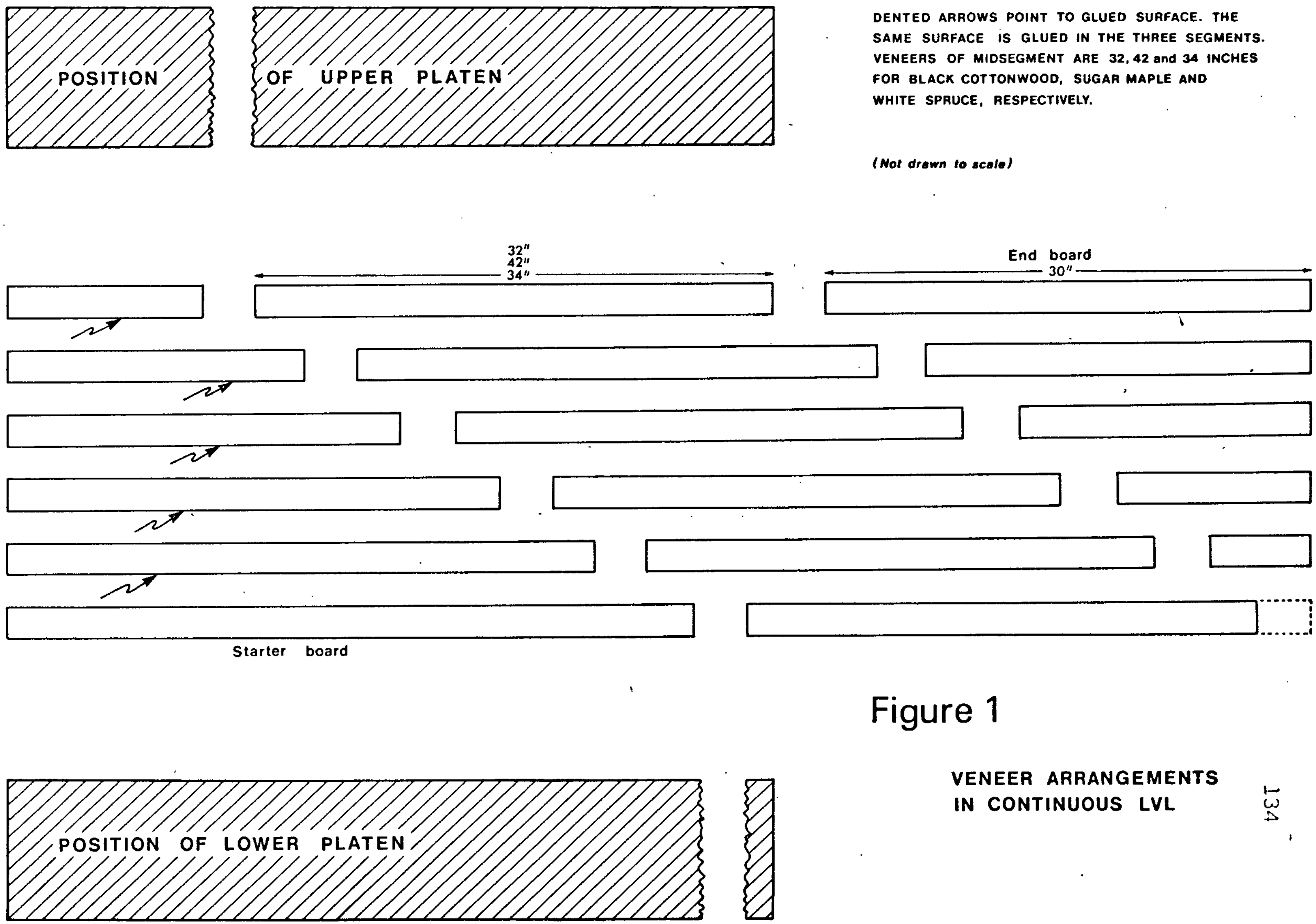


Figure 1

VENEER ARRANGEMENTS IN CONTINUOUS LVL

CHANNELS 1 and 2 ARE LOCATED AT GEOMETRIC CENTRE OF PRESS PLATENS
5 and 8 ARE TWO INCHES FROM PLATEN EDGE
3 and 7 ARE ONE INCH OUTSIDE PLATEN EDGE
4 and 6 ARE TWO INCHES OUTSIDE PLATEN

ARROWS SHOW STEPS PROTRUDING OUT OF PLATENS.

(Not drawn to scale)

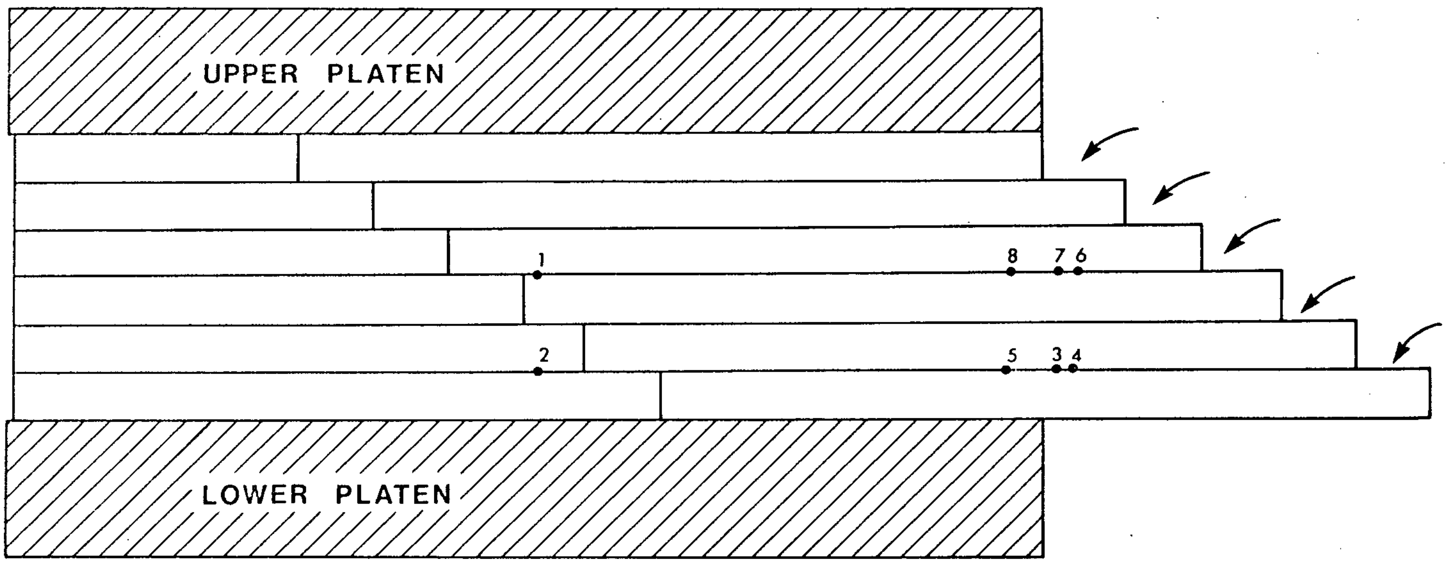


Figure 2 **LOCATION OF THERMOCOUPLES IN GLUELINES OF CONTINUOUS LVL**

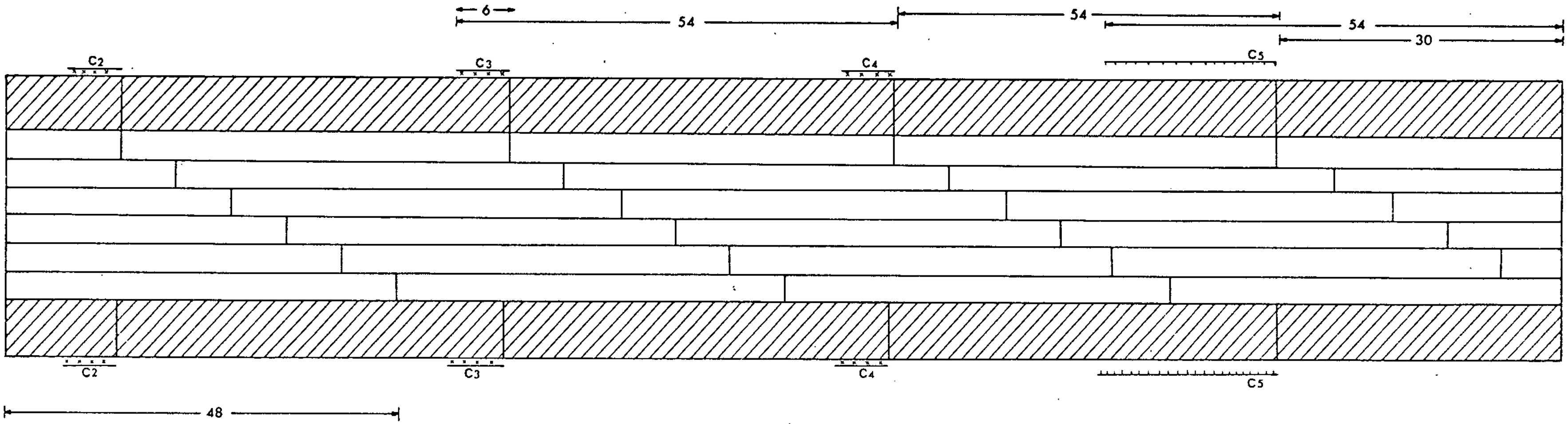


Figure 3 A 16 – FOOT CONTINUOUS LVL BOARD

L E G E N D

THE SUCCESSIVE PLATEN CLOSURES

PORTIONS DOUBLE – PRESSED OWING TO OVERLAP OF PLATEN ON PREVIOUSLY PRESSED PORTIONS ARE MARKED C2, C3, C4 and C5, RESPECTIVELY.

Legend: Arrows point to panels which were not constructed. In such cases, measurements on panels in previous tests were used. CGLT refers to central glueline temperature. MPRG refers to modified phenol-resorcinol glue.

Test						Pressing conditions other than factors tested
	BROADLEAF MAPLE					
Adequate gluespread	Spread (lb/MSGL) Panel No.	27.5 1	30 2	37.5 3	42.5 4	200 psi, 233°F CGLT and 300°F platen temperature
Effect of platen	Platen temp.(°F) Panel No.			300 1	400 2	200 psi, 233°F CGLT, Gluespread of 42.5 lb/MSGL
Adequate curing temperature	CGLT (°F) Panel No.		233 1	240 2	300 3	Platen temperatures of 300, 350 and 400°F, respectively, gluespread of 42.5 lb/MSGL
Effect of pressure	Platen pressure (psi) Panel No.		200 1	250 2	275 3	CGLT of 240°F, gluespread of 42.5 lb/MSGL
	BLACK COTTONWOOD					
Adequate gluespread	Spread (lb/MSGL) Panel No.		30 1,2	37.5 3,4	42.5 5,6	69 psi, CGLT of 240°F and platen temperature of 350°F[a]
Adequate pressure	Platen pressure (psi) Panel No.			69 1,2	100 3,4	Gluespread of 42.5 lb/MSGL, CGLT of 240°F
Bond quality with MPRG	Aging Panel No.			Dry 1	CVPS 2	100 psi, gluespread of 42.5 lb/MSGL and CGLT of 180°F+
	SUGAR MAPLE					
Adequate gluespread	Spread (lb/MSGL) Panel No.		30 1,2	37.5 3,4	42.5 5,6	250 psi, CGLT of 240°F
Adequate pressure	Platen pressure (psi) Panel No.			250 1,2	275 3,4	Gluespread of 42.5 lb/MSGL, CGLT of 240°F
Effect of double-pressing	Press time/glue (min) PF IB-337 Panel No.			20 1,2	40 3,4	Gluespread 42.5 lb/MSGL 275 psi and 350°F platen temperature
Effect of double-pressing control	Press time/glue (min) PF IB-334 Panel No.			20 1,2	40 3,4	" " "
Adequate gluespread with MPRG	Spread (lb/MSGL) Panel No.			37.5 1,2	42.5 1,2	275 psi, CGT 180°F+

FIGURE 4. SMALL PANELS CONSTRUCTED FOR THE VARIOUS TESTS

[a] In subsequent tests, platen temperature was at 350°F.

DENTED ARROWS SHOW FOUR-INCH STRIPS FROM WHICH
THREE 4 x 4 SPECIMENS (STRIPED) WERE SAWN

(Not drawn to scale)

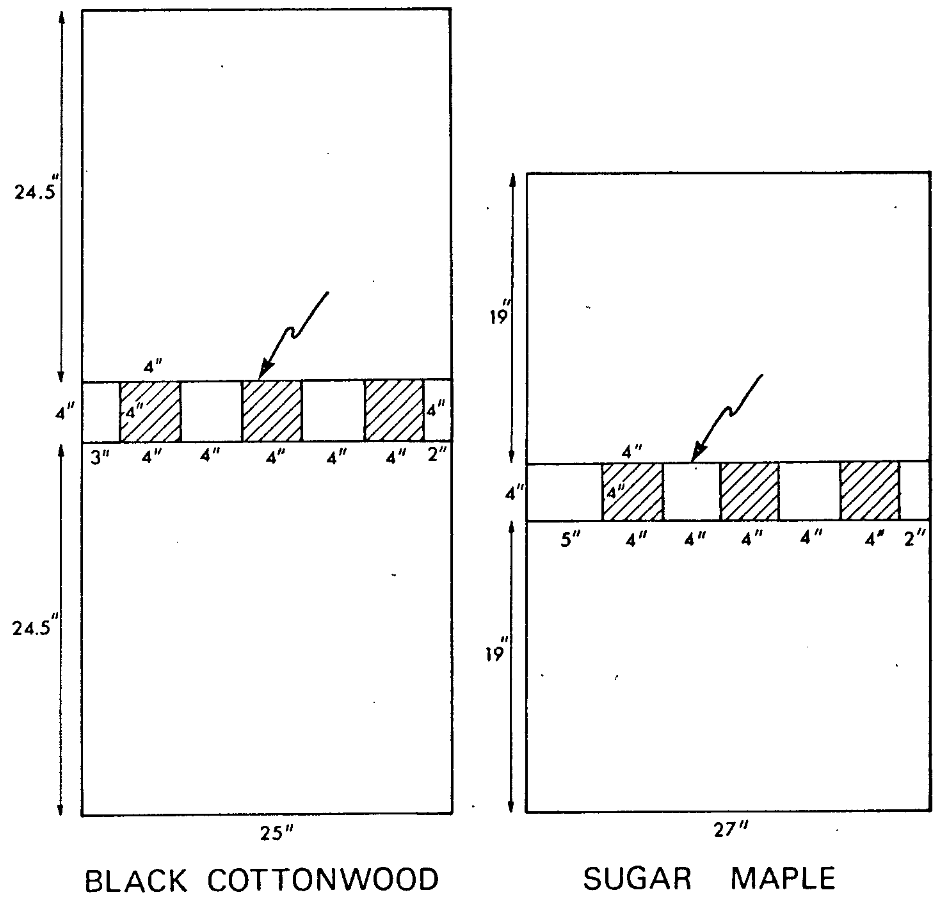


Figure 5 CUTTING FOUR - INCH STRIPS FROM FULL SIZE VENEERS

DENTED ARROWS SHOW THE VENEER QUALITY SPECIMENS.

(Not drawn to the scale)

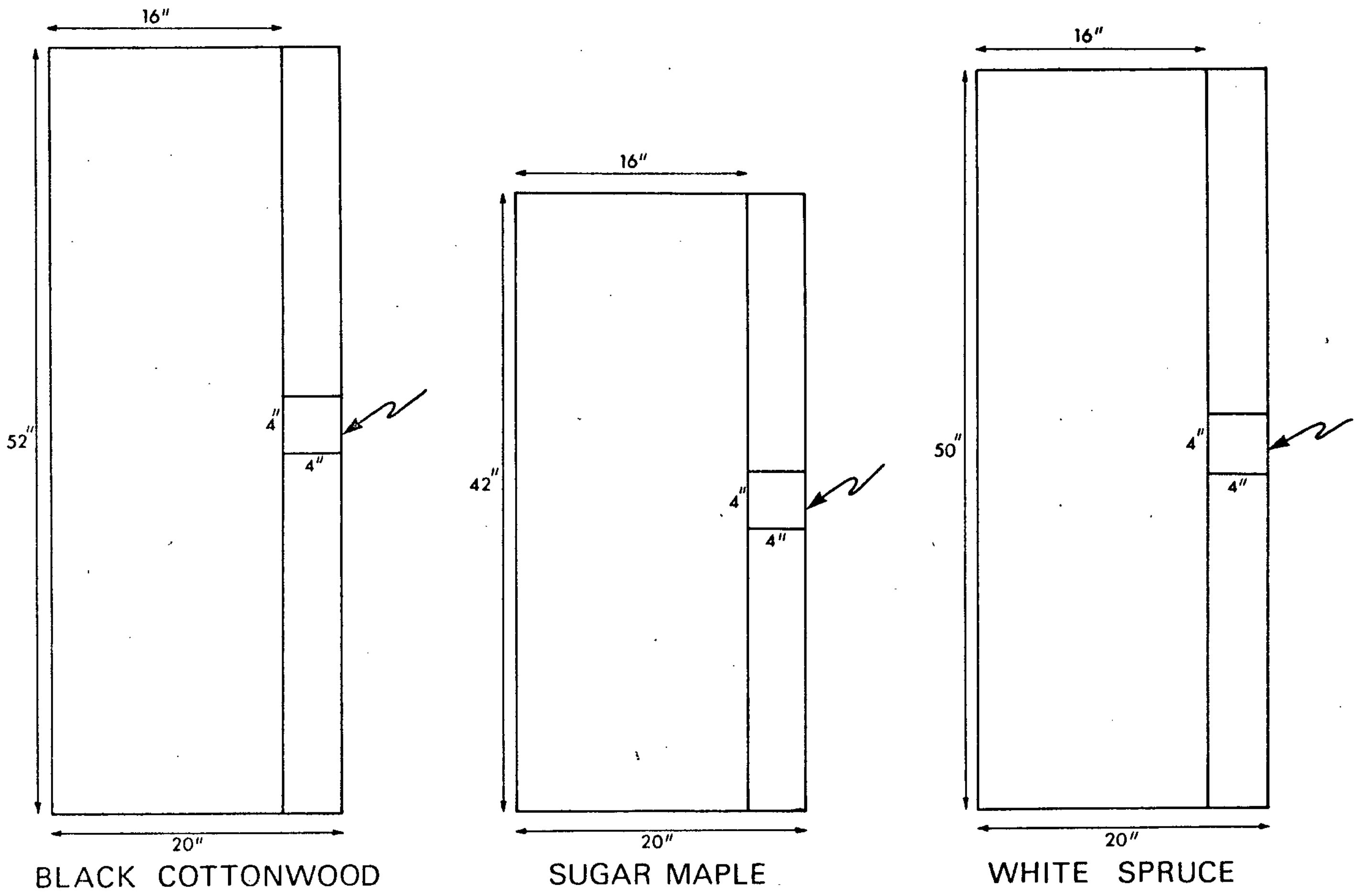


Figure 6 CUTTING OF VENEER QUALITY SPECIMENS FROM LARGE VENEER SHEETS FOR THE COTINUOUS LVL

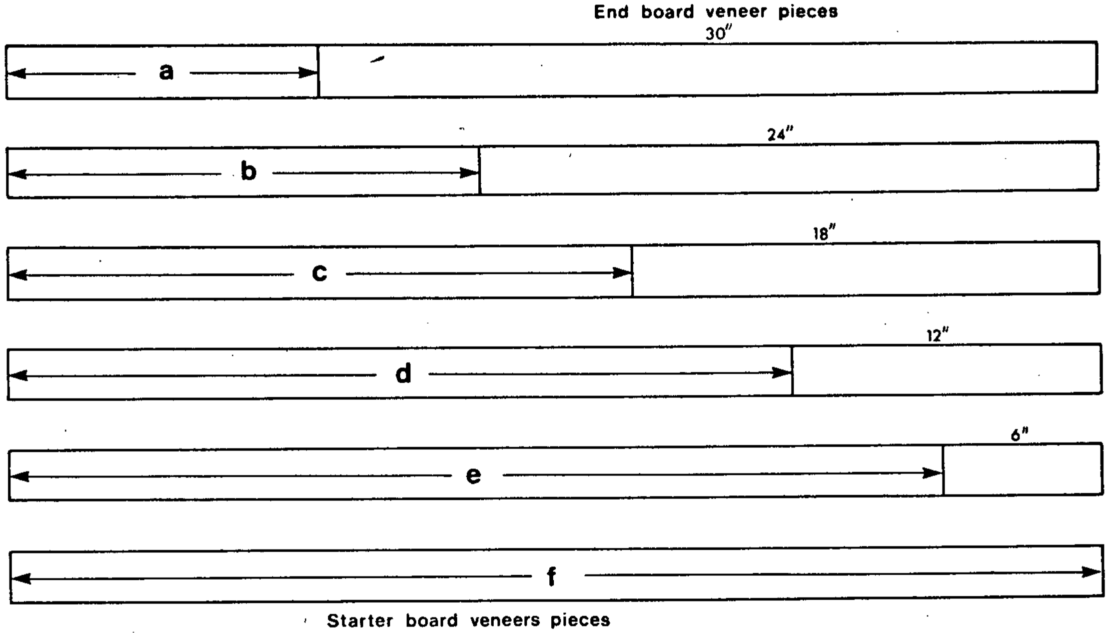


Figure 7 CUTTING THE STARTER AND END BOARDS FROM ONE SET OF FULL LENGHT ¼ INCH THICK VENEERS.

L E G E N D

LENGHT OF STARTER BOARD LAMINATES VARIED AS SHOWN BELOW
(FIGURES ARE IN INCHES)

	a	b	c	d	e	f
BLACK COTTONWOOD	22	28	34	40	46	52
SUGAR MAPLE	12	18	24	30	36	42
WHITE SPRUCE	20	26	32	38	44	50

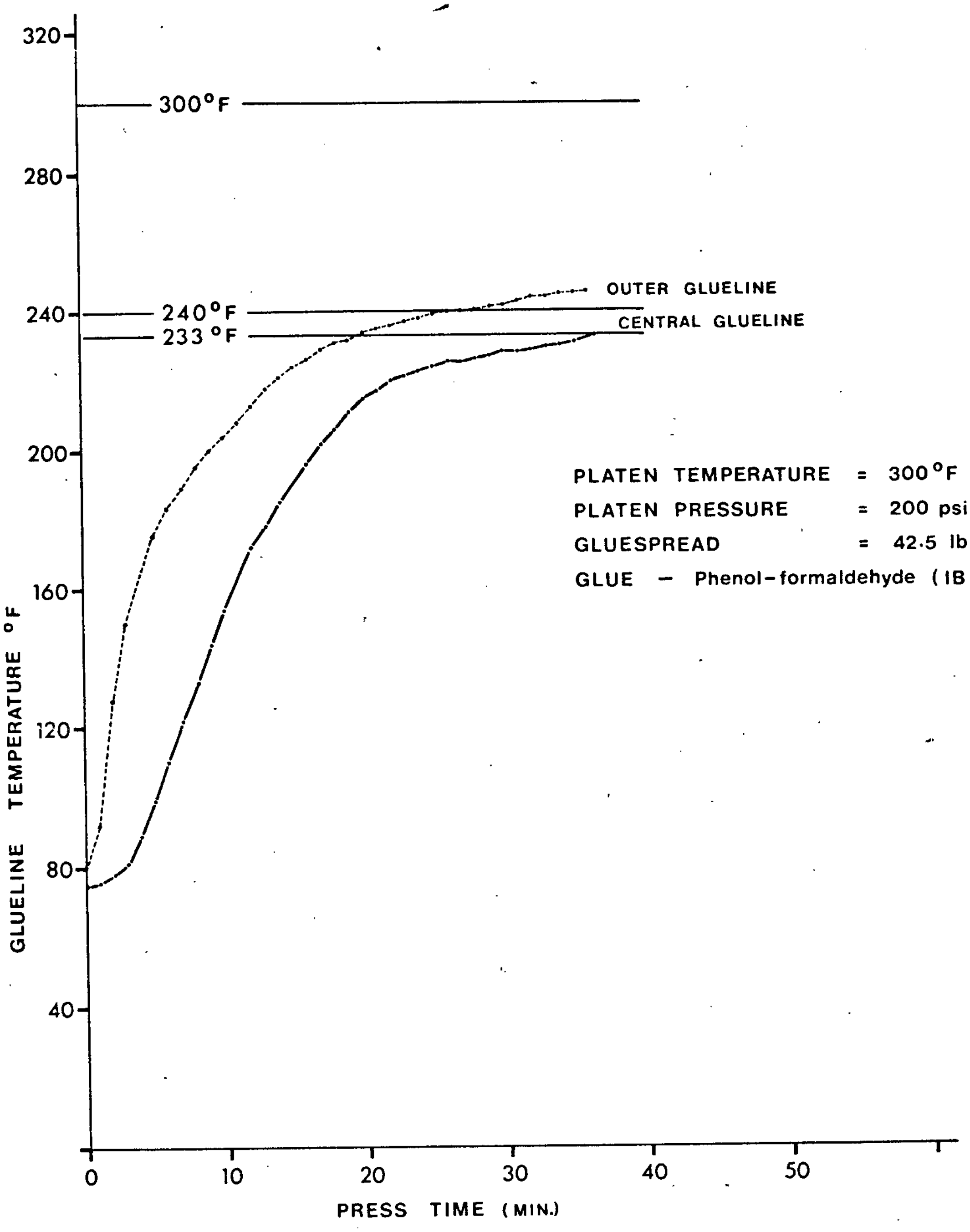


Figure 8 TEMPERATURE RISE AT GEOMETRIC CENTRE OF INNER AND OUTER GLUELINES OF BROADLEAF MAPLE LAMINATED VENEER LUMBER.

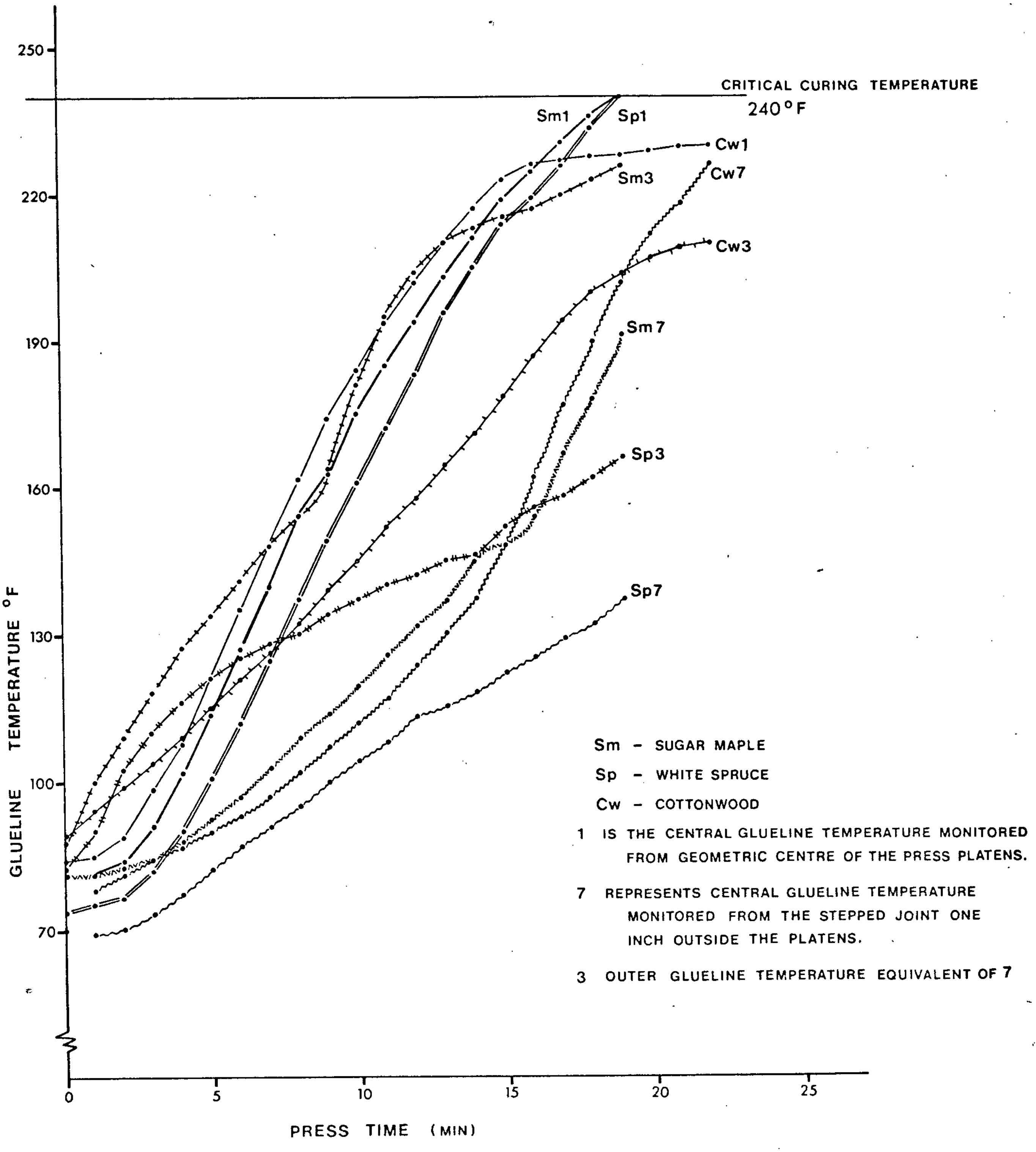


Figure 9 TEMPERATURE RISE AT THREE CRITICAL POINTS IN THE LVL LAYUP IN CONTINUOUS BOARD PRODUCTION PROCESS

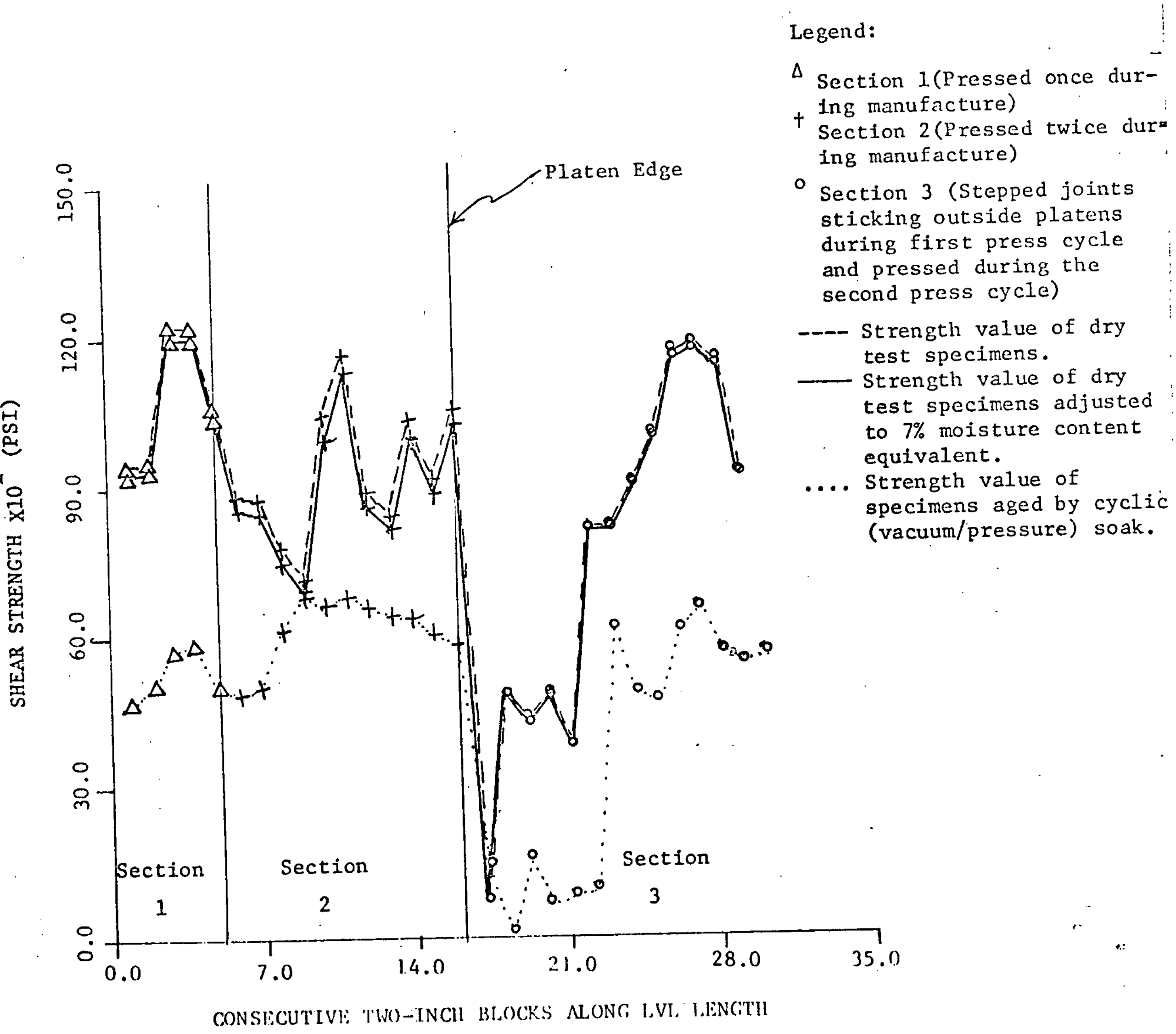


FIGURE 10. BLACK COTTONWOOD LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B337

Legend :
Δ Section 1 (Pressed once during manufacture)
† Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)
---- Strength value of dry test specimens.
.... Strength value of specimens aged by cyclic (Vacuum/pressure) soak.

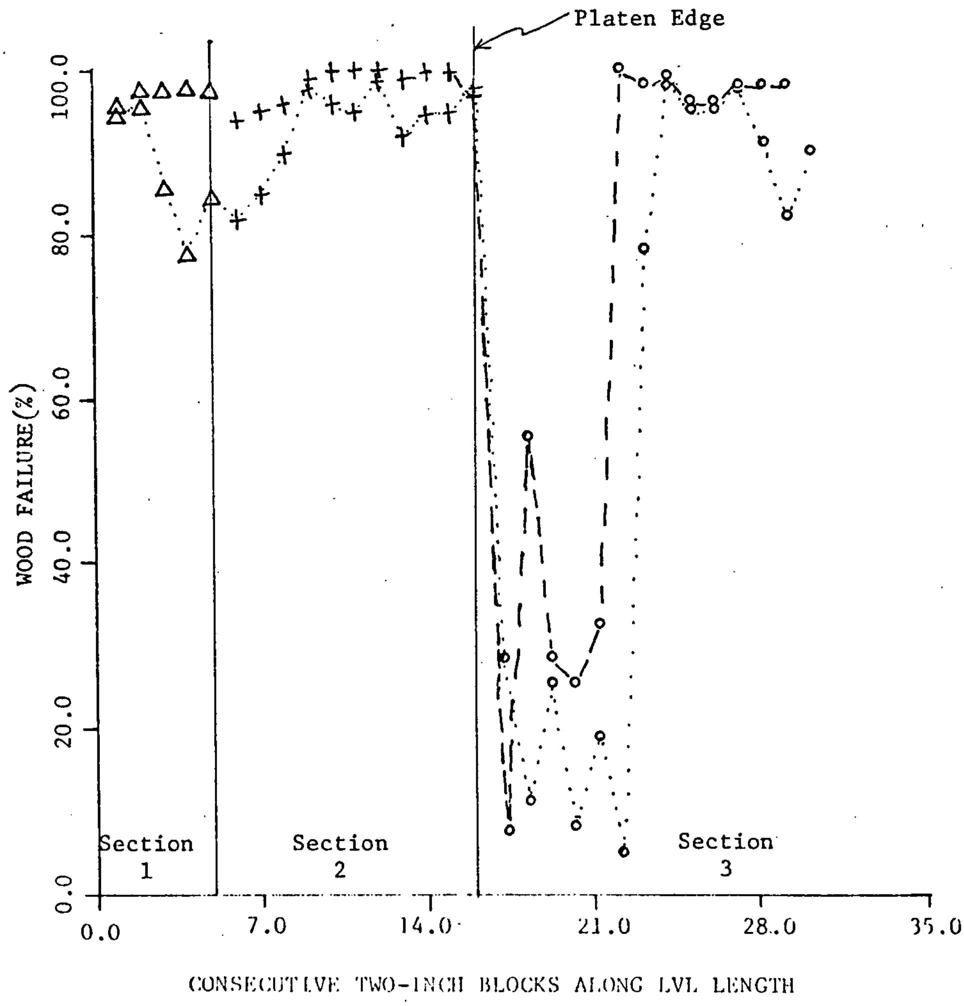


FIGURE 11. BLACK COTTONWOOD LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B337

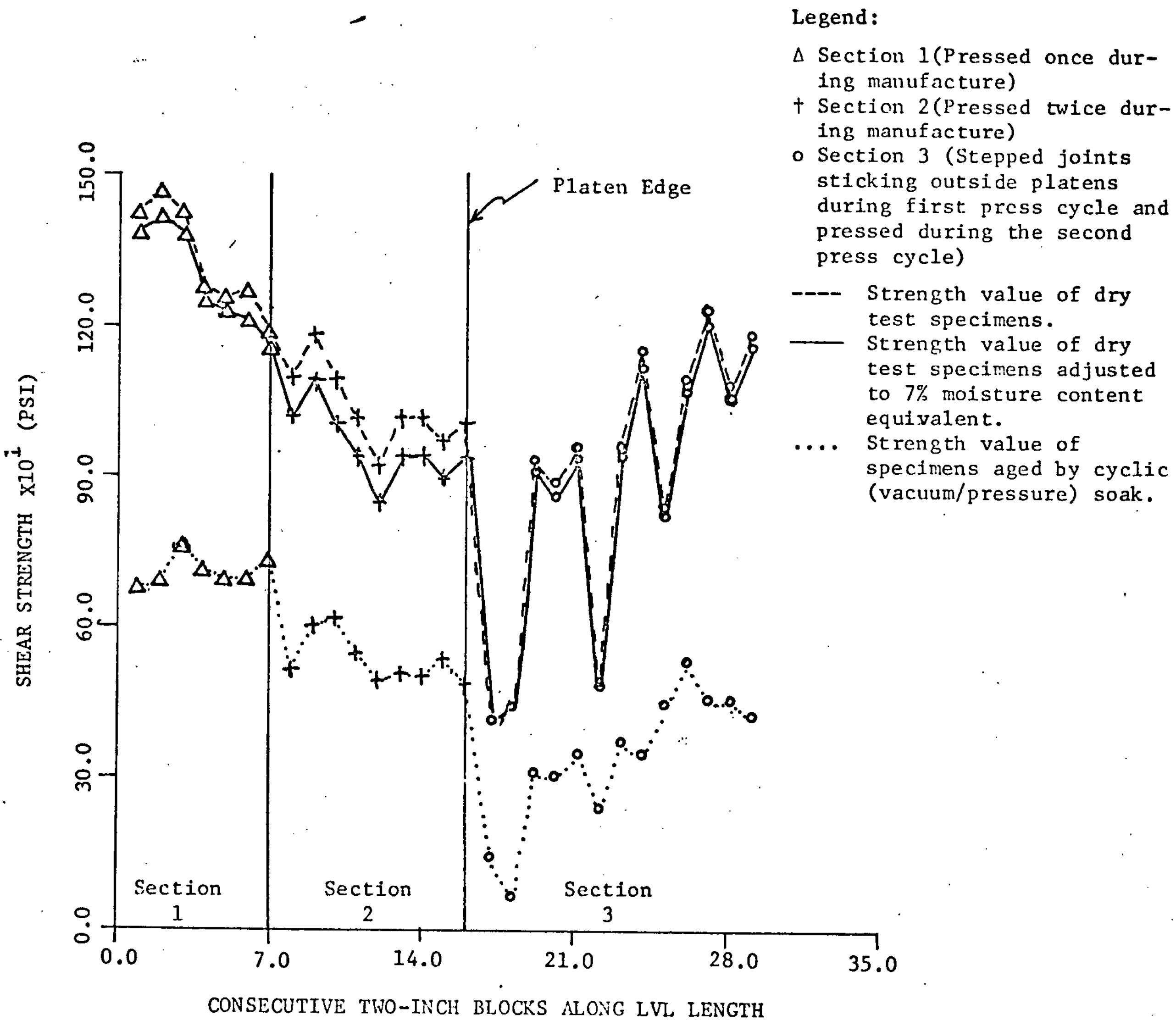


FIGURE 12. BLACK COTTONWOOD LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B334

Legend :
Δ Section 1(Pressed once during manufacture)
+ Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)
---- Strength value of dry test specimens.
.... Strength value of specimens aged by cyclic (Vacuum/pressure) soak.

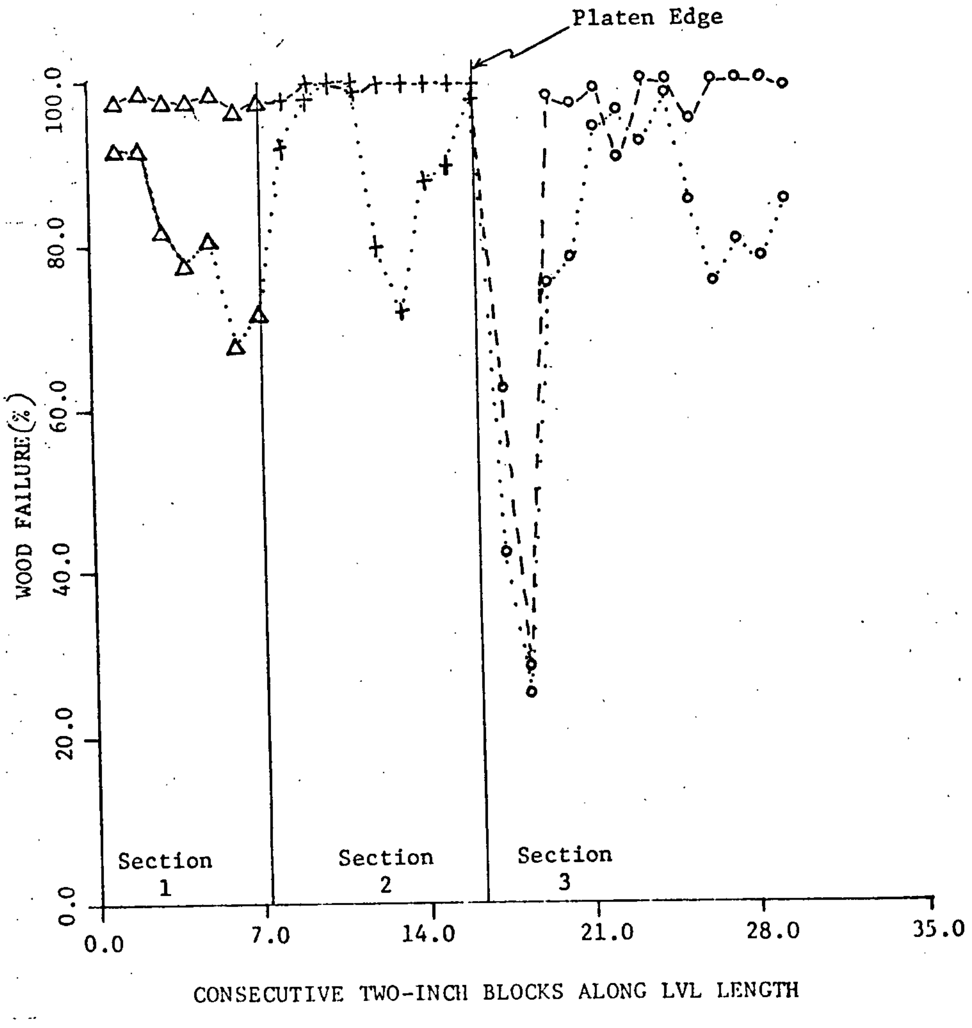


FIGURE 13. BLACK COTTONWOOD LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B334

Legend: Δ Section 1 (Pressed once during manufacture)
† Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)

---- Strength value of dry test specimens.
____ Strength value of dry test specimens adjusted to 7% moisture content equivalent.
.... Strength value of specimens aged by cyclic (vacuum/pressure soak.

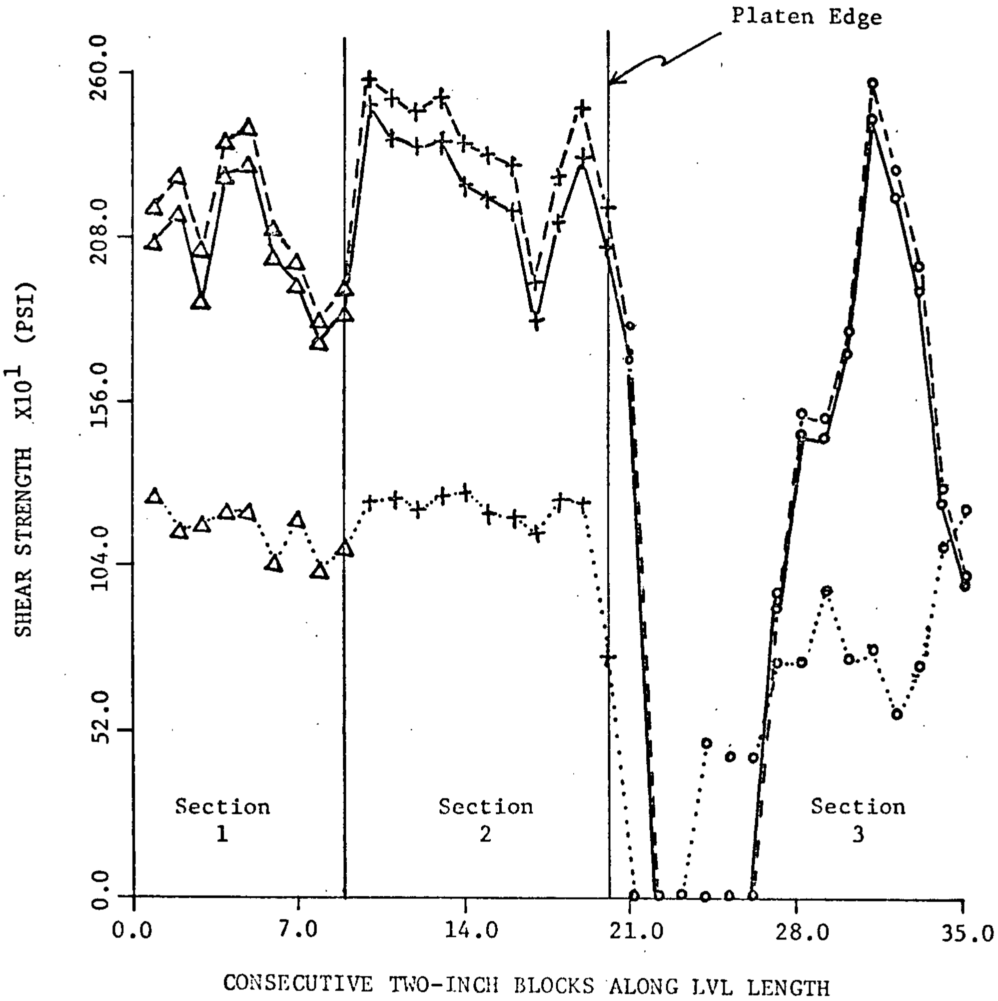


FIGURE 14. SUGAR MAPLE LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B337

Legend :
Δ Section 1 (Pressed once during manufacture)
† Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)
—— Strength value of dry test specimens adjusted to 7% moisture content equivalent
.... Strength value of specimens aged by cyclic (Vacuum/pressure) soak.

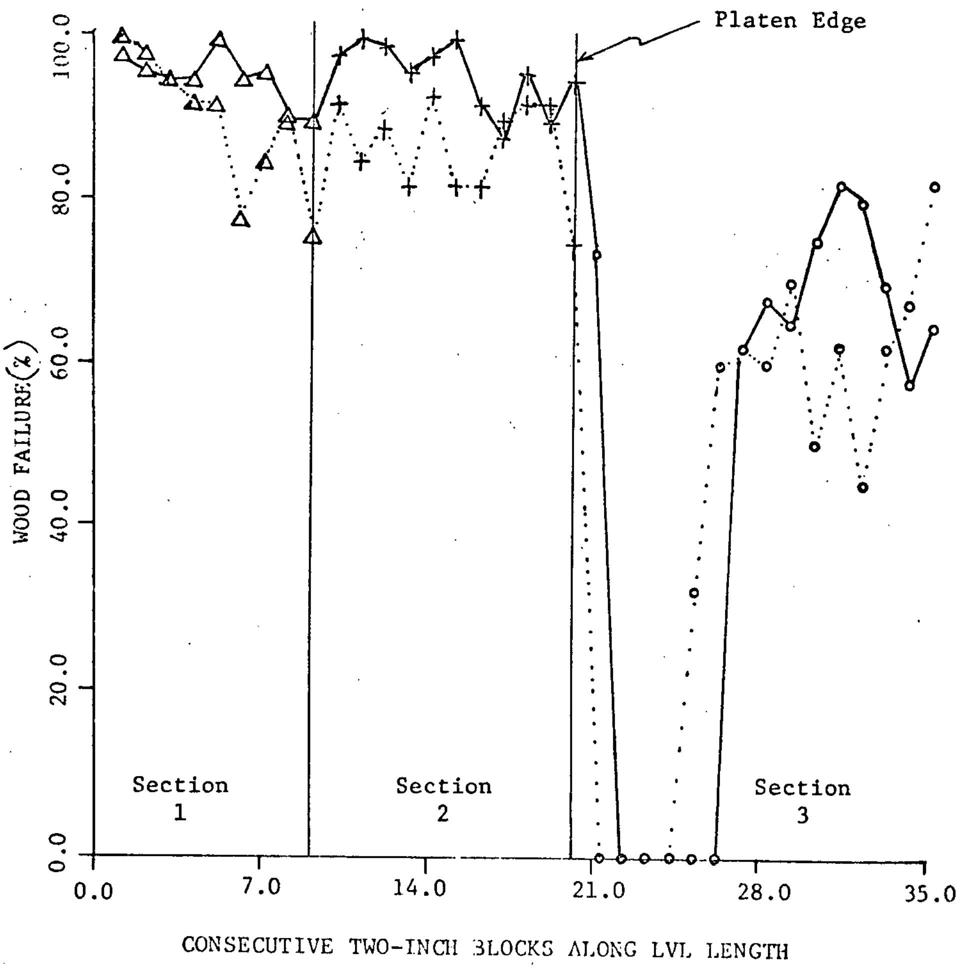


FIGURE 15. SUGAR MAPLE LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B337

Legend:

Δ Section 1 (Pressed once during manufacture)
† Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)

---- Strength value of dry test specimens.
—— Strength value of dry test specimens adjusted to 7% moisture content equivalent.
.... Strength value of specimens aged by cyclic (vacuum/pressure) soak.

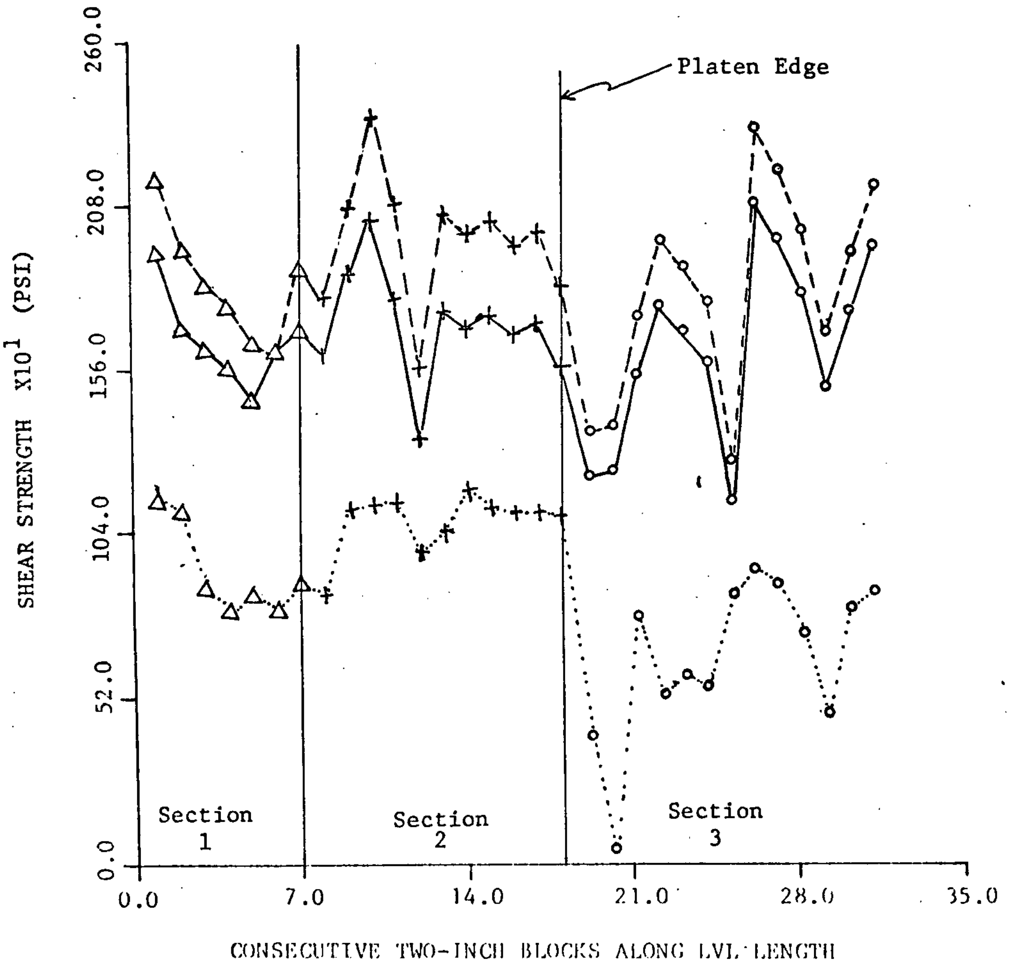


FIGURE 16. SUGAR MAPLE LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B334

Legend :
Δ Section 1 (Pressed once during manufacture)
† Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)
---- Strength value of dry test specimens.
.... Strength value of specimens aged by cyclic (Vacuum/pressure)soak.

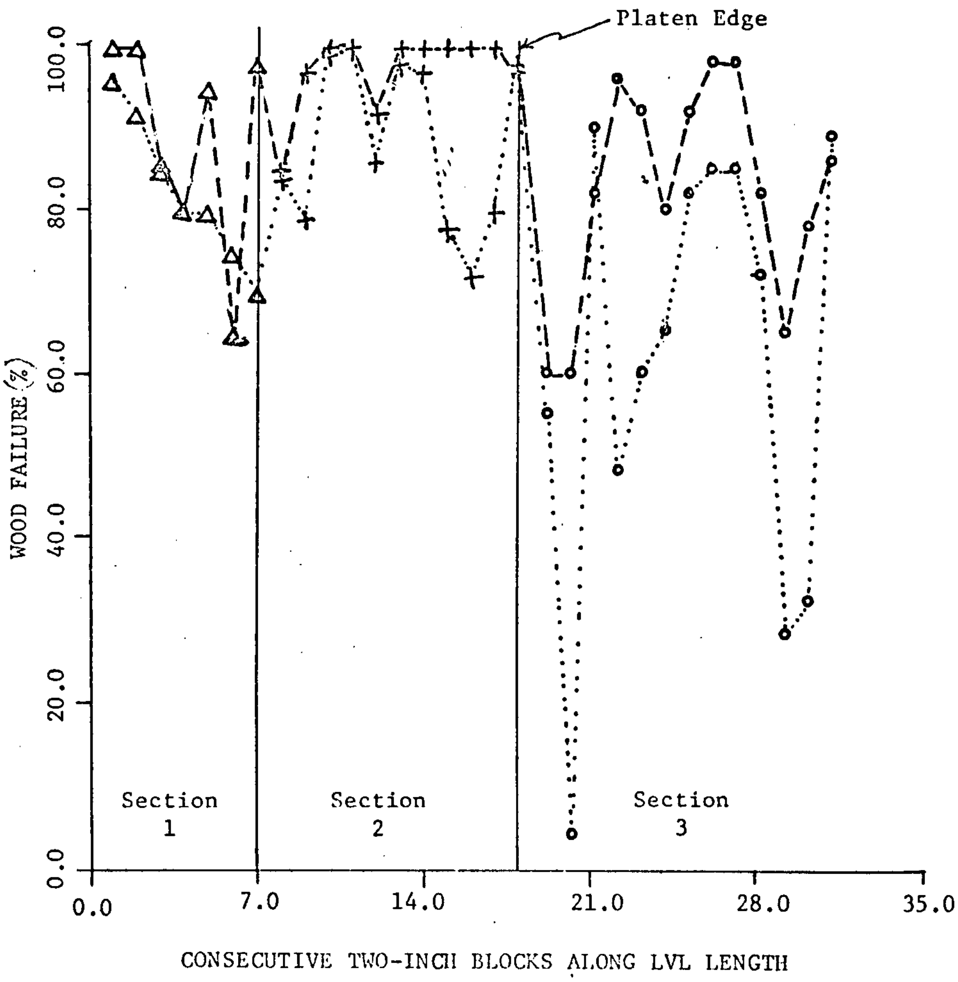


FIGURE 17. SUGAR MAPLE LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B334

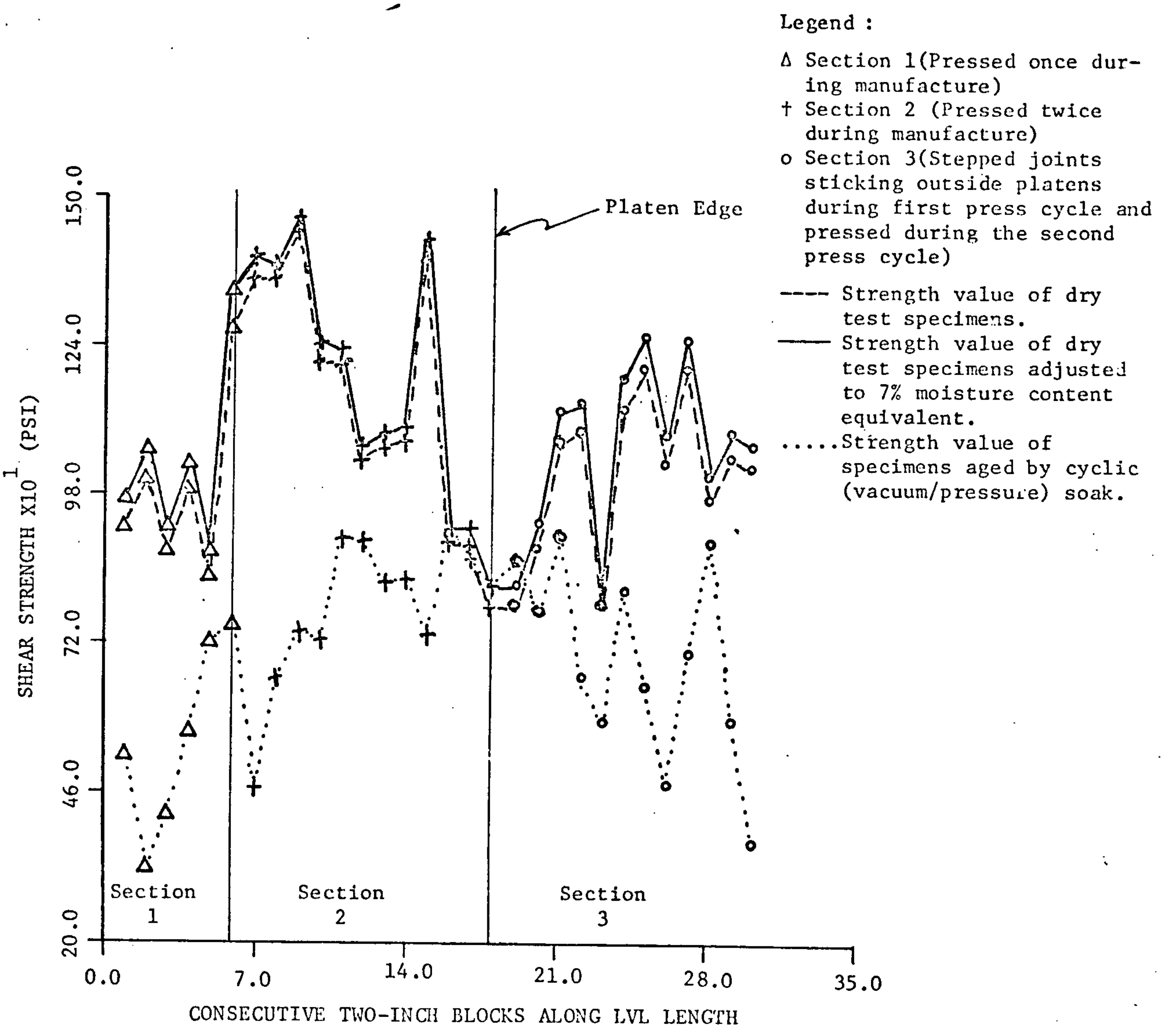


FIGURE 18. WHITE SPRUCE LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B337

Legend :
Δ Section 1 (Pressed once during manufacture)
† Section 2 (Pressed twice during manufacture)
o Section 3 (Stepped joints sticking outside platens during first press cycle and pressed during the second press cycle)
---- Strength value of dry test specimens.
.... Strength value of specimens aged by cyclic (Vacuum/pressure)soak.

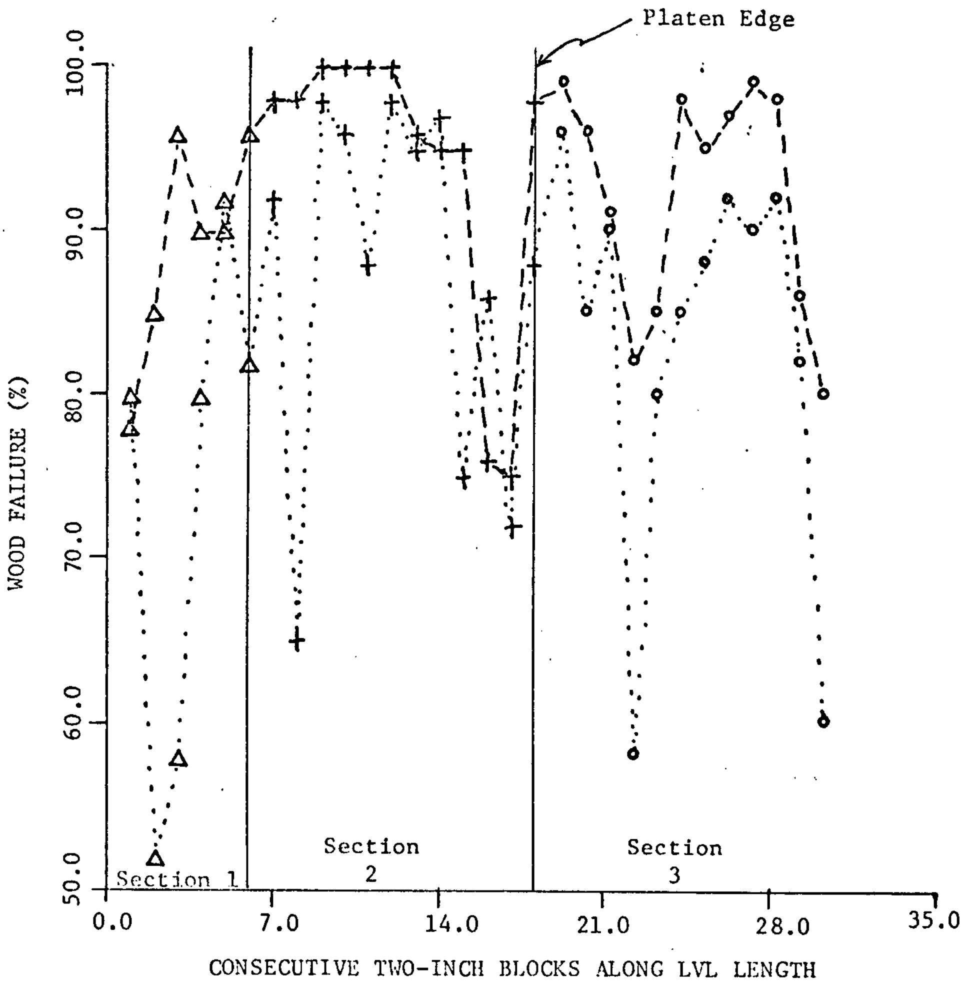


FIGURE 19. WHITE SPRUCE LVL STRENGTH QUALITY RESPONSE TO CONTINUOUS LAMINATING PROCESS USING PHENOL FORMALDEHYDE GLUE 1B337

11 APPENDICES

Your file Votre dossier

Our file Notre dossier 361-3-1-1

Environment Canada Environnement Canada

Canadian Forestry Service,
Eastern Forest Products Lab,
Montreal Road, Ottawa K1A-OW5.

August 24, 1973.

Dr. W.V. Hancock,
Western Forest Products Laboratory,
6620 N.W. Marine Drive,
Vancouver 8, B.C.

Dear Bill:

I first wish to thank you for the copies of your report VP-X-109 on cedar veneer and the use of the steam knife. We found this report to be very interesting.

I wish to inform you that today we were successful in peeling 1/4 inch hard maple veneer which should be suitable for the manufacture of laminated-veneer lumber (LVL). The cutting conditions were:

Species: acer saccharum (Spec. gravity 0.66)
Thickness: 0.272" (green)
Horiz. gap: 0.260"
Vert. gap: 0.060"
Knife angle (24" diam) 89°00'
Knife angle (9" diam) 88°00'
Knife bevel 20°
Bar angle 14°
Bolt temperature 200°F

Veneer thickness varied from 0.277 in. to 0.283 in. The average depth of roughness was 0.008 in. and the maximum about 0.020 in.; lathe check penetration varied from 50 to 75% of the thickness of veneer. Some sheets were broken right through, coming off the lathe; also more breakage should be expected from handling dry veneer. All the sheets were slightly corrugated; however, we do not feel that the corrugation would interfere with gluing. This quality, of course, is that of veneer peeled under laboratory conditions.

We are now ready to peel the 600 square feet of veneer required for your project. We hope to find all the material in the four logs we now have in storage; if not, we would have to travel 100 miles to the nearest mill which can supply us. The dimensions of these logs are:

Log No.	Length	Butt diam.	Top diam.
7 sound	11'	18"	17"
2 sound	8'	17"	15"
3 sound	6'6"	12"	11"
4 some decay and ring shake	8'	11"	10"

On the basis of these dimensions can you tell us the length and width of the sheets you require. The maximum length we can peel is 4 feet but would prefer not to exceed 40 inches. Should we get more breakage than expected, what is the minimum width you can accept?

Finally what should be the moisture content of the dry veneer?

As for the financial side of this enterprise, only the freight (approx. $50) will be charged to your Laboratory.

Yours sincerely,

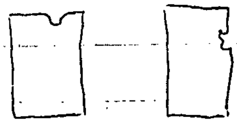
O. Feihl and V. Godin
Veneer & Plywood Group,
Wood Production Division.

Ottawa Sept. 12, 1973

1/4 in. Hard Maple Veneer

Veneer Yield

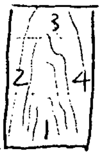
Bolt No	Bolt diam. (in.)	Full Solid Sheets[1] (sheet No.)	Full Solid Sheets with Edge Defects[2] (sheet No.)	Narrow Sheets[3] (sheet No.)
1	24	1F to 19F	1D to 3D	1N to 3N
2	15	20F to 28F	0	4N
3	24	29F to 39F	4D to 6D	5N to 14N
4	26	40F to 54F	7D to 8D	15N to 24N
5	18	55F to 64F	0	25N to 33N
6	16	65F to 73F	9D	34N to 46N
Total		73 sheets	9 sheets	46 sheets

1. These sheets may contain ~~knots~~, single splits, rough areas.
   Green dimensions: 30 in. (across grain) by ~ 42 in.
2. These sheets contain defects of this kind ⟶ 
   Green dimensions: same as (1)
3. These sheets are ~ 42 in. long by anything from 6" to 29" across the grain (green)

O. F.

 *

Thickness Measurements of 1/4 in. Hard Maple Veneer



Bolt No	Full Sheet No	1	2	3	4
			(1/1000 in.)		
1	19	290	288	295 max.	284
	5	283	290	289	289
	10	283	283	286	286
2	28	283	283	285	284
	20	284	284	288	282
3	39	275	282	276	286
	35	281	285	280	284
	30	285	290	290	291
4	54	280	283	280	279
	50	278	283	283	282
	45	279	278	278	278
	40	280	281	278	286
5	64	280	282	286	283
	60	278	280	278	281
	55	280	282	280	282
6	73	276	281	281	280
	70	279	285	284	285
	60	276	285	273 min.	280

O.F.

* Thickness set: 0.272 in.

SEP 3 1974

Q◆
CFS WFPL VCR

CFS FPL OTT

SEPT 3/74

DR HANCOCK

DRYING SCHEDULE FOR ONE QUARTER INCH SUGAR MAPLE VENEER
INITIAL MC = 90 PERCENT FINAL MC = 2 PERCENT TEMP = 325 F
ANXX AIR VELOCITY = 900 FT/MIN VENEER WAS PASSED TWICE
TRHOUGH THE TWO ZONES OF THE DRYER FOR A PERIOD OF 30 MIN EACH
PASS

OLIVER HEIHL FEIHL
CFS FPL OTT
◆
CFS WFPL VCR
EV

APPENDIX II

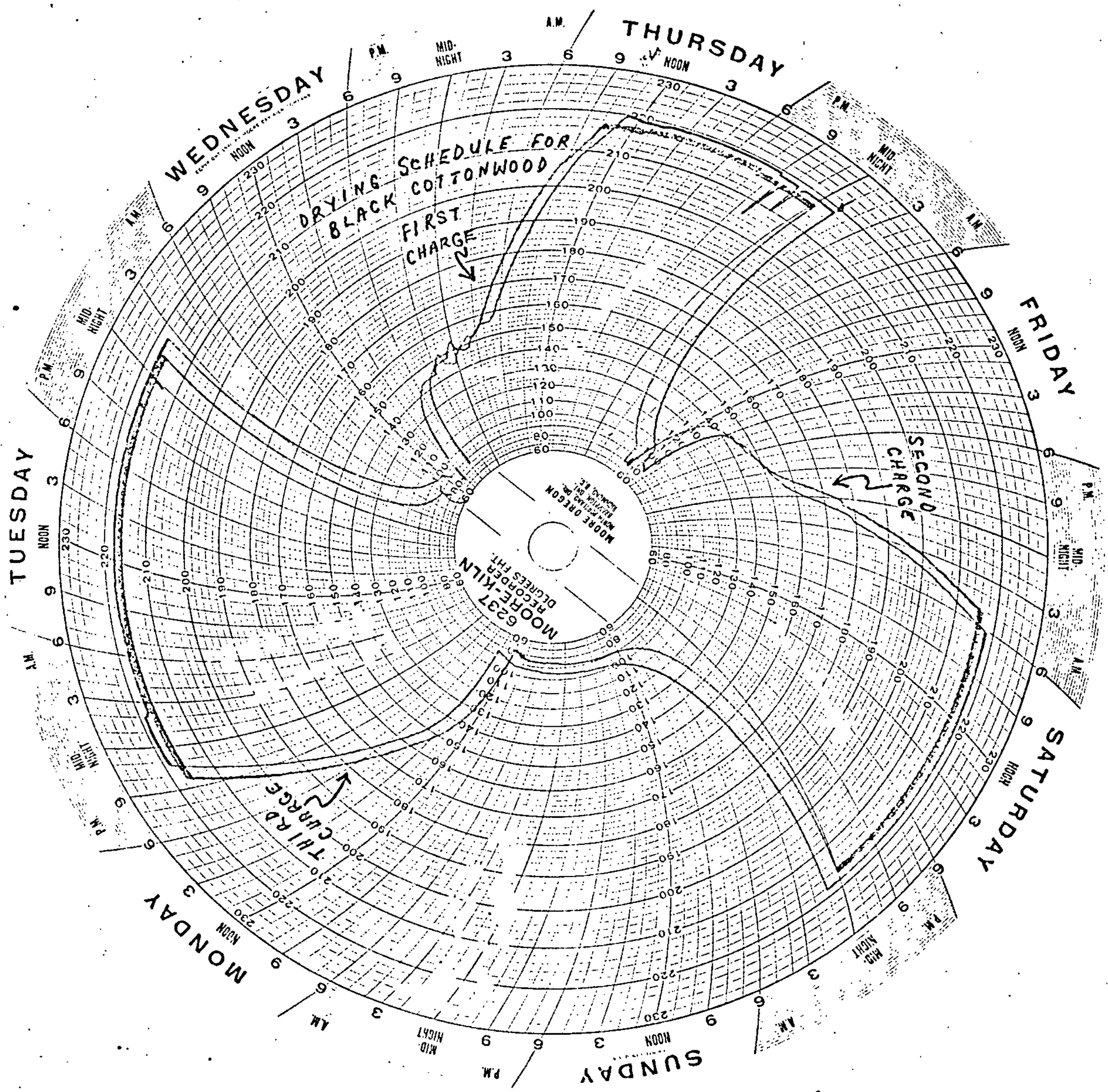
Peeling parameters for black cottonwood bolts

Thickness set:	0.273 in.
Vertical gap:	0.118 in.
Knife (pitch) angle* (at bolt diameters greater than 12 in):	90° 00'
Knife (pitch) angle (at 12 in. bolt diameters and lower):	89° 30'
Knife angle:	20° 50'
Knife thickness:	5/8 in.
Knife hardness	56 Rockwell hardness
Peeling speed:	150 fpm.

*One of the bolts was peeled at 89° 50'.

APPENDIX III

Kiln schedule used for drying black cottonwood used in this study



APPENDIX IV(a)

Glue mix and Mixing Sequence for a Five-Gallon Bucket of PF IB-337

	g
Water	890
IB-337	6240
Norprofil	1340
Wheat flour	445
(mix for 5 min.)	
Soda ash	356
(mix for 30 min.)	
IB-337	8900
Water	1780
	19,951

Other information supplied by the manufacturer:

PF solids	26.6%
Total solids	41.1%

APPENDIX IV(b)

Glue Mix and Mixing Sequence for a Five-Gallon Bucket of PF IB-334

	g
IB-334 Plyophen	5872
Water	1781
Norprofil	1444
Wheat flour	963
Soda ash	409
(mix for 15 min. 4000 rpm Bowers mixer)	
IB-334 Plyophen	7702
Water	1829
	20,000

Other information:

PF solids	23.8%
Wheat flour	4.8%
Total solids	43.9%

August 9th, 1974

Mr. A. Afolayan,
c/o Dr. W. Hancock,
Forest Products Laboratory,

Dear Mr. Afolayan:

This letter is in response to your telephone enquiry for information on the relative speeds-of-cure of IB-334 Plyophen and IB-337 Plyophen.

During lab. development of these resins, our speed-of-cure test involving press time reductions indicated that IB-337 had a noticeable faster cure rate than resin IB-334. The assembly time tolerance of both resins were equivalent in the lab.

IB-337 accounts for only a small portion of our phenolic sales and the customers using it have not fully utilized its fast cure capabilities.

Yours very truly,

REICHHOLD CHEMICALS LIMITED

W. C. Ainslie,
Wood Lab. Manager

WCA/jm

P.O. Box 130 ∘ Port Moody • British Columbia ∘ Telephone: 604-939-1181 ∘ TWX: 610-926-5096

APPENDIX VI

norman springate & associates ltd.

203-1847 WEST BROADWAY, VANCOUVER, B.C., CANADA. V6J 1Y6 TELEPHONE (604) 736-3511. TELEX 04-55286. CABLE "NORINGATE."

March 27, 1974

Dear Ademola:

Please find enclosed the original list of machinery for your LVL plant study. We have given current budget prices for the equipment and we have also enclosed descriptive literature for some of the major equipment in plywood and sawmill plants.

Trusting this will aid you in your studies, I remain,

Yours truly,

John Ingram

JI:sd

Enclosures

Machinery for an LVL Plant

	Machinery	Cost
1.	Log Barker 35"	$ 65,500
2.	Hot Water Heating System	$ 30,000
3.	8' Lathe, 42" swing	$109,000
	Lathe Charger	$ 29,900
	Back-Up Roll	$ 7,500
	Lathe Drive (150 HP DC)	$ 36,900
4.	Veneer Clipper (8')	$ 31,000
	Clipper Infeed System (45')	$ 24,000
	Clipper Outfeed Conveyors (75')	$ 9,500
5.	Panel Saw	$ 43,500
	Panel Saw Feeder	$ 17,000
6.	Veneer Roller Dryer 8 Deck x 12 Sections (approx. 70' of drying length)	$190,000
	Dryer Feeder (includes storage chain, hydraulic hoist section)	$ 30,000
	Dryer Unloader	
	Veneer Outfeed Apron	$ 21,000
	Moisture Detector	6,000
		6,500
7.	4' Glue Spreader (53")	$ 17,900 each
	Curtain Coater	$ 50,000
	Infeed & Outfeed to Curtain Coater	$ 65,000
8.	4' x 16' 8 opening Press	$250,000
9.	Edger (13 Saw Gang)	$ 30,000

10.	Trim Saw	$ 9,000
11.	Fork Lift (7000# cap)	$ 15,000
12.	Push Carts	approx. $300 - 400 each
13.	Flat Deck Truck for log delivery	$ 85,000 each
14.	Truck (Marketing & General office)	$ 10,000

Above prices refer to equipment purchase costs only. No estimate is included for installation, labour, start-up, shipping or export costs.

Where possible, the price given is an overage cost of any particular piece of machinery. For example, a 36" ring barker can cost anywhere from $45,000 up to $100,000, depending on the supplier and the options desired.

received 27-3-74