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Title: Effect of Solvent Extraction and Planing of Veneers from Southeast Asian Species Upon Glueline Characteristics and Bond Durability

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Robert L. Krahmer

Using Southeast Asian hardwood veneers for exterior plywood siding has caused problems because some species produced quality plywood while other species produced plywood which delaminated soon after being put in service in exterior exposure. This study attempted to improve the durability of glue bonds of some Southeast Asian hardwood veneers by treating the veneer surfaces prior to gluing with a phenolic adhesive that has the advantage of shorter press time in plywood production. The species selected were known to produce plywood panels having a range of bond durabilities for untreated veneer glued with this adhesive. Kapur (Dryobalanops aromatica) was chosen because it has consistently glued poorly. A low density Meranti (Shorea curtisii) having good gluability and a high density Balau (Shorea ochropholia) having poor gluability were selected. Also six Keruing species (Dipterocarpus spp.) having variable bond durabilities were included.

The two treatments were planing the veneer surface and extracting the veneer surface with a one percent caustic solution. A statistical

analysis was performed on wood failure data from plywood shear tests using a split plot experimental design. The design factors were three treatments (planing, extraction, control), ten species including the Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco] control, two phenolic adhesives (A and B), two assembly times (20 and 45 minutes), two test methods (vacuum-pressure and automatic boil) and four replications.

A second phase of the study focused on anatomical observation of the veneer surfaces and plywood gluelines of treated and untreated veneer. Stereo light microscopy, incident fluorescence microscopy and scanning electron microscopy were used.

Plywood made of untreated veneer using adhesive A produced the variable bond quality previously observed for these species, many being below the commercial standard. Planing the veneer surface prior to gluing was an effective treatment. All of the hardwood species producing unacceptable plywood bonds when made with untreated veneer produced plywood panels with acceptable bonds when made of planed veneer. Planing altered the veneer surface anatomically. The surface appeared smooth with cellular debris deposited in the vessel lumens. Planing appeared to produce veneer surfaces with larger amounts of intra-wall failures rather than cross-wall failures common for unplaned veneer surfaces. The plywood gluelines were of uniform thickness and appeared to cause an even adhesive distribution.

Extracting the veneer surface with a caustic solution prior to gluing was not an effective treatment. The variable bond quality of the species was not eliminated. Extraction produced a darker colored

veneer surface and it appeared that new extractives might have migrated to the surface following the extraction sequence.

Effect of Solvent Extraction and Planing of Veneers from Southeast Asian Species Upon Glueline Characteristics and Bond Durability

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INTRODUCTION

Exterior plywood siding has been manufactured in the United States since the 1940s. In the early stages of the plywood industry in the Pacific Northwest adequate supplies of clear, high grade Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco) veneers were available. As the United States population expanded and the standard of living increased, the plywood market boomed and domestic supplies of clear, full size veneers decreased. Thus, as early as 1950 foreign veneers from the Philippines were being imported.

Veneers from Southeast Asia began to arrive in the late 1950s and early 1960s. The Southeast Asian species used were primarily Meranti (Shorea, Parashorea and Pentacme spp.). As expected the demand for these high grade veneers increased even more. Soon species of Kapur (Dryobalanops spp.) and Keruing (Dipterocarpus spp.) were imported. These veneers began to arrive in the early 1970s and almost immediately gluing difficulties occurred.

As early as 1971 field delaminations were reported. It was at this time that the Forest Products Department at Oregon State University started its investigation of this plywood problem. A goal of this investigation was to determine causes of delamination in order that exterior durability of plywood using these Southeast Asian veneers might be improved. Thus, an investigation of these Southeast Asian veneers led by Oregon State University (38) and combined with the research of

others (1, 5, 13, 14) paved the road for this further research.

Excessive shrinkage and swelling of these dense hardwoods were considered as probable causes of the delamination (5). However, the effect of shrinkage and swelling proved to be secondary when viewed in relation to the plywood failures (38).

Poor wettability has been known to be a key factor in poor bond durability (13, 14) for some species. For Keruings, however, poor wettability occurred with some which glued well (38). Likewise, Kapur wet well but gave poor glue bonds (38).

High extractives content has been reported to block the adhesive from the wood surface (1, 14). The high extractives content (9-11%) of Kapur appeared to be the reason for its poor bonds (38). However, the poor bonds found when using some Keruing veneers could not be related to extractives content (38). Extractives might also interfere with the curing process of the adhesive (1, 14). Nyguen (26) concluded this to be the case with Kapur but not necessarily with Keruing.

Causes for gluing difficulties involving Kapur are fairly well understood. The causes associated with Keruing delaminations have not been as adequately explained. Although excessive shrinkage and swelling, high density, poor wettability and a moderate extractives content might contribute to the gluing problem, findings indicate that for the Keruings the gluability problem may lie at the wood surface and that the application of surface treatments to the hardwood veneers might improve the bond durability. Therefore, this study investigates the effect of planing and caustic extraction of veneer surfaces on plywood bond durability.

OBJECTIVES

The objective of this study was to determine the effect of solvent extraction and planing of veneer surfaces of Kapur, Keruing and Meranti on plywood bond durability and on adhesive distribution in the glueline.

To accomplish this objective the following procedures were executed:

1. Exterior plywood panels were produced using treated and untreated Southeast Asian veneers on the face and back, glued to Douglas-fir core. Wood failure was used to measure bond durability for two phenolic adhesives.
2. Veneer surfaces and plywood gluelines were examined microscopically for anatomical characteristics and distribution, location and penetration of adhesive.

LITERATURE REVIEW

Gluability of Southeast Asian hardwood veneers has been the subject of much research in the past. In the beginning one of the major problems was one of identification. As field delaminations of the exterior plywood began to occur there arose much speculation as to which species were the ones involved. Krahmer and Wellons (17) in cooperation with the Plywood Research Foundation were one of the first to deal with this problem. By producing various Southeast Asian hardwood identification keys they were able to separate Southeast Asian woods into trade groups such as Keruing (Apitong), Meranti (Lauan), Kapur, Mersawa and Mengkulang. In some cases separation into subgroups within a trade group was possible. Through further work by Wellons and Krahmer (37) it was found that not only Kapur but also some Keruings (Apitong) and even a few of the Meranti (Lauan) were the Southeast Asian hardwood species responsible for the field delaminations.

Now that identification of the Southeast Asian veneers in the delaminated plywood was complete, attempts were made to determine why these delaminations occurred. Excessive shrinkage and swelling, high density, poor wettability and moderate extractives content were thought to be causes of the delaminations. However, especially with the Keruing species no clear answer was found.

Machining of Veneer Surfaces

Machining wood surfaces to improve gluability has been investigated for many years. Kaufert (15) performed experiments to improve gluing characteristics of refractory plywood surfaces by sanding. He concluded

that light hand-sanding of the plywood surfaces did improve their gluability. The light hand-sanding removed most of the undesirable surface characteristics of the plywood so as to produce a good clean surface for gluing. Suchsland (33), in working with coniferous wood stated that surface roughness improves gluability up to a point but after that the decreased wood strength due to crushing takes over. Bryant (4) in reviewing surface treatments pointed out that the S_2 layer of the wood cell wall is the ideal surface for bonding and that this surface can best be generated on veneer by planing dense hardwood veneer. If the hardwood is not of high enough density too much crushing will occur. River and Miniutti (30) further emphasized that the planing of hardwood blocks enhances the formation of good bonds as long as the wood density is high enough. Bodig (3) investigated wettability as related to gluability of Philippine mahoganies and found that light sanding or microtoming of the hardwood veneer surfaces greatly improved the wettability of that surface and therefore would improve gluability.

Results of machining the surfaces of the Southeast Asian hardwood veneers used in this study have not been extensively studied. Sleet (32) at the American Plywood Association (APA) laboratory investigated the effects of sanding Kapur veneers and found that the gluability of the Kapur was only slightly improved. In a similar fashion Boise Cascade Company[1] performed experiments on species of Kapur as well as Keruing and found that sanding of these hardwood veneer surfaces greatly improved bond durability. Knowing this information, Wellons et al. (39)

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[1]Personal communication, Mr. Alan L. Lambuth.

used planing as a pretreatment on Keruing veneers but were unable to attribute the good glue bonds produced to the planing because all panels were glued with a high quality adhesive and even the unplaned control Keruing veneers glued well. Nguyen et al. (28), however, found that for Apitong (Keruing) species sanding improved gluability of the unextracted veneers but not of the extracted veneers. In the study by Nguyen et al. (28) extraction was also a pretreatment performed on the hardwood veneers.

Extraction of Veneer Surfaces

The extraction of veneers has been a pretreatment used for many years in an effort to remove extractive materials from the surface which might interfere with gluing. Extraction falls under the broad class of treatments known as chemical surface treatments. Wellons (36) has thoroughly reviewed the subject of chemical surface treatments of veneer. Here I am primarily concerned with solvent extraction of veneers to remove extractives to improve gluability.

Hare and Kutscha (12) worked with Douglas-fir veneer pretreated with a 50% caustic solution. They reported that the wettability of the pretreated veneers increased yet the glueline shear strength decreased for plywood panels made of these pretreated veneers and glued with a phenolic adhesive. Many of the panels exhibited starved gluelines, perhaps suggesting overpenetration of the adhesive into the extracted veneers. Bryant (4) treated veneer surfaces with a chrome complex solution which did not improve gluability. He pointed out that redrying of veneer after extraction can cause extractive migration back to the

surface. Thus, it is possible that after an extraction sequence and during the reconditioning period extractives may recontaminate the veneer surface.

Nguyen et al. (28) in their study using Apitong (Keruing) veneers found that sanding of unextracted veneers improved gluability but sanding was not as effective as extraction alone with a methanol-benzene solution.

Chen (6) in working with tropical woods found that a 10% sodium hydroxide extraction pretreatment of veneers improved the strength of the adhesive joints but that this improvement did vary from species to species. The species used were Mahogany (Swietenia macrophylla), Primavera (Tabebuia donnell-smithii), Acupu (Vouacapoua americana), Almendro (Coumarouna oleifera), Angelim (Hymenolobium excelsum), Purpleheart (Peltogyne venosa), Mora Amarilla (Chlorophora tinctoria), and Bannia (Swartzia bannia).

Sleet (32) extracted Kapur veneer with a one percent caustic solution and found that indeed it did improve the gluability of the veneer. Sleet, however, did not perform the same experiment on Keruing veneers. However, Wellons et al. (39) extracted Keruing veneer but once again any possible effects of the extraction were masked by the fact that all the veneers, including the control, glued well with the high quality adhesive.

Light and Electron Microscopy

Predicting and explaining bond durability as affected by many wood and production variables can involve microscopic observations of

gluelines. White (40) defines the three dimensional region of wood penetrated by adhesive as the "interphase." This region contains not only properties of the adhesive and the wood but a combination of both. By obtaining a more complete understanding of the role of wood as well as adhesive in this "interphase" region it then becomes possible to make progress in explaining bond durability as it relates to wood species and production variables.

Microscopy of plywood gluelines has become a valuable technique in plywood research. High powered microscope equipment is necessary to give the magnifications required to observe phenomena such as adhesive penetration and distribution or simply to observe the arrangement of anatomical characteristics on a wood surface. Koran and Vasishth (16) and Hancock and Northcott (9) used light microscopy to observe that in order to have a durable glue bond the plywood produced must possess a solid, continuous glueline, a glueline not having air or moisture pockets. Koran and Vasishth (16) further state that a rough veneer surface can lead to a discontinuous glueline in certain press conditions and that overpenetration of an adhesive can also cause a discontinuous glueline. Similarly, Otto Suchsland (34) observed with light microscopy that an increased depth of adhesive penetration does not necessarily yield an improved glue bond.

In many cases the higher magnifications and greater depth of field of a scanning electron microscope (SEM) are required for observation purposes. Hare and Kutscha (12) used SEM as well as light microscopy to observe that adhesive penetration must go beyond the weak surface zone of veneer in order to form a good bond and that any void areas

present in a glueline are undesirable. Fengel and Kumar (8), with the use of SEM, state that deep penetration of the adhesive into the wood substrate is prevented by the aspiration of the pits in pine and that most of the adhesive penetration occurs in the fissures of the wood. Harada et al. (10) confirmed with SEM that in his hardwood plywood gluelines, good adhesion occurred between cell wall material and the adhesive. Harada and Okuno (11) also used SEM to show that any microcavities in the glueline or poor contact between adhesive and the cell wall would indeed decrease the strength of plywood. Even with particleboard, Wilson and Krahmer (42) use SEM to describe the wood-adhesive relationships as found in particleboard gluelines.

Delaminations of Southeast Asian hardwood plywood have been studied microscopically. Wellons et al. (37) with the use of light microscopy as well as SEM, have described the interfacial failures of Kapur plywood gluelines showing the gluelines as unanchored to the Kapur face, but adhering to the Douglas-fir core veneers. It is clear that light microscopy and electron microscopy have provided and will continue to provide much information in the study of plywood gluelines.

Fluorescence Microscopy

Plywood gluelines do not lend themselves easily to microscopic evaluation. Sample preparation techniques are usually difficult and obtaining contrast between adhesive and wood is not always the simplest task. Fluorescence microscopy has enabled researchers to obtain a greater degree of color contrast so necessary to adequately examine plywood gluelines. Wood autofluoresces which means that it is a

naturally fluorescing material and requires no dye added to it. In the "interphase" region is found wood and adhesive. Using fluorescence microscopy the wood fluoresces a yellow-green color while the adhesive remains a dark red to black color. This creates an excellent contrast enabling one to observe adhesive properties in the glueline.

What are the fundamental theories that account for the occurrence of fluorescence? As light rays are emitted onto a wood surface molecules on the surface of the wood absorb the light as energy and are raised to an excited higher energy state. This high energy state exists for a very short period (10^{-18} seconds) at which time the molecules release energy. This energy release may take the form of heat but may also be reemitted as luminescent light. With wood the time between absorption and emission is less than 10^{-4} seconds and thus the luminescence is known as fluorescence.

There are two types of fluorescence microscopy, incident and transmission fluorescence microscopy. In transmission fluorescence microscopy the excited light is passed through a thin section of material. In this study incident fluorescence has been used. The excited light in incident fluorescence is emitted onto a solid wood surface where some light is absorbed, some reflected and some reemitted as fluorescence. For adequate excitation and fluorescence to occur short wave lengths of light of high energy are required. Short wavelengths of light yield higher quanta of energy causing greater excitation of the molecules at the wood surface.

Fluorescence microscopy had its first beginnings in the study of wood and not of gluelines. Marts (21) has used fluorescence microscopy

to observe woody tissues of hardwoods and softwoods. Marts (22, 23) further used fluorescence microscopy for measuring fibril angles in pine tracheids as well as observing fibril structure in gelatinous fibers of California white oak (Quercus alba). He discusses techniques of sample preparation as well as staining techniques to improve further the fluorescence of the wood. Kutscha and Ethington (18) describe the use of fluorescence microscopy in studying shelling failures in softwoods.

One of the early studies using fluorescence microscopy to observe plywood gluelines was done by Marian and Suchsland (20). They used fluorescence microscopy to study adhesive penetration and surface properties of the wood glue interphase. Schneider and Côté (31) used incident fluorescence microscopy to describe the penetration of coatings into wood. They observed that the coating penetrated the cell lumens and that ahead of this lumen penetration occur cell wall penetration by some fraction of the coating system. Côté and Robinson (7) used both transmitted and incident fluorescence microscopy to describe gross versus wood cell wall penetration of coatings. They stated that the solvent of the coating system penetrated the wood cell walls ahead of the lumen penetration. Quirk (29) described the adhesive location on fracture surfaces with incident fluorescence microscopy, while Lehmann (19) was able to demonstrate through the use of fluorescence microscopy that nearly continuous gluelines can be obtained on flakes with a fine adhesive spray.

Nearn (24, 25) described lumen and wood cell wall penetration by adhesives with the use of fluorescence microscopy. He defined two zones

of penetration: that of cell lumen penetration and that of cell wall penetration. He also observed a zone of penetration ahead of the cell lumen penetration and attributed the zone to that caused by the caustic from the adhesive. Nearn (24, 25) emphasized the importance of all forms of microscopy in the study of gluelines, especially in an industrial research environment. Villaflor (35), with the use of incident fluorescence microscopy, attributed overpenetration as the problem with the non-gluability of Apitong (Keruing) sapwood. Of all species used he further stated that penetration was deepest in the Apitong (Keruing), but mainly concentrated in the open vessels.

Fluorescence microscopy has proven effective in producing the desired contrast between wood and adhesive necessary to examine adequately the changes in adhesive penetration and distribution in a wood-glue system. Further, it enables the researcher to observe changes in the wood surface and then to relate how these changes may influence glue bond performance in a plywood glue line.

EXPERIMENTAL PROCEDURE

Gluing and Testing

Species Identification and Selection

The wood species used in this study are listed in Table 1 along with their species number, specific gravity and the company who supplied the veneer. The Merantis, Kapur and three West Malaysian Keruings were positively identified by a representative of the Regional Forestry Department of that Southeast Asian country in cooperation with the American Plywood Association (APA). The Keruings from Sumatra were only identified as to their genus, Dipterocarpus. All the hardwood veneers were peeled in Southeast Asia. Only sheets of "A" grade veneer were selected, dried at temperatures below 320°F and shipped to Oregon State University.

Careful thought was given in selecting the ten species for this study. A wide range of plywood panels with varying degrees of bond durability based on previous studies (39) was needed. Once this range of panels was produced the plywood gluelines could be observed anatomically in an attempt to better explain the variable bond durability. Kapur, species no. 20, was chosen because it is known to bond extremely poorly under most conditions (39). One Meranti, species no. 21, was chosen because of its low density and good gluability and served as somewhat of a hardwood control species. The other Meranti, species no. 4, was chosen for just the opposite reasons, high density and poor gluability. Wellons et al. (39) have shown that bond durability of Keruing plywood panels was quite variable. Therefore, gluable as well as

Table 1. Species used in gluing study.

Trade Group	Scientific Name	Species No.	SG Dry*	Supplier
Douglas-fir	*Pseudotsuga menziesii* (Mirb.) Franco	0	.45	SWF Plywood
Meranti				
Red Meranti	*Shorea curtisii*	21	.40	Mentiga
Red Balau	*Shorea ochrophloia*	4	.80	Pacific Veneer
Kapur	*Dryobalanops aromatica*	20	.69	Mentiga
Keruing				
West Malaysia	*Dipterocarpus sublamellatus*	16	.73	Mentiga
	Dipterocarpus costedatus	26	.91	Mentiga
	Dipterocarpus verrucosus	28	.67	Mentiga
Sumatra	*Dipterocarpus* spp.	10	.67	Boise Cascade Co.
	Dipterocarpus spp.	14	.79	Boise Cascade Co.
	Dipterocarpus spp.	15	.84	Boise Cascade Co.
TOTAL	Ten Species			

*Based on dry weight and volume.

non-gluable Keruings were chosen for this study. Keruing, species no. 28, performed well (39). Keruings, species nos. 16 and 14, performed moderately well, while Keruings, species nos. 10, 15 and 26, performed poorly (39).

Plywood panels made of all Douglas-fir veneer, species no. 0, served as an overall control in the study.

Veneer Preparation and Treatment

Four 1/8" x 52" x 100" veneer sheets were selected for each species, one sheet per replication, therefore four replications. The veneers were chosen with the least amount of knots, streaks, cross grain, etc. so as to maintain veneer conditions as uniform as possible within species as well as from species to species. Each 1/8" x 52" x 100" sheet was cut into twenty-four 10" x 14" pieces. These 24 veneer pieces were then randomly paired into groups of two assembly times (TA) (20 or 45 minutes), one of three treatments (TR) (none, solvent extraction and planing), and one of two adhesives (AD) (A and B). Each pair of veneers served as the face and back of a plywood panel. Figure 1 shows one random assignment of these variables to a veneer sheet.

Douglas-fir "A" grade veneers (1/10" x 24" x 96" along the grain) were cut into twelve 10" x 14" pieces to use as the core. These veneers were as clear of flaws as possible. Thus, the 12 pairs of hardwood veneers and the 12 pieces of core veneer were crosslapped to produce twelve 10" x 14" plywood panels for one replication of a species. All veneers were labeled and put into a controlled climate room to equilibrate to 6±1% moisture content.

						14"	10"
TA 1 TR 1 AD 1	TA 1 TR 1 AD 2	TA 2 TR 1 AD 1	TA 2 TR 1 AD 2				
TA 1 TR 2 AD 1	TA 1 TR 2 AD 2	TA 2 TR 2 AD 1	TA 2 TR 2 AD 2				4'
TA 1 TR 3 AD 1	TA 1 TR 3 AD 2	TA 1 TR 3 AD 1	TA 1 TR 3 AD 2				

8' Grain Direction

Figure 1. Random assignment of variables.

This study included two treatments and a control. One-third of the veneers were extracted for 60 seconds with a one percent solution of sodium hydroxide (NaOH), rinsed in water for 60 seconds, then conditioned to 6±1% moisture content before gluing. Another one-third of the veneers were also conditioned to 6±1% moisture content and then planed within 60 minutes of gluing, removing about 0.025 inches from the veneer surface. The last one-third of veneers had no treatment.

Adhesives and Gluing Variables

Two adhesives, A and B, were used in this study. They were both commercial phenolic adhesives and their resin characteristics are listed in Table 2. In a previous study Wellons *et al*. (39) showed that adhesive B bonded the difficult to glue Keruings to an acceptable level, with or without veneer surface treatment.

However, this same experiment had not been performed for adhesive A using treated veneer. Adhesive A is a higher molecular weight adhesive causing it to have a faster curing time than adhesive B. In a

Table 2. Characteristics of phenolic resins used in adhesives.

	Adhesive	
	A	B
% phenolic solids	45.0	40.0
pH	11.2	10.5
molecular weight	moderate	low
viscosity, centipoise	1,100.0	800.0

production situation this would lead to a shorter press time which would be advantageous.

If both adhesives performed as in the study by Wellons et al. (39), then plywood panels glued in this study with adhesive B would glue all species well and panels made with adhesive A would have variable bond quality. These differences in bond durability caused by adhesive might then be reflected in the plywood gluelines as differences in adhesive characteristics such as adhesive penetration which could be investigated microscopically. However, when the panels using adhesive B were being made, an error in communication occurred. All of these panels were placed in the press 30 seconds to one minute early and allowed to remain on the hot platen for as much as one minute before the press closed. This would cause adhesive B to begin cross linking before hot pressing. The effect of this error on bond durability was noticeable and resulted in adhesive B performing like adhesive A.

There were two closed[2] assembly times in this study, 20 minutes and 45 minutes. The 20 minute assembly time represents the optimum

[2]Closed assembly time is the time between assembling and hot pressing the plywood panel.

condition for gluing. It was expected that the moderate molecular weight resin (A) would penetrate the veneer less at the longer assembly time. The resin of low molecular weight (B) would be expected to overpenetrate at the shorter assembly times.

On the day of gluing, adhesive was mixed from the resin, applied to the core veneer, combined with the hardwood face and back and pressed into a plywood panel. Adhesive formulation and spread rates are given in Table 3. Application of adhesive was done with a lab model of a conventional rubber roll glue spreader. Face and back veneers were assembled with the loose side[3] against the core and left for the desired assembly time. For each species, replication, adhesive, and treatment the 20 and 45 minute assembly time panels were hot pressed together in one load. The press conditions were 300°F temperature, 200 psi pressure, a press closing time of 1/2 minute and a full pressure time of 5 1/2 minutes. The panels were then hot stacked for 24 hours before further machining.

As mentioned earlier, four replications were used in this study as recommended by Wilkie (41). Within each adhesive one replication was completed before the next to assure as little variability over time as possible. Species were also randomized within each replication before gluing.

Sample Preparation and Testing

Because some veneer had been planed prior to lay-up, there was

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[3]Loose side is the side of the veneer next to the knife during the peeling operation. Tight side is opposite the loose side.

Table 3. Adhesive formulation.

Adhesive mix	A	B
Resin used	A	B
% resin solids in mix	32.4	29.4
% caustic solids added to mix	1.4	0.0
% filler and extender solids in mix	10.8	13.3
Type of fillers and extenders used	walnut shell flour wheat flour	walnut shell flour wheat flour
Application rate		
Liquid adhesive #/MDGL*	75.0	76.0
Resin solids #/MDGL	24.3	22.3

* #/MDGL = pounds per 1000 square feet of double glueline.

variation in face veneer thickness so all plywood panels were planed equally after conditioning to obtain a uniform thickness for the panels. Panels were then trimmed to 8" x 12", removing approximately 1" of trim from each edge. A central strip, 1" x 12", was removed from each panel and labeled for later use in anatomical study. One piece, 3 1/4" x 7", was then cut out of each panel to be placed in outdoor exposure conditions as permanent test fence samples. These samples are currently on the test fence at the APA grounds in Tacoma, Washington. The remaining portions of the panel were cut into 14 standard shear specimens such that the lathe checks would be pulled closed during testing. Figure 2 shows a diagram of the cutting pattern for one panel. Figure 3 reviews the standard shear specimen as illustrated by Wilkie (41).

From the 14 shear specimens produced, two groups of six each were randomly picked and the two remaining specimens were kept as spares. One set of six specimens was tested by the vacuum/pressure soak test (PS 1-74) (2) currently in use in the plywood industry. The second set of six specimens was sent to Weyerhaeuser Company and subjected to the automatic boil cycling test. Table 4 describes both of these tests. Upon being returned from Weyerhaeuser Company the automatic boil specimens were vacuum/pressure soaked and all specimens were sheared while wet by tension loading to failure with secure grips (no slippage). Breaking loads and wood failures were recorded.

In this study only wood failure data are analyzed because these values are quite independent of species properties and are therefore a good measure of bond durability. Breaking load values are dependent on density and strength and are therefore not the best indicator of bond durability.

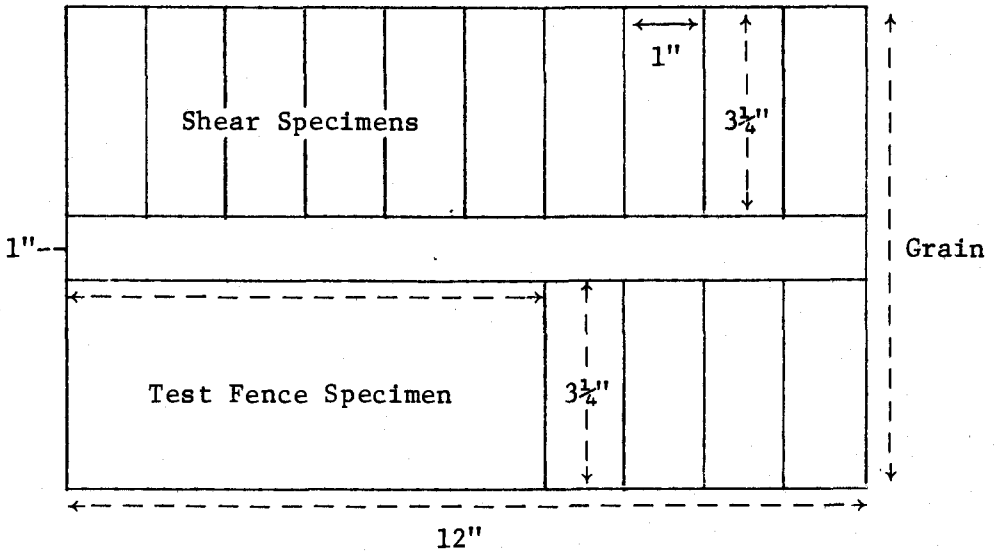


Figure 2. Cutting pattern for an 8" x 12" plywood panel.

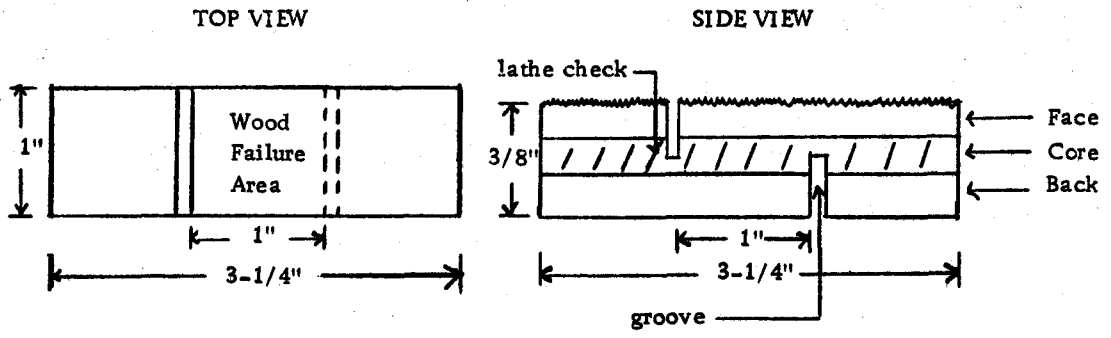


Figure 3. The standard shear specimen.

Table 4. Tests performed on shear specimens.

1. Vacuum Pressure Soak	Specimens were submerged in water at 70° for 30 minutes at vacuum of 25 inches of mercury, then for 30 minutes at 70 psi pressure.
2. Automatic Boil	Specimens were submerged in water for 10 minutes, chilled in ambient air for 3.75 minutes and dried at 225°F for 57 minutes. This cycle was repeated 40 times.

Wood failure values are estimated over a one square inch area as illustrated in Figure 3. The procedure for estimating percent wood failure is described in Appendix A. Wood failure for each specimen was read by two people and their estimations averaged. If their readings differed by more than ten percent a third person read the specimen and his percentage was averaged with the reading closest to it.

Statistical Procedure

Experimental Design

The statistical design for this study is a split plot design with four replications. The factors described in the previous section along with their levels are summarized in Table 5. Listed in Table 6 is a summary of the experimental design with degrees of freedom.

The "split" occurs at the species stage of the design. In other words, species are the "whole units" to which levels of other factors such as treatments, adhesives, etc., are applied. This was shown in the previous procedure section where the twelve 10" x 14" veneers were

Table 5. Factors and their levels.

Factor	Number of Levels	Description
Species	10	Ten species listed in Table 1
Replications	4	Four replications
Assembly Times	2	20 and 45 minutes
Treatments	3	None, extraction, planing
Adhesives	2	A, B
Test Methods	2	Vacuum/pressure and automatic boil

Table 6. Summary of experimental design.

Factor	Degrees of Freedom (d.f.)
Species (SP)	9
Replication (RP)	3
Error 1	27
Test Method (TM)	1
SP x TM	9
Adhesive (AD)	1
SP x AD	9
TM x AD	1
SP x TM x AD	9
Treatment (TR)	2
SP x TR	18
TM x TR	2
SP x TM x TR	18
AD x TR	2
SP x AD x TR	18
TM x AD x TR	2
Assembly Time (TA)	1
SP x TA	9
TM x TA	1
SP x TM x TA	9
AD x TA	1
SP x AD x TA	9
TM x AD x TA	1
TR x TA	2
SP x TR x TA	18
TM x TR x TA	2
AD x TR x TA	2
Error 2	773
TOTAL	959

cut from a large 1/8" x 52" x 100" veneer of a certain species. These twelve 10" x 14" veneers were then assigned randomly a combination of factors. The first error term is used for the tests involving species which are the whole units.

Data Preparation

The dependent variable or yield variable of primary importance is the wood failure value. Each panel produced two sets of six shear specimens and each set of six wood failure values was averaged, thereby eliminating any within panel variation from the analysis. Thus the yield value used throughout this analysis is an average of six wood failure values.

Wood failure values are read as percentages and these values are not distributed normally as illustrated by the histogram in Figure 4 for data from this study. The best transformation found to convert these data to a more normal distribution is the arcsine transformation, using the following formula:

$$X_{\text{transformed-degrees}} = \text{Arcsine } (X_{\text{percent}}/100)^{1/2}$$

Figure 5 illustrates the histogram from the wood failure data from Figure 4 after transformation. In effect this transformation moves the grand mean of the wood failure data from about 84% to approximately 69%. Although the transformation is not ideal it is adequate.

Analysis of Variance

An analysis of variance was performed on the transformed wood failure data, producing mean squares for all combinations of all factors.

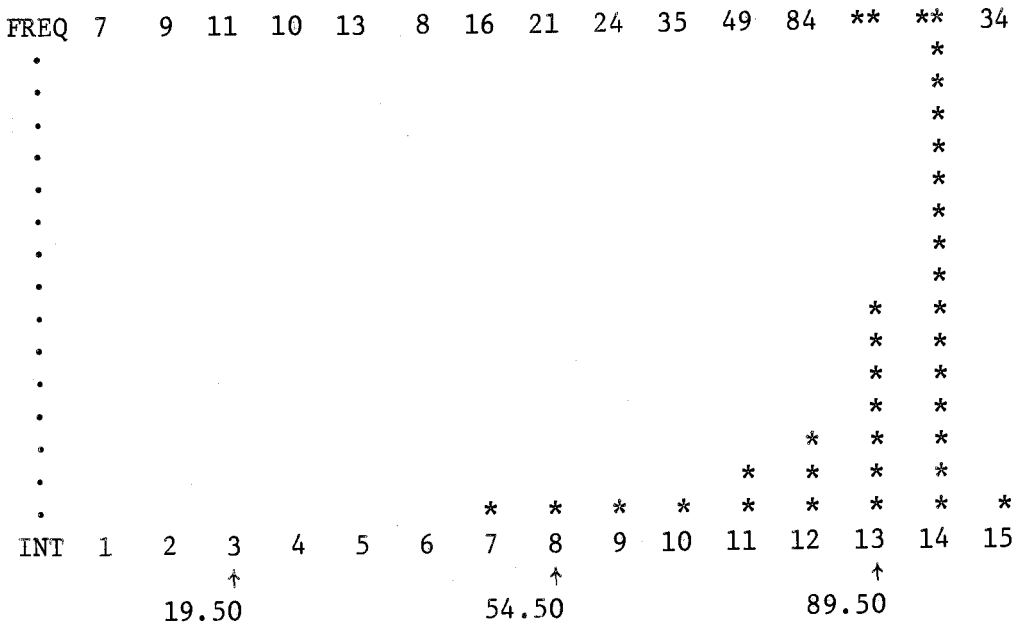


Figure 4. Histogram of variable, yield: not transformed.

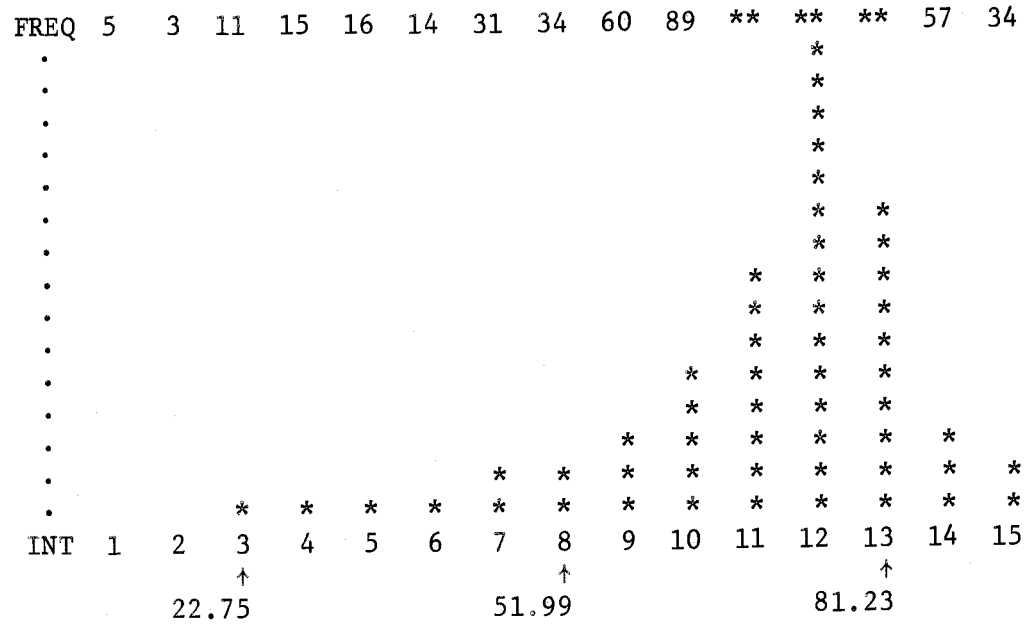


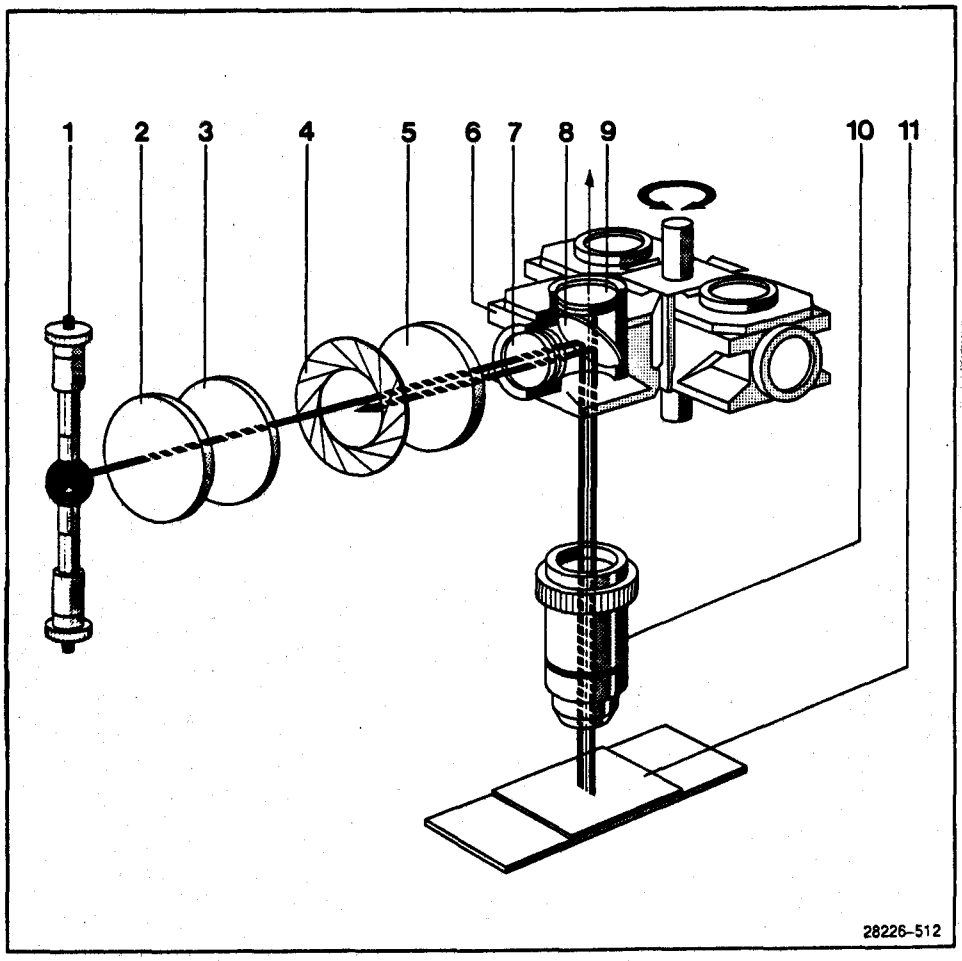
Figure 5. Histogram of variable, yield: transformed.

From this output mean squares were pooled to produce the subplot error term shown as Error 2 in Table 6. After this pooling was completed what remained was simply all the mean squares corresponding to each combination of factors shown in Table 6. With these mean squares, F values were generated and the effect of each factor and combination of factors were tested. For significant factors (95% probability or greater) means were produced and linear comparisons were performed to determine individual effects of the levels of each significant factor and their combinations.

Anatomical Procedure

Microscopy

The fluorescence microscope was the primary tool used in this study. The system consisted of a light source, microscope and photography equipment. A 150 W Xenon high-pressure lamp was used. This lamp produces high energy wavelengths falling in the ultraviolet to visible light range. Once emitted the light travels into the microscope system. Figure 6 outlines the path that the light travels in the microscope. The light first travels through a heat filter and red suppression filter where the potentially dangerous long wavelength heat waves are absorbed. The remaining light which is not absorbed then passes through a field diaphragm and a lens. The light next enters a filter system cube which includes an exciting filter, a dichroic beam-splitting mirror and a suppression filter. As the light hits the exciting filter only certain wavelengths of light of high energy are allowed to pass through. This light is referred to as the exciting light composed of light waves of



1 Light source
2 Heat filter
3 Red-suppression filter
4 Field diaphragm
5 Lens
6 Filter system with exciting filter, dichroic beam-splitting mirror and suppression filter
7 Exciting filter
8 Dichroic beam-splitting mirror
9 Suppression filter
10 Objective
11 Specimen

Figure 6. Incident fluorescence microscope light flow diagram.[4]

[4]Reprinted from Leitz Wetzlar Ploemopak. 2.3 Fluorescence Vertical Illuminator Instruction Manual. 513-142/Engl.

short wavelength and high energy. The dichroic beam splitting mirror then directs this exciting light through the objective onto the specimen. From the specimen fluorescence and some reflected exciting light are emitted. These light waves move straight up through the objective and to the dichroic beam-splitting mirror where only the fluorescence continues to the eyepiece. The remaining exciting light is stopped by the suppression filter.

The fluorescence microscope system used was a Leitz Dialux. A Leitz H-2 wide band blue high intensity filter transmitted wavelengths of 390 to 490 nm or violet-blue excitation. The emitted fluorescence consisted of lower energy, longer wavelength light and the wood fluoresced yellow-green color. The dichroic beam splitting mirror was a RKP 510 for blue excitation and the suppression filter was a LP 515 or long-pass filter. The objectives were Leitz 4 and 12.5 power.

A Wild MPS 20 Semiphotomat camera system was used for photomicrography. This system features the MPS 15 exposure Meter which proved highly sensitive to low light intensities commonly obtained when using fluorescence microscopy. Kodachrome 25 and Ektachrome 200 film were used for color slides. Color prints were made from the color slides.

Two other microscope systems were used in this study. They were an I.S.I. mini-scanning electron microscope model MSM-2 and a Carl Zeiss stereo microscope.

Wood Surface and Glueline Preparation for Microscopy

The ten species used in this study were Douglas-fir, Balau, Meranti, Kapur and six Keruings. A solid wood block approximately 1/4" x 1/4"

in cross section and 1/2" long was cut for six of these species. Included were Douglas-fir, the high and low density Meranti, the highest and lowest density Keruing and Kapur. Cross sectional surfaces were cut with a razor blade and a color photograph of each was taken with fluorescence microscopy. Overall anatomical characteristics, including vessel size and distribution and parenchyma patterns could be illustrated, as well as the fluorescence characteristics of the woods.

For the study of gluelines with fluorescence microscopy the 1" x 12" strip that had been from each plywood panel was used. Because there were four replications, four plywood strips were available for microscopic study for each combination of factors.

The plywood strips were crosscut such that the Southeast Asian hardwood veneer faces were in cross section along the long edge of the piece. Along this edge approximately in the center of the plywood strip a 1" section was chosen. This 1" section was then smoothed using a sharp razor blade. Although various techniques were attempted, the razor blade technique produced the cleanest cut with the least amount of degradation occurring to the gluelines. Once smoothed the plywood strips were placed onto the fluorescence microscope stage. Moulding-clay was placed underneath the plywood strips serving as a leveling device. In most cases proper focusing could be achieved over the entire field of view. Throughout the anatomical studies spot checks were performed where sections of the plywood strip were smoothed away from the center of the strip. This was an assurance that what was seen at the center of the strip could be seen at other locations on the strip.

Using this procedure the plywood gluelines were observed using

incident fluorescence microscopy. While examining the plywood gluelines anatomical observations were recorded. These included the general appearance of the glueline, adhesive penetration into the faces, adhesive distribution and location in the glueline and any possible effects of the surface treatment or the lack of them on the glueline appearance. Whenever possible color photographs were taken illustrating anatomical observations.

For surface examination using stereo and scanning electron microscopy pieces of veneer which has been planed were selected from Kapur, Meranti, Douglas-fir and Keruing no. 26. A second piece of veneer for each of the four species which had been extracted was also collected. The final piece of veneer from each of the four species served as the control and had no treatment applied to it. Small sections 1/4" square were cut from each veneer and mounted on aluminum stubs for the scanning electron microscope. These veneer surfaces were then examined and photographed under the stereo microscope. The small sections of veneer on the stubs were then coated with platinum paladium metal in preparation for the scanning electron microscope. Each section of veneer was examined and photographed. At each stage of examination any veneer surface changes due to the surface treatments were recorded.

RESULTS AND DISCUSSION

Statistical Results and Discussion

This experiment used a split plot design in computing the analysis of variance from wood failure data. The species and replication factors comprise the whole plot and the test method, adhesive, treatment, and assembly time factors comprise the subplot. Table 7 is the analysis of variance table including mean squares, F-ratios and probability values. The two error terms in this analysis of variance table constitute combinations of factors which are given in Table 8. Any combination of factors which included the replication factor was combined into the error term. Thus, error 1, which is the whole plot error, is replication by species. At the onset of the study the effect of replication was assumed to be negligible and as the result indicates in Table 7 the replication factor was non-significant. Throughout this discussion probability values greater than 5% are considered as non-significant and probability values less than 5% as significant. Error 2 also contains any combination containing four or more factors. It is very difficult to interpret or draw meaningful results from such large combinations of factors and so they too are included in error 2.

The effects of species and treatments on wood failure results were found to be highly significant as shown in Table 7. The interaction of species and treatments was also highly significant indicating that neither of these factors should be examined further without the other. A more meaningful examination could therefore be performed on species means as affected by the treatments. Appendix B lists the transformed

Table 7. Analysis of variance for transformed wood failure data using a split plot design.

Source	Degrees of Freedom	Mean Square	F	Probability[1] (%)
Replication (RP)	3	421.522	.4417	>50.0
Species (SP)	9	5,941.290	6.2262	<0.1
Error 1[2]	27	954.247		
Test Method (TM)	1	13.570	.2309	>50.0
SP x TM	9	636.765	10.8351	<0.1
Adhesive (AD)	1	.116	.0020	>50.0
SP x AD	9	206.388	3.5119	<0.1
TM x AD	1	495.296	8.4279	<0.1
SP x TM x AD	9	43.169	.7346	>50.0
Treatment (TR)	2	14,881.600	253.2219	<0.1
SP x TR	18	1,393.720	23.7153	<0.1
TM x TR	2	1,633.170	27.7897	<0.1
SP x TM x TR	18	147.864	2.5160	<0.1
AD x TR	2	460.491	7.8356	<0.1
SP x AD x TR	18	116.966	1.9903	<0.1
TM x AD x TR	2	6.294	.1071	>50.0
Assembly Time (TA)	1	169.455	2.8834	9.0
SP x TA	9	85.942	1.4624	15.0
TM x TA	1	14.624	.2488	>50.0
SP x TM x TA	9	15.328	.2608	>50.0
AD x TA	1	30.391	.5171	48.0
SP x AD x TA	9	174.585	2.9707	<0.1
TM x AD x TA	1	24.575	.4182	>50.0
TR x TA	2	72.077	1.2265	29.0
SP x TR x TA	18	63.045	1.0728	42.0
TM x TR x TA	2	75.042	1.2769	27.0
AD x TR x TA	2	3.793	.0645	>50.0
Error 2[2]	773	58.769		
TOTAL	959			

[1]Probability that the difference occurred by chance rather than by treatment.

[2]Refer to Table 8.

Table 8. Combination of factors included in the two error terms used for the analysis of variance.

Error	Factor	Degrees of Freedom
1	Replication (RP) x Species (SP)	27
2	RP x Test Method (TM)	3
	RP x SP x TM	27
	RP x Adhesive (AD)	3
	RP x SP x AD	27
	RP x TM x AD	3
	RP x SP x TM x AD	27
	RP x Treatment (TR)	6
	RP x SP x TR	54
	RP x TM x TR	6
	RP x SP x TM x TR	54
	RP x AD x TR	6
	RP x SP x AD x TR	54
	RP x TM x AD x TR	6
	SP x TM x AD x TR	18
	RP x SP x TM x AD x TR	54
	RP x Assembly Time (TA)	3
	RP x SP x TA	27
	RP x TM x TA	3
	RP x SP x TM x TA	27
	RP x AD x TA	3
	RP x SP x AD x TA	27
	RP x TM x AD x TA	3
	SP x TM x AD x TA	9
	RP x SP x TM x AD x TA	27
	RP x TR x TA	6
	RP x SP x TR x TA	54
	RP x TM x TR x TA	6
	SP x TM x TR x TA	18
	RP x SP x TM x TR x TA	54
	RP x AD x TR x TA	6
	SP x AD x TR x TA	18
	RP x SP x AD x TR x TA	54
	TM x AD x TR x TA	2
	RP x TM x AD x TR x TA	6
	SP x TM x AD x TR x TA	18
	RP x SP x TM x AD x TR x TA	54
	Error 2 total	773

and untransformed means of wood failure data for species within treatments. As explained in the section on Statistical Procedure, wood failure data must be transformed before proper statistical tests and comparisons can be made. Thus, however, by applying the statistical conclusions on transformed data to the untransformed data, the practical significance of a statistical test can be understood better. For example, the Construction and Industrial Plywood Standard, PSI-74 (2) required 85% wood failure as an acceptable plywood bond durability level. Although there could be a statistically significant difference between 91% and 96% wood failure, both values would be above the acceptable level.

Species means by treatment are graphed in Figure 7 for untransformed data. The line drawn at the 85% level indicates the level of acceptable plywood bond durability. Every species having an average wood failure below 85% when using untreated veneer showed an increase to an acceptable wood failure level above 85% when planed veneer was used. This result is reinforced by using statistical linear contrasts of treatment means for species as shown in Figure 8. Included in Table 9 are the average difference for the contrast, the sum of squares, F-ratios and probability values. Contrasts C_{11} through C_{20} statistically test for each species if the percentage of wood failure is affected by planing the veneer when compared to no surface treatment of the veneer. Balau, Meranti and Keruings nos. 10, 26, 16 and 14 all show statistically significant increases in bond durability from planing the veneer surfaces prior to gluing. Kapur, which had previously been shown by Wellons (39) to be very difficult to glue, was greatly improved from

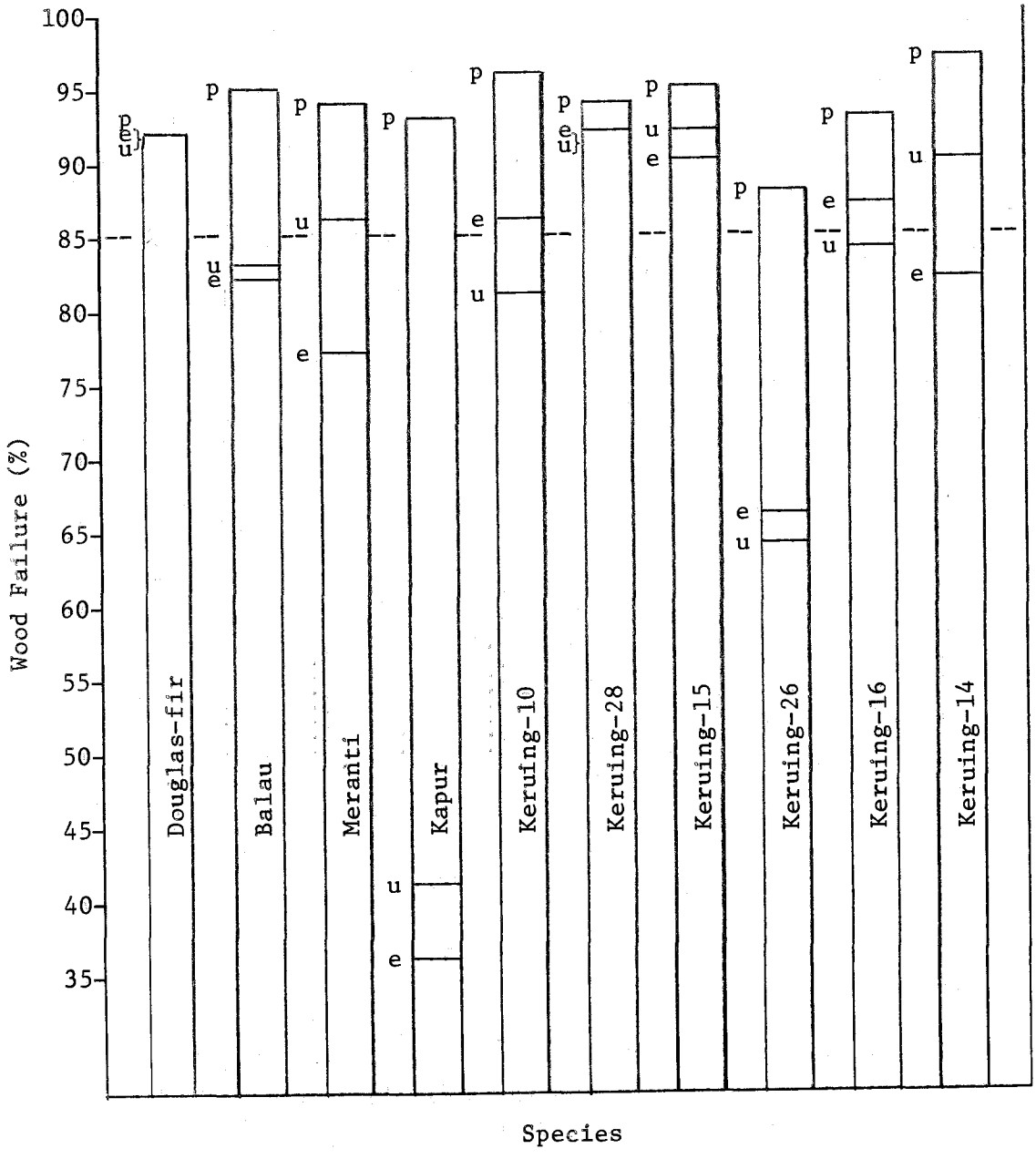


Figure 7. Species by treatment means using untransformed data; p = planed veneer, e = extracted veneer, u = untreated veneer.

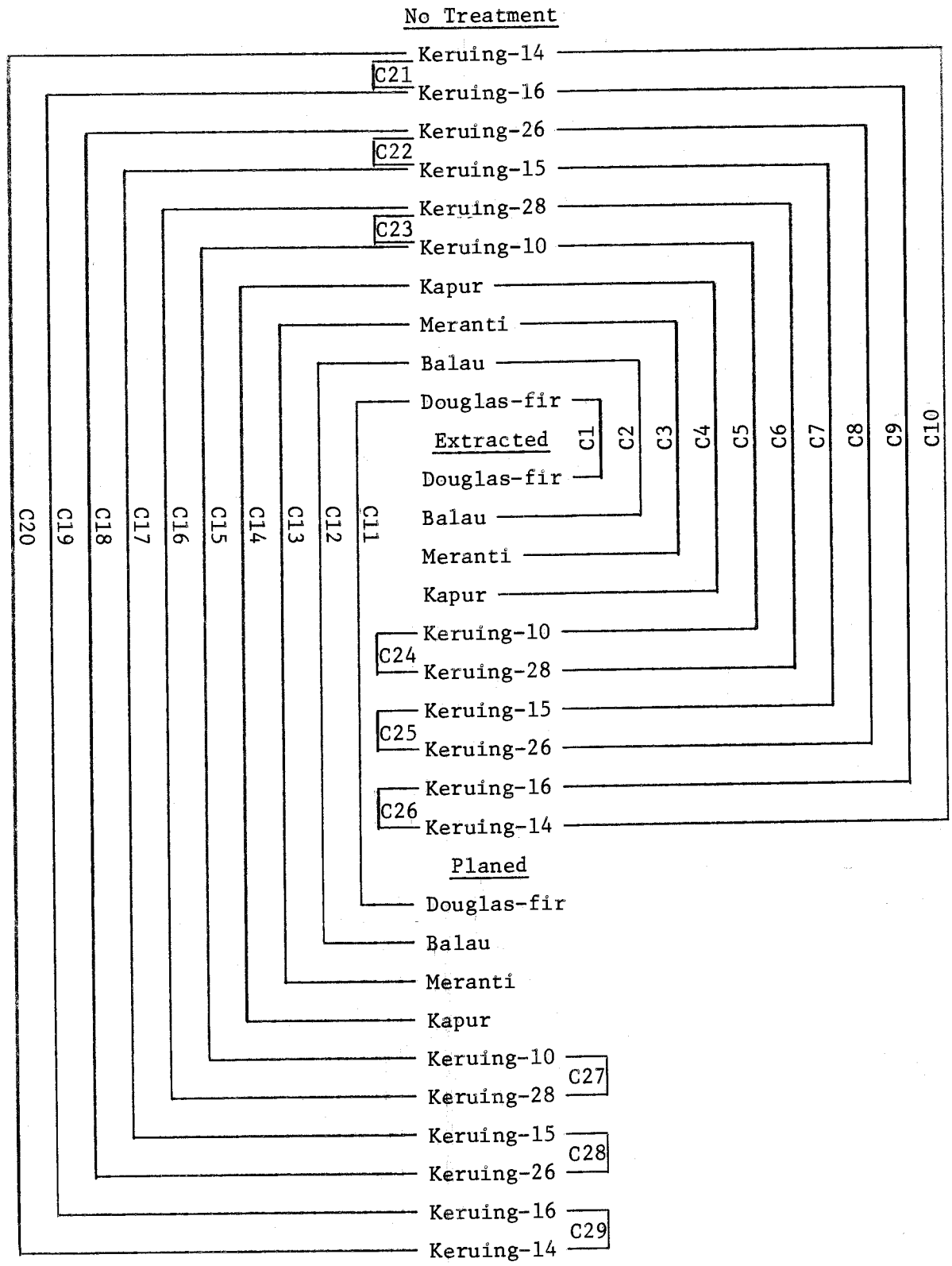


Figure 8. Scheme for linear contrasts (C).

Table 9. Linear contrasts used to determine the effect of planing the veneer surface.

Species[1]	Contrast[2]	Avg. Difference for Contrast	Sum of Squares	F	Probability[3] (%)
Douglas-fir	C11	0.392	2.459	0.042	>50.0
Balau	C12	10.325	1,705.690	29.024	<0.1
Meranti	C13	7.548	911.557	15.511	<0.1
Kapur	C14	37.953	23,046.883	392.161	<0.1
Keruing-10	C15	13.068	2,732.362	46.493	<0.1
Keruing-28	C16	3.725	222.010	3.778	5.0
Keruing-15	C17	3.349	179.453	3.054	7.0
Keruing-26	C18	18.159	5,275.988	89.775	<0.1
Keruing-16	C19	10.247	1,680.016	28.587	<0.1
Keruing-14	C20	8.034	1,032.722	17.573	<0.1

[1]Contrasts the effects of planed veneer to untreated veneer within the same species.

[2]Scheme for contrasts found in Figure 8.

[3]Probability that the difference occurred by chance rather than by treatment.

41% to 94% wood failure because of planing. Douglas-fir and Keruing nos. 15 and 28 did not show as significant an increase. However, with these three species the wood failure values for untreated veneer were already above 90% and were therefore acceptable plywood glue bonds.

Contrasts C_1 through C_{10} in Figure 8 statistically test the effect of extracting the veneer surface prior to gluing for each species when compared to no surface treatment of the veneer. The probability values produced by these contrasts (Table 10) indicate a range of wood failure results. Douglas-fir, Balau and Keruing no. 28, 15, 26 and 16 did not show a significant difference in wood failure as a result of the extraction treatment. Wood failure values of extracted Meranti, Kapur and Keruing no. 14 were found to be significantly lower than their corresponding untreated controls. However, extraction significantly increased wood failure values for Keruing no. 10 over the untreated Keruing no. 10. These results clearly indicate that the extraction treatment was not as strongly one-sided as the planing treatment. As seen in Figure 7, the extraction treatment only brought two species up to an acceptable wood failure level above 85% but the treatment also causes a couple of species to decrease to an unacceptable level for plywood glue bonds.

Of particular interest in this study was the investigation of the variable bond durabilities associated with the Keruings. Contrasts C_{21} through C_{23} listed in Table 11 and shown in Figure 8 compare untreated Keruings with each other. The results indicate that each of these contrasts were highly significant. Each set of Keruings differ from each other and have variable bond durabilities ranging from 64% to 92%. These results confirm those of Wellons (39) who reported the same

Table 10. Linear contrasts used to determine the effect of extracting the veneer surface.

Species[1]	Contrast[2]	Avg. Difference for Contrast	Sum of Squares	F	Probability[3] (%)
Douglas-fir	C1	1.092	19.079	0.325	>50.0
Balau	C2	0.883	12.475	0.212	>50.0
Meranti	C3	7.532	907.696	15.445	<0.1
Kapur	C4	3.707	219.870	3.741	4.0
Keruing-10	C5	3.915	245.236	4.173	3.0
Keruing-28	C6	1.439	33.132	0.564	46.0
Keruing-15	C7	1.841	54.228	0.923	29.0
Keruing-26	C8	1.376	30.294	0.515	47.0
Keruing-16	C9	1.671	44.676	0.760	39.0
Keruing-14	C10	4.724	357.059	6.076	1.0

[1]Contrasts the effect of extracted veneer to untreated veneer within the same species.

[2]Scheme for contrast found in Figure 8.

[3]Probability that the difference occurred by chance rather than by treatment.

Table 11. Linear contrasts used to determine the variability of the Keruings.

Treatment	Species[1]	Contrast[2]	Average Difference for Contrast	Sum of Squares	F	Probability[3] (%)
Untreated	K-10 to K-28	C23	7.621	929.274	15.812	<0.1
	K-15 to K-26	C22	20.697	6,853.853	116.624	<0.1
	K-16 to K-14	C21	5.165	426.836	7.263	<0.1
Extracted	K-10 to K-28	C24	5.145	423.536	7.207	1.0
	K-15 to K-26	C25	17.480	4,888.806	83.187	<0.1
	K-16 to K-14	C26	1.230	24.206	0.412	>50.0
Planed	K-10 to K-28	C27	1.722	47.445	0.807	37.0
	K-15 to K-26	C28	5.887	554.508	9.435	<0.1
	K-16 to K-14	C29	2.952	139.429	2.372	18.0

[1]Contrast between the Keruings (K) noted within a treatment.

[2]Scheme for contrast found in Figure 8.

[3]Probability that the difference occurred by chance rather than by treatment.

Keruings to have this variable bond durability at acceptable as well as unacceptable wood failure levels. Similar contrasts were performed within the extracted Keruings group between the same species. Table 11 lists the results of contrasts C_{24} through C_{26}. Once again the Keruings exhibited variable bond durabilities at acceptable and unacceptable levels. When the identical contrasts were performed for the planed Keruings this variability in bond durability all but disappears. The results of contrasts C_{27} through C_{29} are shown in Table 11 and only contrast C_{28} shows significance. The mean values of contrast C_{28} are wood failures of 88% and 95%. Both of these values are well above the acceptable plywood bond durability level. The untreated and extracted Keruings display the variable bond durabilities reported earlier. The planing treatment alone brings all of them to an acceptable level and eliminates much of their variability.

The species means were calculated from the combined results of the two adhesives. The interaction of species, treatments and adhesives was found significant, as seen in Table 7, although the adhesive factor alone was not significant. However, because of a gluing error with adhesive B, the effect of treatments within species for each adhesive was examined further.

As described in the section of Gluing and Testing Procedures all plywood panels glued with Adhesive B were inadvertently left on the platen up to an extra minute before hot pressing. The precure time for these panels was therefore increased and the high bond durabilities that had previously been reported by Wellons (39) using the same adhesive B were not found. Table 12 is a table of species means for each treatment

Table 12. Table of means for species by treatment by adhesive interaction using transformed wood failure data.

Treatment	Species	Mean of Yield Adhesive A	Mean of Yield Adhesive B
None	Douglas-fir	75.918	74.734
	Balau	73.932	61.828
	Meranti	67.640	74.011
	Kapur	40.292	33.334
	Keruing-10	63.297	68.224
	Keruing-28	73.293	73.472
	Keruing-15	74.249	75.854
	Keruing-26	51.001	57.709
	Keruing-16	62.553	73.251
	Keruing-14	73.361	72.773
Extracted	Douglas-fir	73.080	75.388
	Balau	70.120	63.875
	Meranti	61.717	62.869
	Kapur	34.847	36.366
	Keruing-10	68.420	70.725
	Keruing-28	74.128	75.514
	Keruing-15	71.860	74.563
	Keruing-26	54.369	57.092
	Keruing-16	66.408	72.945
	Keruing-14	68.243	68.443
Planed	Douglas-fir	75.404	74.464
	Balau	78.742	77.668
	Meranti	77.660	77.085
	Kapur	79.699	74.833
	Keruing-10	78.661	78.998
	Keruing-28	78.429	75.784
	Keruing-15	80.035	76.767
	Keruing-26	76.936	68.092
	Keruing-16	79.756	76.541
	Keruing-14	82.507	79.696

and adhesive, using transformed wood failure data. Identical linear contrasts (C) were performed on the means in Table 12 for each of the two adhesive groups independently and on the species means of the two adhesives combined (Appendix B). The scheme for these linear contrasts is illustrated in Figure 8. Table 13 lists the average differences for each contrast, the t-ratios and the significance of the contrast. These contrasts were chosen to be representative of those to be asked in this study. Upon examination of the Significance columns in Table 13, it is apparent that in nearly all cases the same significance for each contrast was attained whether using data for adhesive A or data for adhesives A and B combined. Although in a few more cases the significances of the contrasts when using adhesive B differed from the two adhesives, A and B, combined, these differences did not appear to adversely affect the further usage of the means of the combined adhesive data. Therefore the analysis performed at the beginning of this section used the means of the species within treatments (Appendix B).

The assembly time and test method factors were non-significant as shown in Table 7. Because of this non-significance and because of the error with adhesive B, further analysis of these two factors and their interactions was not performed.

Anatomical Results and Discussion

Anatomical Description of Species

The species used in this study were Douglas-fir, a low density Meranti, a high density Balau, Kapur and six Keruings of different densities. Table 1 lists these species by scientific name and lists

Table 13. Linear contrasts of species by treatment means for each adhesive A and B and for their combination A+B using transformed wood failure data.

	Average Difference for Contrast			t-Ratio			Significance[1]		
Contrast	A	B	A+B	A	B	A+B	A	B	A+B
C1[2]	2.838	0.654	1.092	1.047	0.241	0.570	NS	NS	NS
C2	3.812	2.047	0.833	1.406	0.755	0.461	NS	NS	NS
C3	5.923	0.142	7.532	2.185	3.373	3.930	NS	S	S
C4	5.445	3.032	3.707	2.009	1.119	1.934	NS	NS	NS
C5	5.120	2.501	3.915	1.889	0.923	2.042	NS	NS	NS
C6	0.835	2.042	1.439	0.308	0.753	0.751	NS	NS	NS
C7	2.389	1.291	1.841	0.881	0.476	0.961	NS	NS	NS
C8	3.368	0.617	1.376	1.243	0.228	0.718	NS	NS	NS
C9	3.855	0.306	1.671	1.422	0.113	0.872	NS	NS	NS
C10	5.118	4.330	4.724	1.888	1.598	2.465	NS	NS	S
C11	0.514	0.270	0.392	0.190	0.100	0.205	NS	NS	NS
C12	4.810	15.840	10.325	1.775	5.844	5.387	NS	S	S
C13	10.020	5.074	7.548	3.697	1.872	3.938	S	NS	S
C14	39.407	41.499	37.953	14.539	15.311	19.803	S	S	S
C15	15.364	10.774	13.068	5.669	3.475	6.819	S	S	S
C16	5.136	2.312	3.725	1.895	0.853	1.944	NS	NS	NS
C17	5.786	0.913	3.349	2.135	0.337	1.747	NS	NS	NS
C18	25.935	10.383	18.159	9.569	3.831	9.475	S	S	S
C19	3.855	3.290	10.247	1.422	1.214	5.347	NS	NS	S
C20	14.264	6.923	8.034	5.263	2.554	4.192	S	S	S
C21	10.808	0.478	5.165	3.988	0.176	2.695	S	NS	S
C22	23.248	18.145	20.697	8.577	6.695	10.799	S	S	S
C23	9.996	5.248	7.621	3.688	1.936	3.977	S	NS	S
C24	5.708	4.789	5.145	2.106	1.767	2.685	NS	NS	S
C25	17.491	17.471	17.480	6.453	6.446	9.121	S	S	S
C26	1.835	4.502	1.230	0.677	1.661	0.642	NS	NS	NS
C27	0.232	3.214	1.722	0.086	1.186	0.899	NS	NS	NS
C28	3.099	8.675	5.887	1.143	3.201	3.072	NS	S	S
C29	2.751	3.155	2.952	1.015	1.164	1.540	NS	NS	NS

[1]Significance measured at $\alpha = .01$ level; NS = not significant at $\alpha = .01$ level, S = significant at $\alpha = .01$ level.

[2]Scheme of contrasts described in Figure 8.

their specific gravity. Each genus is illustrated in Figure 9A through 9F with a fluorescence photograph of the cross section of the wood. The species photographed include Douglas-fir, the low density Meranti, the high density Balau, Kapur and a high and low density Keruing, nos. 10 and 26. By examining these cross sections one can imagine that the veneer produced from each species will yield a different anatomical configuration at the veneer surface which will face the glueline in a plywood panel. The number and size of the vessels, the amount and distribution of parenchyma, and the amount of fiber tracheid areas facing the glueline will vary from species to species.

For example, we see that all the hardwoods are diffuse porous. Meranti, Balau and Kapur have resin canals in tangential rows while the Keruings have scattered resin canals. The low density Red Meranti has large vessels but of more importance has large fiber lumens. Large fiber lumens means less cell wall material which primarily accounts for the low density of this species. Parenchyma are particularly evident on the cross section of Keruing no. 10.

The increased depth of field and color contrast when using fluorescence microscopy allows the minute anatomy of each species to be more easily visable. The middle lamella regions fluoresce a white color and the wood cell walls a yellow-green color causing the general fiber arrangement to be easily observed. The material in the resin canals of the Meranti and Balau also fluoresces a bright white color. Because the wood cell walls fluoresce quite brightly while the adhesive does not, once adhesive is applied to the veneer, the contrast between the wood and the adhesive allows observation of the adhesive in the void spaces

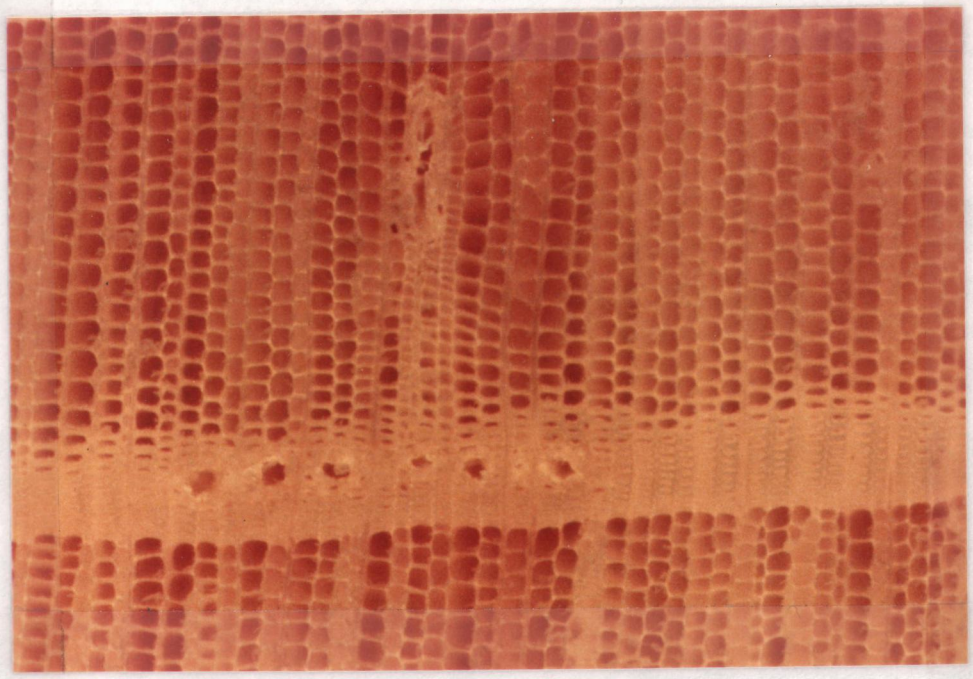


Figure 9A. Cross section of Douglas-fir [Pseudotsuga menziesii (Mirb.) Franco); fluorescence microscope. 60X

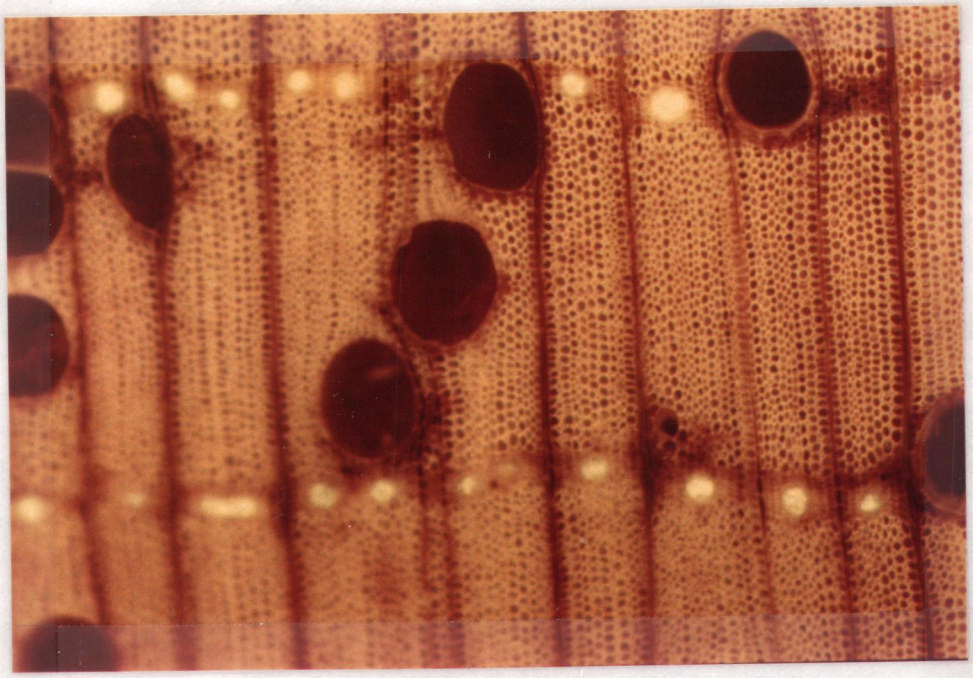


Figure 9B. Cross section of Red Meranti (Shorea curtisii); fluorescence microscope. 60X

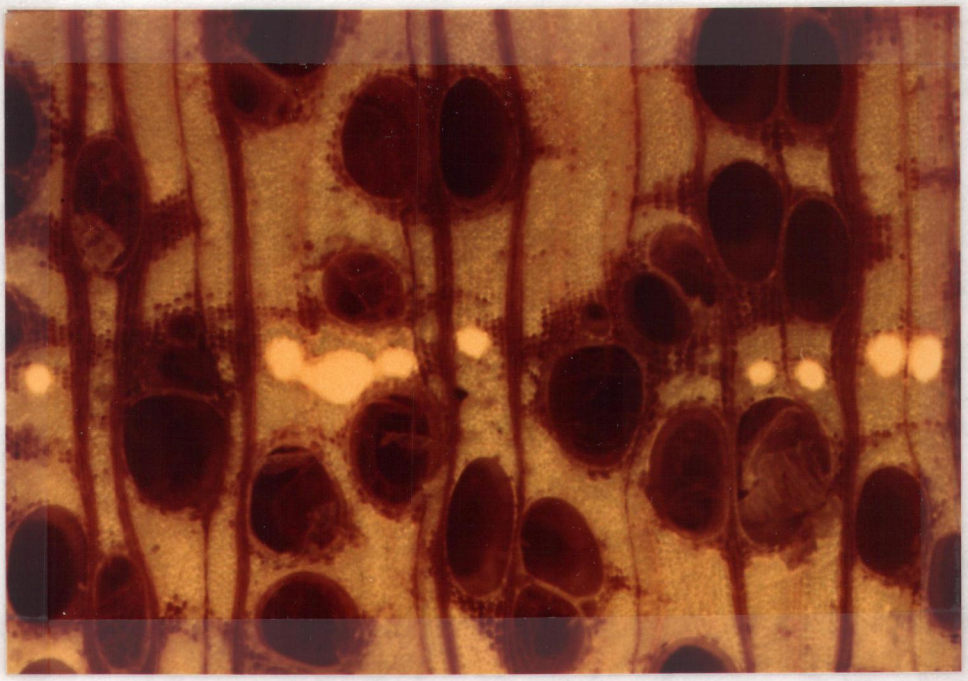


Figure 9C. Cross section of Balau (Shorea ochrophloia); fluorescence microscope. 60X

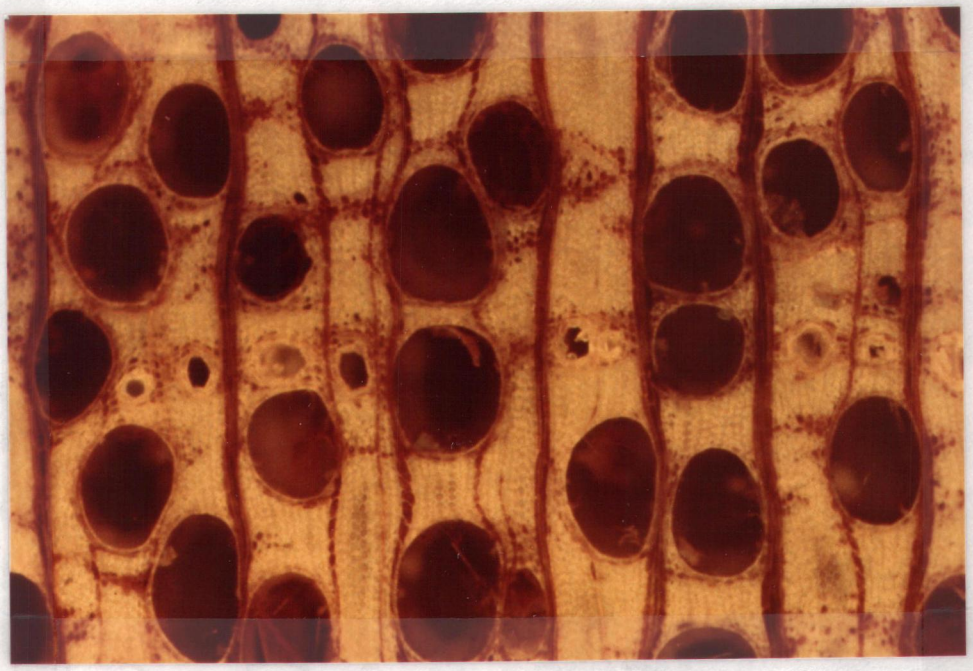


Figure 9D. Cross section of Kapur (Dryobalanops aromatica); fluorescence microscope. 60X

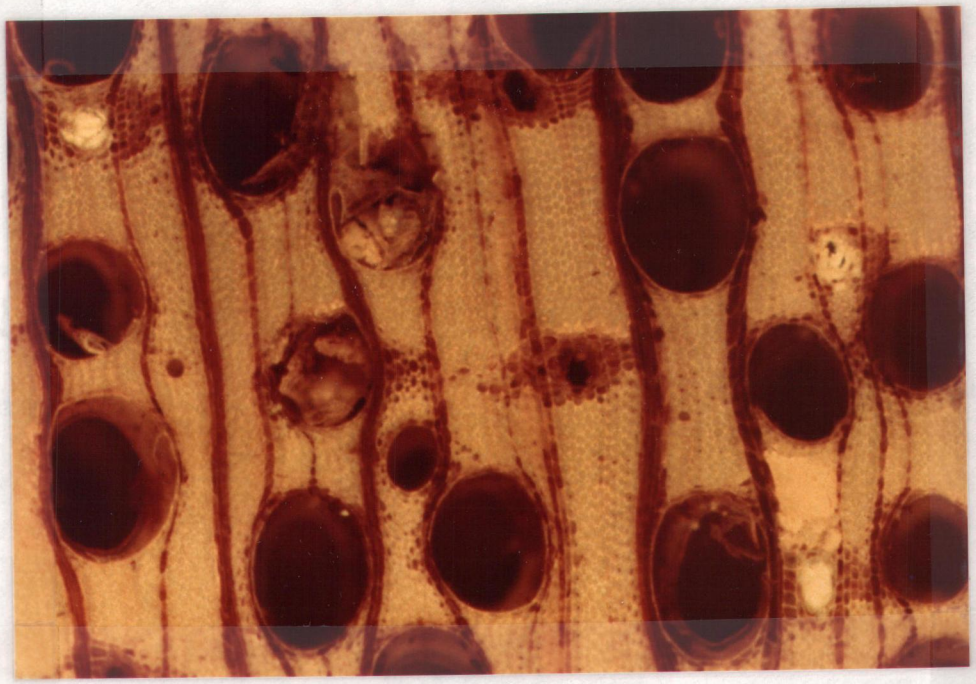


Figure 9E. Cross section of Keruing-10 (Dipterocarpus spp.); fluorescence microscope. 60X

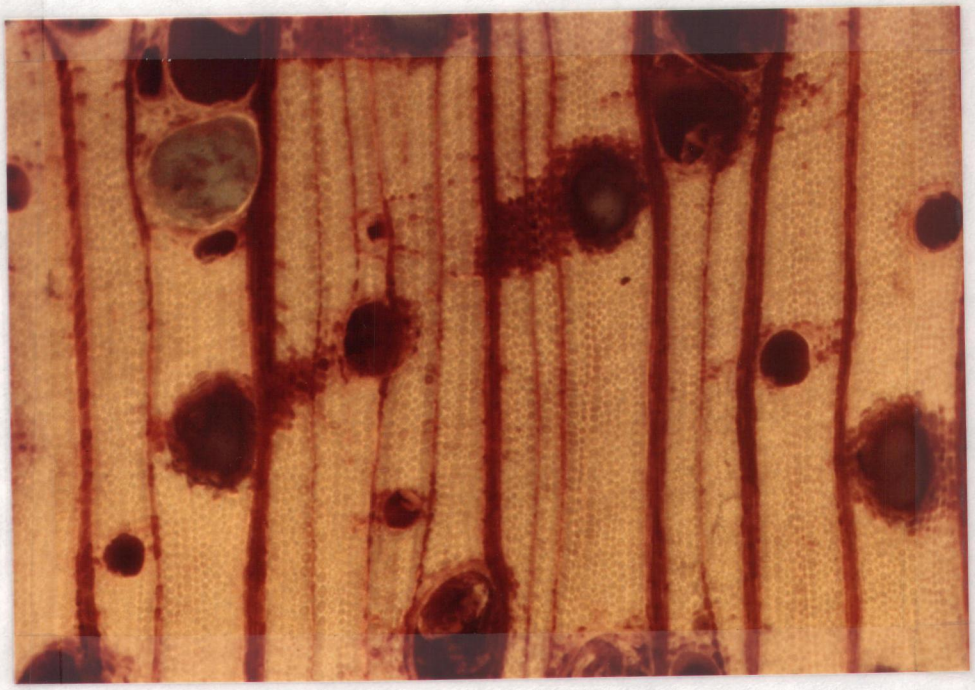


Figure 9F. Cross section of Keruing-26 (Dipterocarpus costulatus); fluorescence microscope. 60X

of the cells, although decisions concerning penetration of adhesive into the cell wall are not as easily made even with this technique.

Description of Plywood Gluelines as Observed Under Flourescence Microscopy

Figure 10A and 10B are incident fluorescent photographs of three-ply plywood gluelines. In both pictures the face veneer is Douglas-fir which is found in cross section and the core veneer which is also Douglas-fir is found in radial longitudinal section at the bottom of the photographs. In both photographs focusing occurred on the face veneer. This was done so that wood and adhesive characteristics found in the face veneer could be examined better. In most cases because of the unevenness of the razor blade sections this caused the core area of the glueline to be out of focus. The photograph in Figure 10A includes a lathe check. Adhesive penetration into the lathe check is clearly visible as a reddish to black material. Throughout all of the gluelines there is present a white to gray material mixed in with the adhesive. After examining the adhesive separately under fluorescence this material was found to be the fillers and extenders mixed with the resin at the time of adhesive formulation. In Figure 10 adhesive has also penetrated the tracheid lumens along the glueline. In Figure 10A the wood rays have also been penetrated by adhesive in varying degrees depending on how far from the center of the glueline they are. In these photographs penetration into the core veneer is difficult to observe. Found in Figure 10B is a white shiny zone ahead of where the adhesive has penetrated. It is seen all along the glueline. This observation coincides

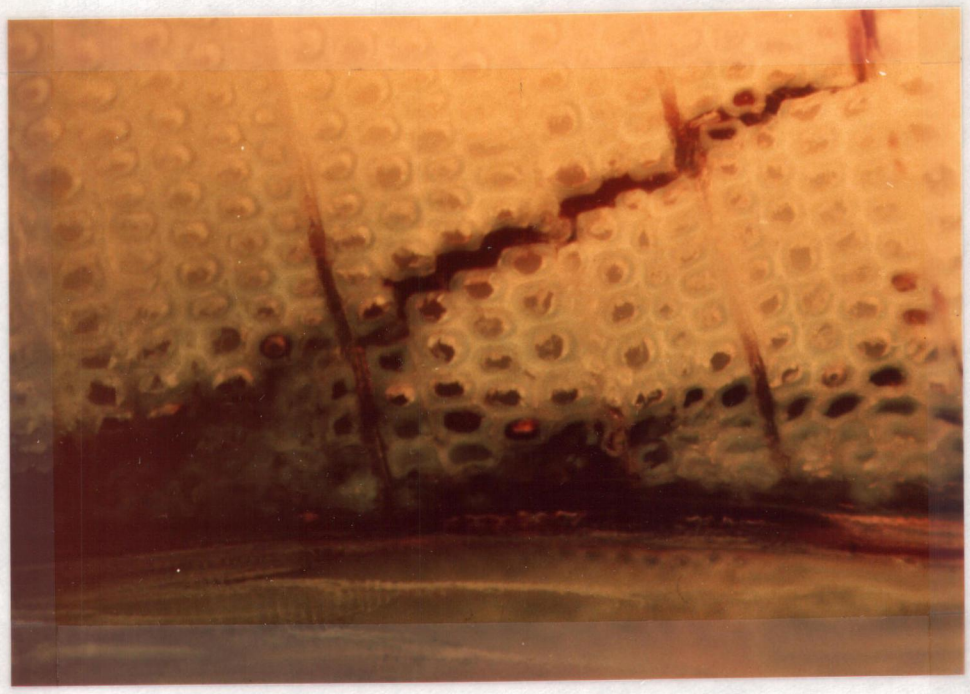


Figure 10A. 182X

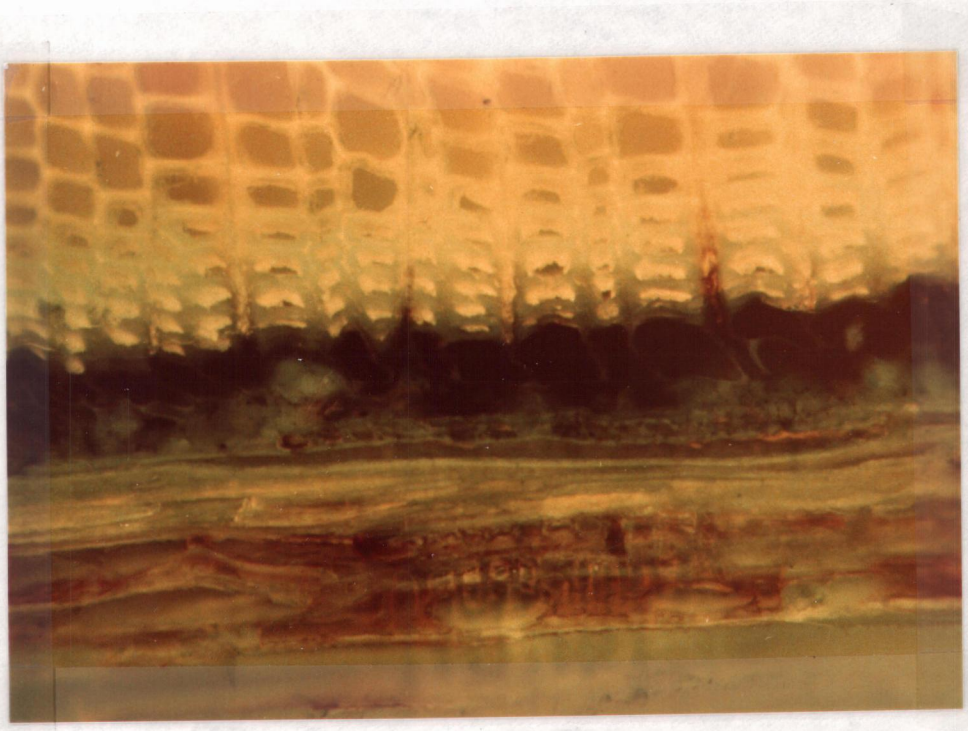


Figure 10B. 182X

Figure 10. Incident fluorescent photographs of gluelines of 3-ply Douglas-fir plywood.

with that reported by Nearn (24) and Schneider and Côté (31) who found this zone to be the caustic front from the adhesive penetrating ahead of the actual adhesive. This caustic front penetrates the cell walls and appears white under the fluorescence microscope. Throughout this study this shiny zone was observed to have no regularity from glueline to glueline.

Illustrated in Figure 11A is a plywood glueline from a three-ply panel composed of a Douglas-fir core veneer and a Southeast Asian hardwood face and back veneer. Immediately the differences between this glueline composed of a hardwood face veneer and the gluelines in Figure 10 composed of Douglas-fir are recognized. In Figure 11A the adhesive appears as a black color in contrast to the wood. Adhesive has penetrated the fiber lumens and the vessel at the right of the photograph. Adhesive can also be observed in the pits found between adjacent fibers. Wood ray penetration into the hardwood face is a bit more difficult to evaluate. Primarily heartwood was selected and thus the ray parenchyma cells of the Southeast Asian hardwoods all contain extractives which show up as reddish to brown color using fluorescence microscopy. Thus, distinguishing between adhesive and the material in the rays is not always a simple task. Adhesive penetration into the core veneer can also be observed in Figure 11A. Adhesive is observed three to four tracheid lumens deep in the core as a red to brown color. As mentioned earlier, focusing occurs on the face veneer and thus this core penetration is not easily observed in many of the photographs.

Figure 11B is a photograph of a hardwood plywood glueline with the hardwood face in radial view and the Douglas-fir core veneer in cross

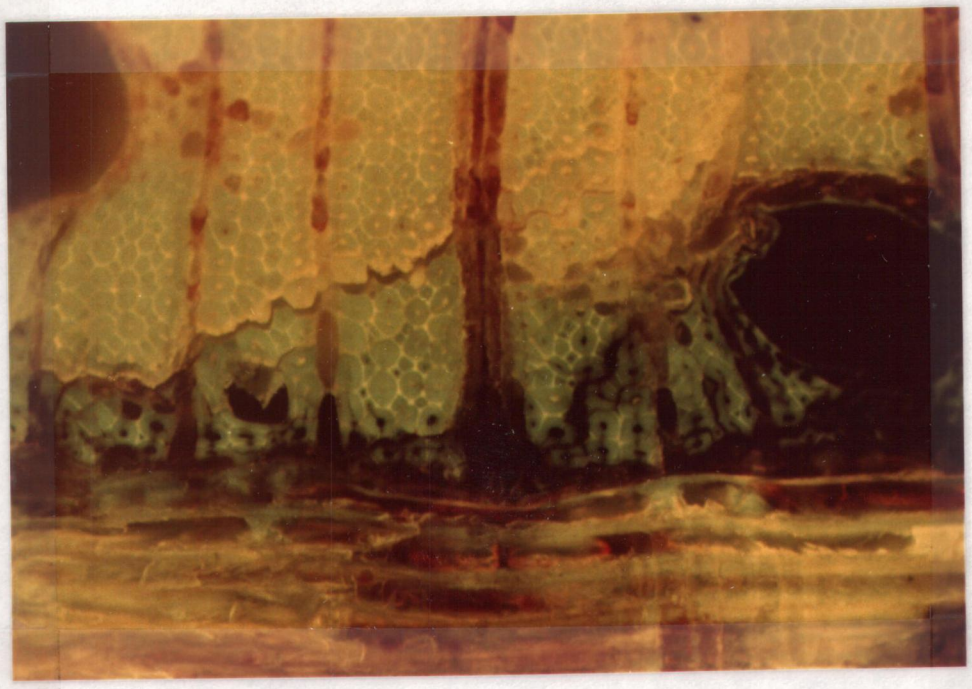


Figure 11A. Fluorescence picture of a Kapur plywood glueline. 182X

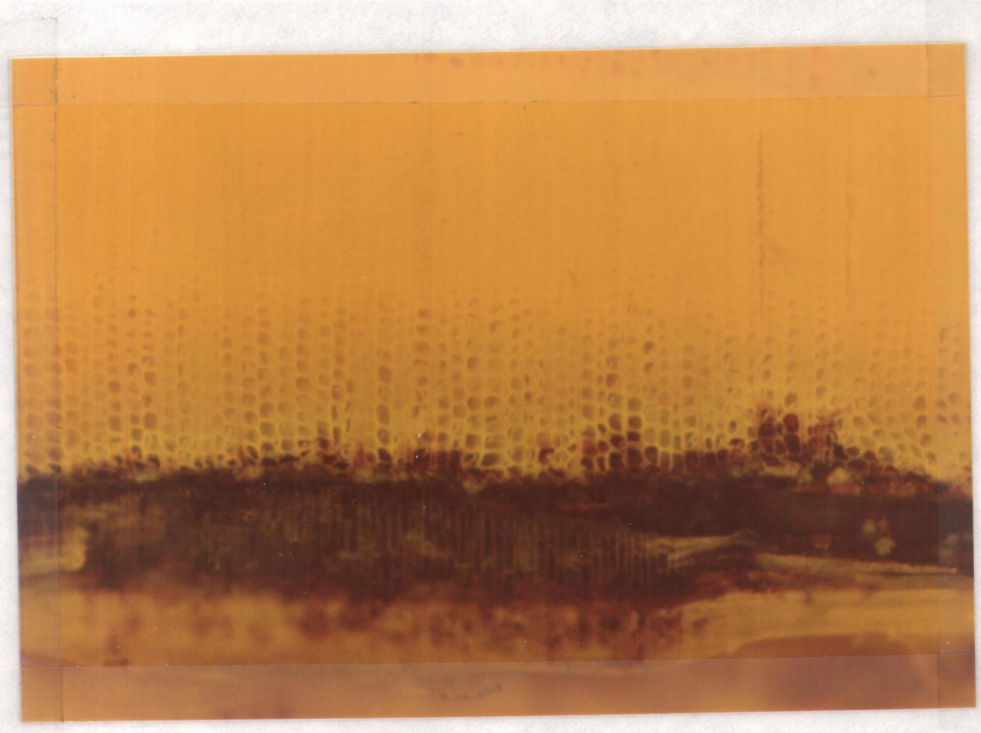


Figure 11B. Fluorescence picture of a Kapur plywood glueline showing adhesive penetration into Douglas-fir veneer. 182X

section. Tracheid lumen penetration of the adhesive into the core as well as the shiny zone can be observed in this view similar to the all Douglas-fir gluelines. However, because treatments were applied only to the face veneers and not to the Douglas-fir core, core penetration, etc., would be fairly constant and the effects of treatment would be noticed on the face side of the glueline. These treatment effects are easier to observe on the face veneer by looking at the cross section of the face.

Effect of Extraction on the Plywood Glueline

Extracting the veneer surface prior to gluing did not uniformly increase bond durability of plywood made of Southeast Asian hardwood veneers. As discussed in the literature section the extraction process can result in negative effects prohibiting good bonds from forming. These effects include the migration of extractives to the surface following extraction, overpenetration of adhesive into the extracted veneer and the possibility of caustic remaining on the surface following the extraction sequence. Anatomically no strong differences were noted between gluelines made of extracted veneer and those made of untreated veneer. Figure 12A and 12B shows gluelines which are composed of extracted hardwood face veneers. In both photographs large amounts of adhesive have gone into the vessel lumens and some of the adhesive appears to have pulled away from the core veneer surface. Examination of gluelines made of extracted as well as unextracted hardwood face veneers has shown there to be fiber lumen penetration but in localized areas along the glueline. This penetration could not be considered

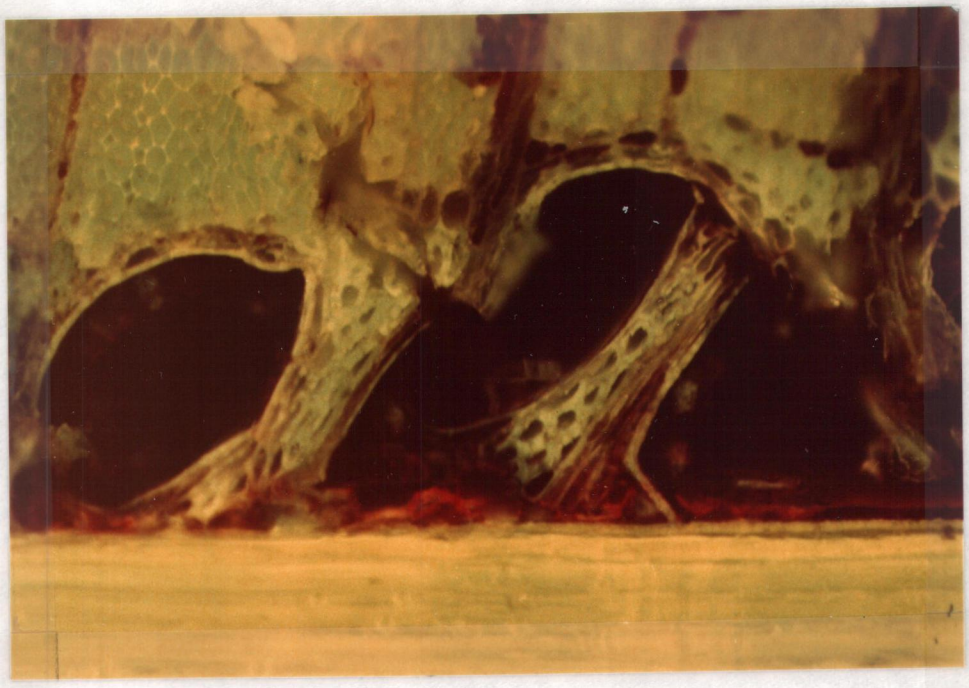


Figure 12A. 182X

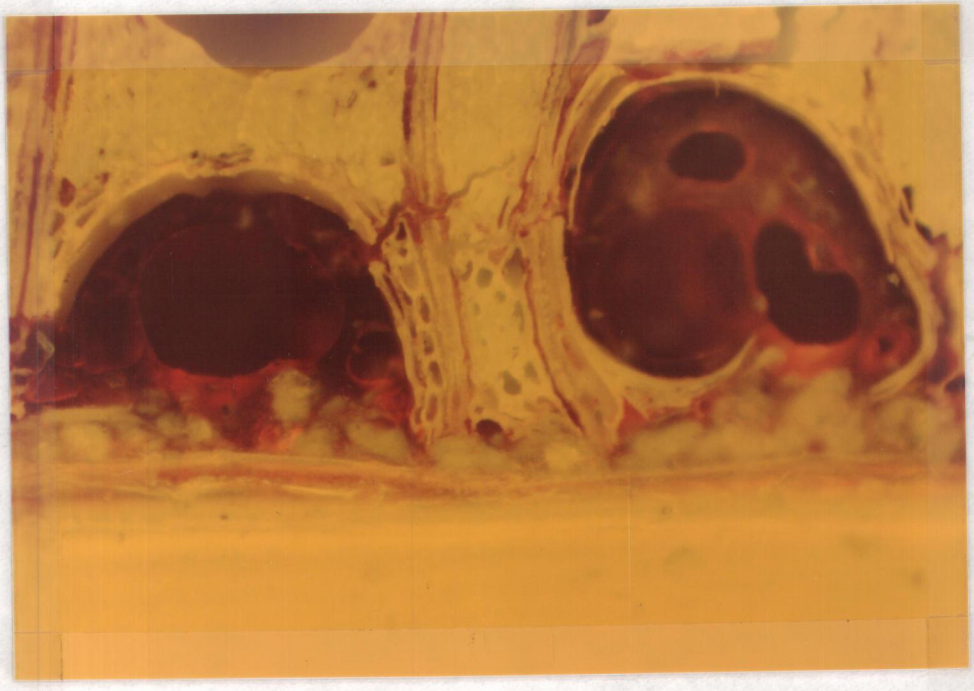


Figure 12B. 182X

Figure 12. Fluorescence pictures of plywood gluelines made of extracted Kapur veneer.

overpenetration when compared to the gluelines made of untreated veneer.

Figure 13 is a glueline composed of an untreated hardwood face veneer showing the adhesive as a reddish color nearly completely filling the vessel lumen. The vessel lumen appears free of any occlusions leaving ample room for the adhesive. This effect was regularly observed throughout the gluelines which were composed of extracted and untreated veneer. It appears in these gluelines that much of the adhesive is distributed in the vessel lumens.

The extraction sequence performed in this study on the veneers did not strongly affect bond durability. This result is somewhat in contradiction with those reported by Sleet (32) and described in the literature review section. In order to investigate this phenomena four matching sheets of Kapur, Keruing, Meranti and Douglas-fir veneer were selected. One sheet of each species was extracted as done to the veneers in this study with a 60 second dip in a one percent NaOH solution and a 60 second rinse in water. A second set of veneers was extracted as done by Sleet (32) with a ten second dip in a one percent NaOH solution and a 60 second rinse in water. A third set of veneers was dipped in caustic for 60 second and rinsed for ten seconds. The fourth and final set of veneers served as a control and were not extracted. All the sheets were then brought to approximately six percent moisture content as had previously been done in the main study.

Figure 14 shows four Kapur veneers each labeled as to its time of extraction first and water rinse second. Immediately the color differences resulting from the extraction sequences are noted. The 60 second caustic dip followed by a 10 second wash produced the darkest colored

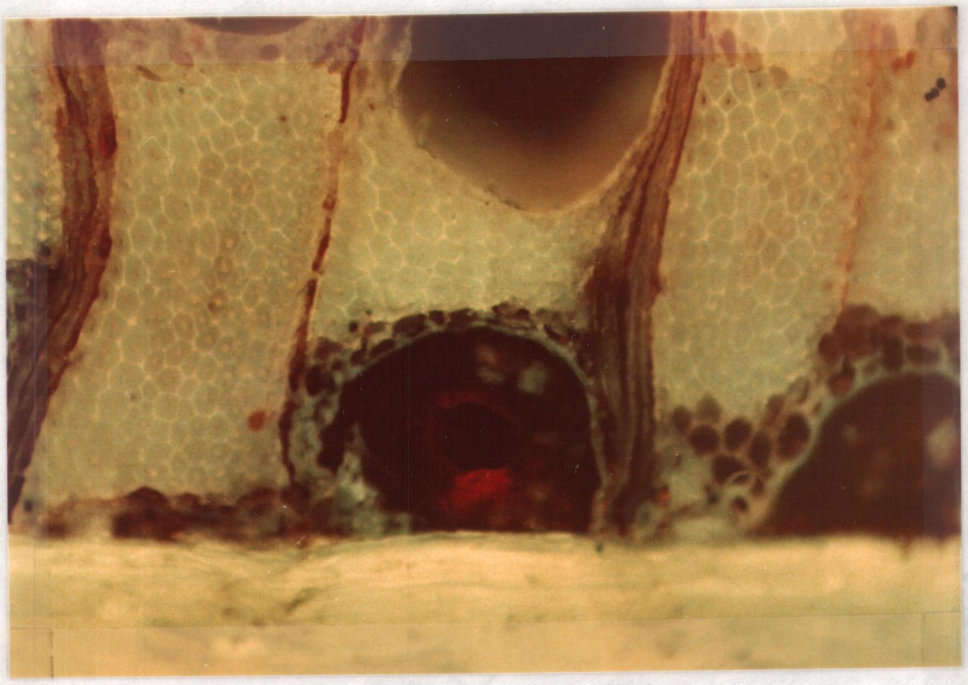


Figure 13. Fluorescence picture of plywood glueline made of untreated Kapur veneer. 182X

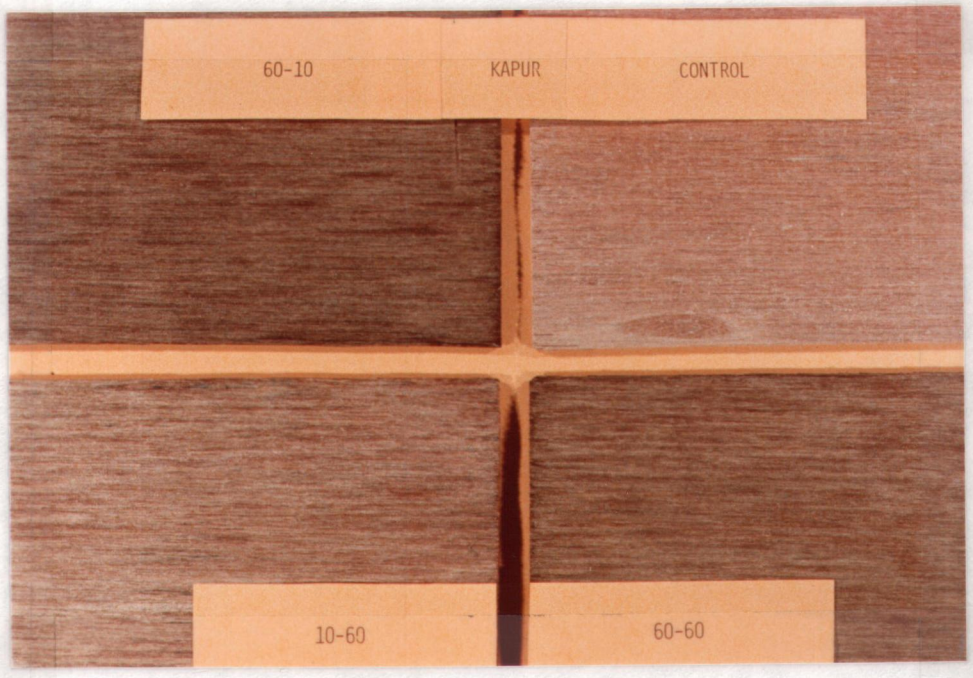


Figure 14. Three extraction sequences on Kapur veneer.

veneer surface of the four sheets. Of more importance, however, is the color difference between the veneer extracted according to the Sleet (32) method and that extracted as done in this study. In this study it appears that the longer extraction time of 60 seconds as compared to 10 seconds used by Sleet (32) may have caused more extractives to remain on the surface and thus inhibit gluability. The 10 second extraction by Sleet (32) served as a quick remover of surface extractives without drawing out extractives located deeper in the wood structure. Thus, when both sets of veneer were equilibrated to six percent moisture content the veneer extracted for 60 seconds was recontaminated with extractives which could have interfered with bonding.

In summary there appear to be time factors involved in the extraction sequence which are critical in determining how the veneer will bond. The fluorescence microscopy performed in this study was able to identify adhesive distribution and adhesive penetration in the glueline composed of extracted veneer but no differences were noted when compared to gluelines of untreated veneer. The presence of extractives in the glueline area could not be observed microscopically.

One observation noted throughout the gluelines made of extracted and untreated veneer was the unevenness or nonuniformity of the glueline. These gluelines commonly exhibited void areas and areas where vessel lumens were filled with adhesive but the adhesive did not appear to be adhering to the cell wall adequately. In order to investigate this phenomena further two 1/4" thick by 1/2" wide by 3/4" long pieces of plywood were cut from the anatomy strip of a panel made with untreated hardwood face veneers. For each piece a cut was made into the

face veneer in a similar fashion as done when producing the plywood shear specimens. The pieces were then placed in water and subjected to a vacuum in order to replace most of the air in the wood with water. The pieces were then placed in a sliding microtome where the ends of the pieces were smoothed with a sharp microtome knife. This procedure produced a specimen which resembled somewhat a miniature shear specimen but with the gluelines smoothed for easy anatomical observation. Figure 15A is an unsheared plywood glueline made with untreated veneer as seen under a fluorescence microscope. In Figure 15B this same glueline has been sheared. Note that in Figure 15B the glueline has failed inside the cell wall of two vessels filled with adhesive. This zone in the glueline appears to be a weak zone and a failure in this region is not surprising. For gluelines made of extracted veneer extractives may coat the vessel walls and inhibit gluing. Figure 16A and 16B is another plywood glueline made of untreated veneers in the unsheared and sheared positions. It appears here that proper adhesion has not occurred at all between the wood and the adhesive. Some adhesive remains in the vessels and some remains attached to the core veneer. This results in little or no wood failure. Although Figures 15 and 16 are gluelines made of untreated veneer, the same results were found for extracted veneers of poor bond quality. The effect of the extraction sequence, the amounts and kinds of the extractives present and their chemical interactions all undoubtedly contribute to bond quality.

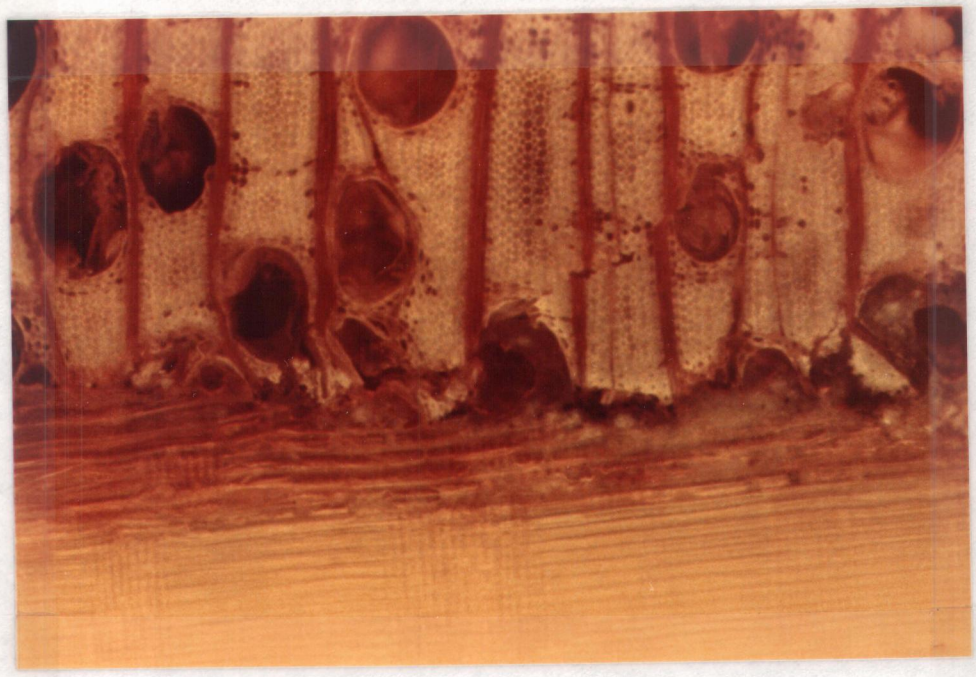


Figure 15A. Unsheared plywood glueline made of untreated Kapur veneers. 60X

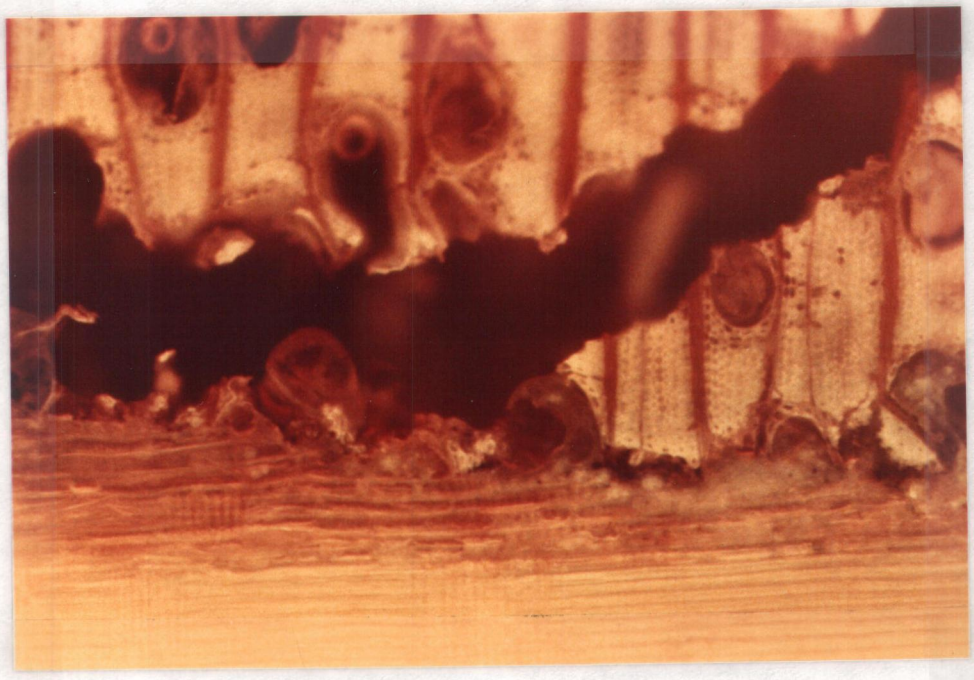


Figure 15B. Sheared plywood glueline made of untreated Kapur veneers. 60X

Figure 16A. Unsheared plywood glueline made of untreated Kapur veneer. 60X

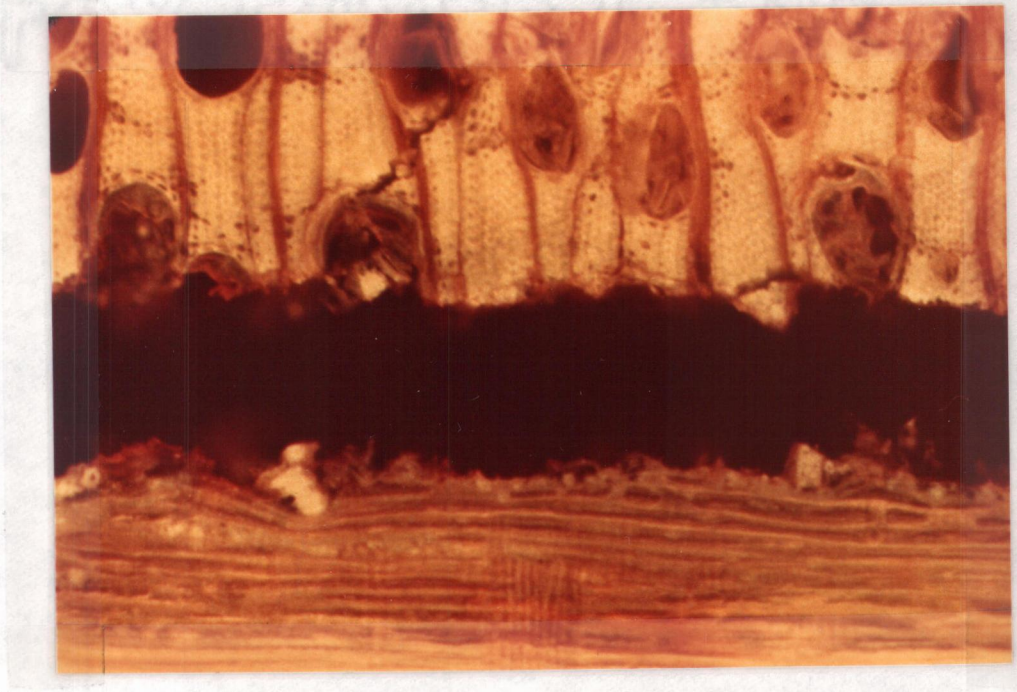


Figure 16B. Sheared plywood glueline made of untreated Kapur veneer. 60X

Effect of Planing on the Plywood Glueline

Planing the hardwood veneer surface prior to gluing caused significant increase in wood failure compared to the wood failures of the untreated veneers. Planing also caused anatomical differences to the veneer surface. Figure 17A is a Kapur veneer surface that has not been treated and Figure 17B is a Kapur veneer surface that has been planed as viewed under a stereo microscope. The planed veneer surface appears "smoother" in conformation than the untreated veneer surface. Figure 18A is a Meranti veneer surface which is untreated and Figure 18B is a Meranti veneer surface which has been planed as seen under the scanning electron microscope. Under the scanning electron microscope the untreated veneer surface appears rougher with more cellular debris scattered about in the form of torn vessels and fibers. The ends of the wood rays appear open in the untreated veneer. Once planed the ends of the wood rays are no longer open but filled in and crushed over. The planed surface appears "smoother" and "cleaner" than the untreated veneer. Much of the cellular debris appears to have been pushed into the large open vessels. Figure 19A and 19B are higher magnification photographs using the scanning electron microscope of untreated and planed Meranti surfaces identical to those in Figure 18A and 18B. The same results as explained above are seen in these photographs. The planed veneer surface particularly shows a vessel partially filled with cellular debris caused by the planing action. In Figure 18B there appears to be more intra-wall fractures perhaps along the S_1 or S_2 layers of the cell wall whereas in Figure 18A there appears to be more cross-wall fractures as defined by Koran and Vasishth (16). These

Figure 17A. Stereo microscope picture of untreated Kapur veneer surface. 12X

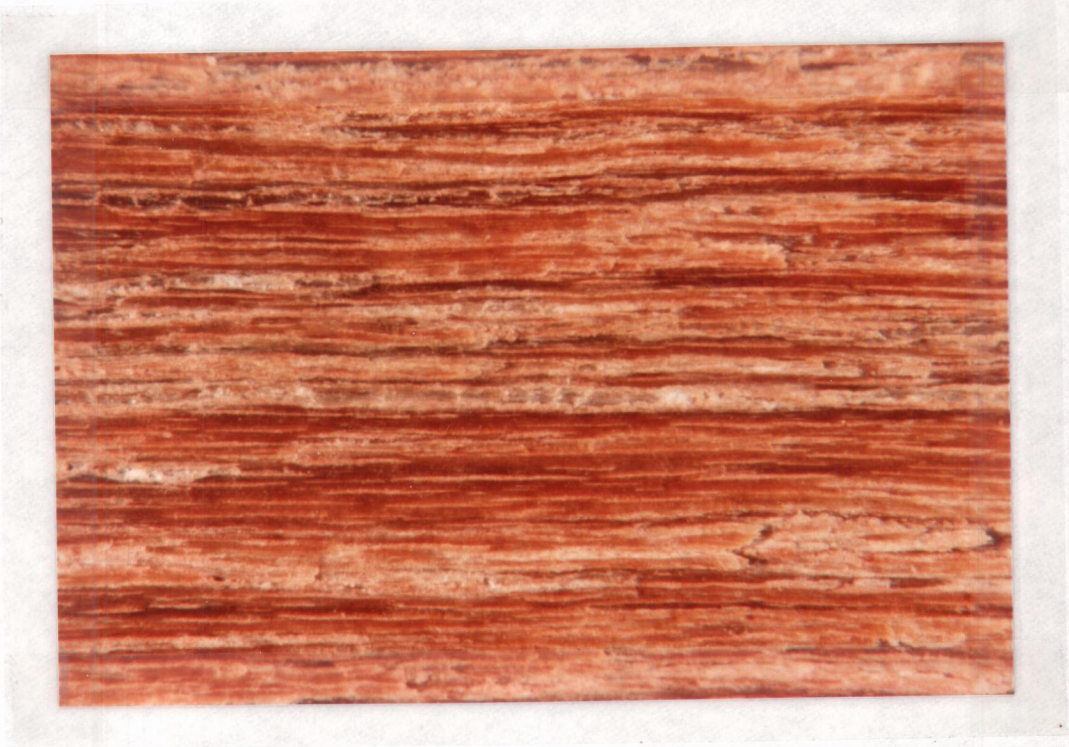


Figure 17B. Stereo microscope picture of planed Kapur veneer surface. 12X

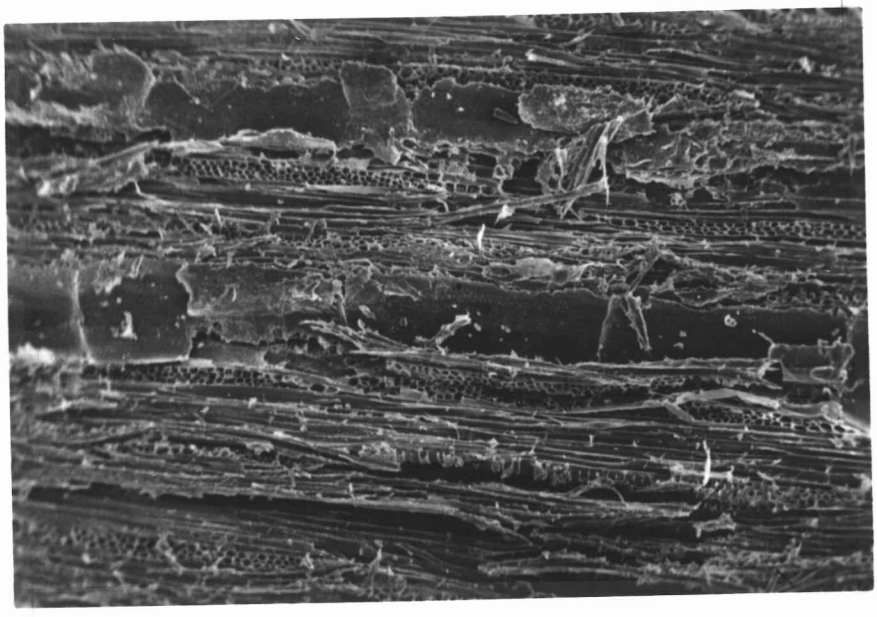


Figure 18A. SEM picture of untreated Meranti veneer surface. 50X

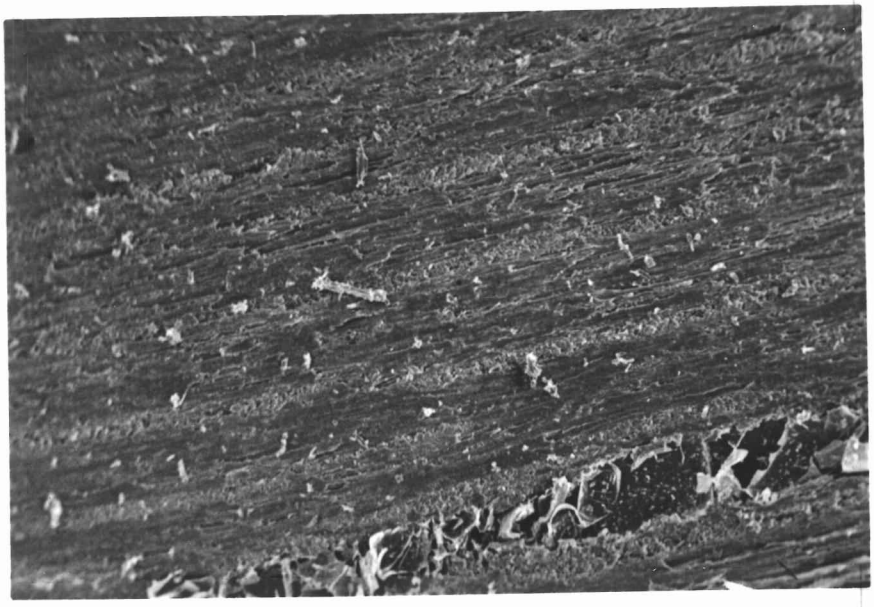


Figure 18B. SEM picture of planed Meranti veneer surface. 50X

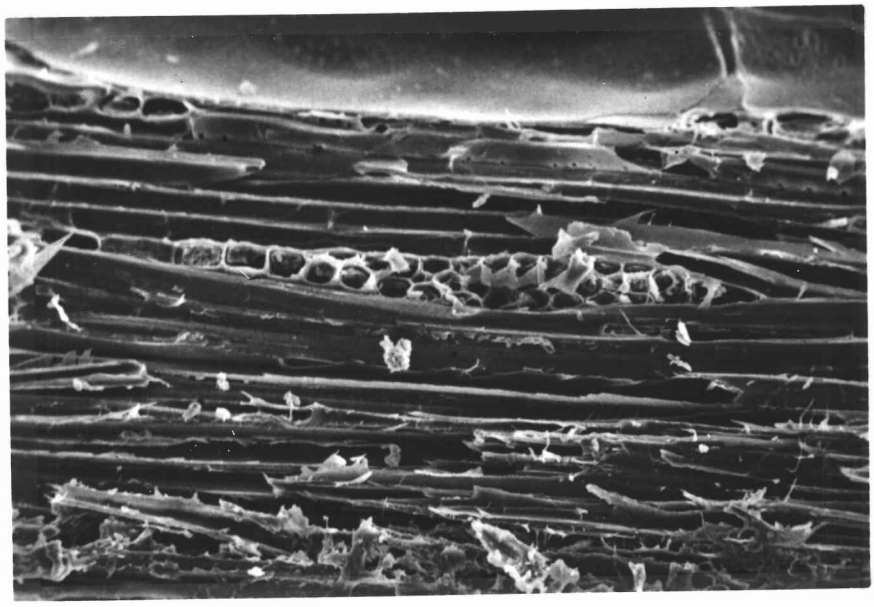


Figure 19A. SEM picture of untreated Meranti veneer surface. 200X

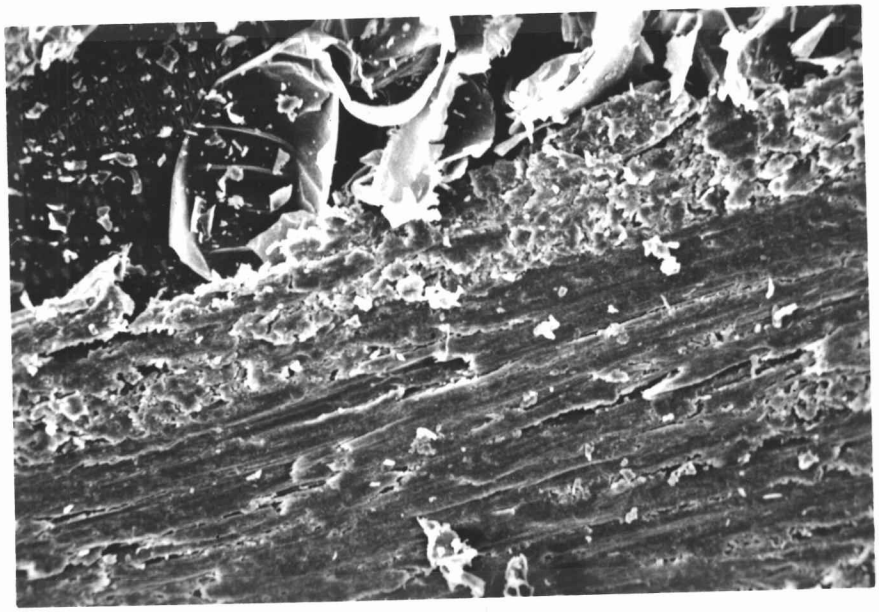


Figure 19B. SEM picture of planed Meranti veneer surface. 200X

cross-wall fractures expose larger amounts of cell lumen area which for many of the hardwood species is an area which may be coated with extractives as suggested by Wellons and Krahmer (37). All hardwood species were observed under the scanning electron microscope and these same results were consistently found.

The results found when using the scanning electron microscope were also found when observing gluelines under the fluorescence microscope. Figure 20A and 20B are incident fluorescence photographs of plywood gluelines made of untreated hardwood face veneers. The adhesive in these photographs appears reddish to black and has penetrated into the vessel lumens and into the fiber tracheids. Adhesive can be seen in the bordered pits connecting fiber tracheids. Plywood panels made of untreated veneers as well as extracted veneer exhibit an uneven glueline as shown in Figure 21A and 21B. Throughout the glueline the Douglas-fir core veneer is forced to conform to the configuration of the dense hardwood face veneer causing a certain amount of curshing to occur in the core. This causes areas of the glueline to be produced where the hardwood face and Douglas-fir core are in close contact with each other as well as areas where the face and core veneer are farther apart. Thus, when the plywood panel is pressed adhesive will flow into the more open areas of less pressure creating a thick and thin or uneven glueline. Figure 21B shows this result. Thin and thick glueline areas are visible and crushed and damaged core areas can be seen. Figure 22A and 22B are plywood gluelines made of hardwood veneer which has been planed. In both of these photographs cellular debris has been pushed into the open vessel lumens at the surface of the veneer. These vessels

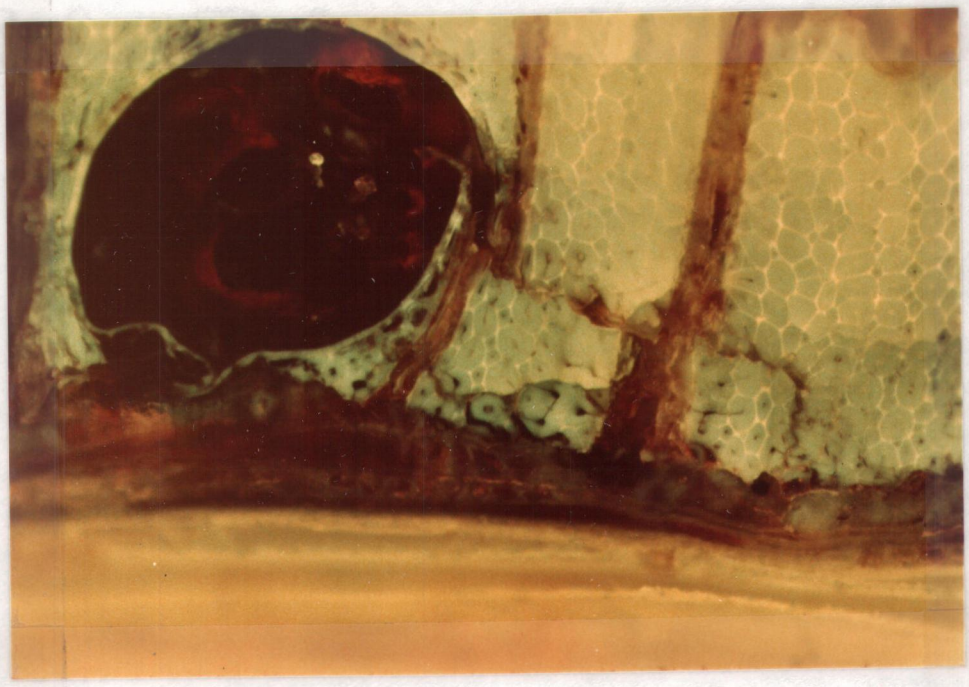


Figure 20A. Fluorescence picture of plywood glueline made of untreated Keruing-15 veneer. 182X

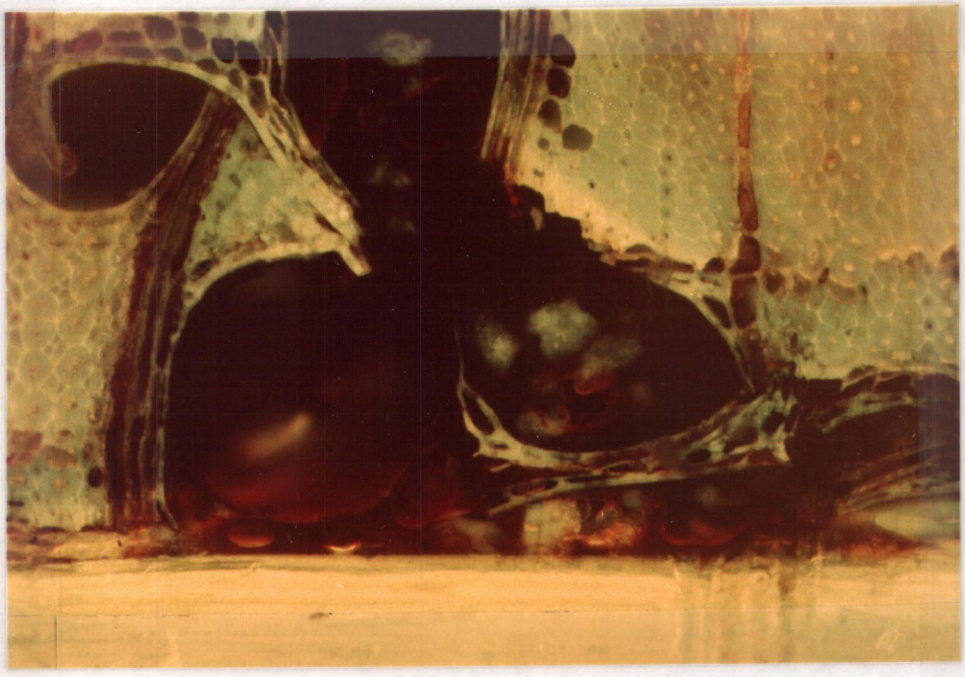


Figure 20B. Fluorescence picture of plywood glueline made of untreated Kapur veneer. 182X

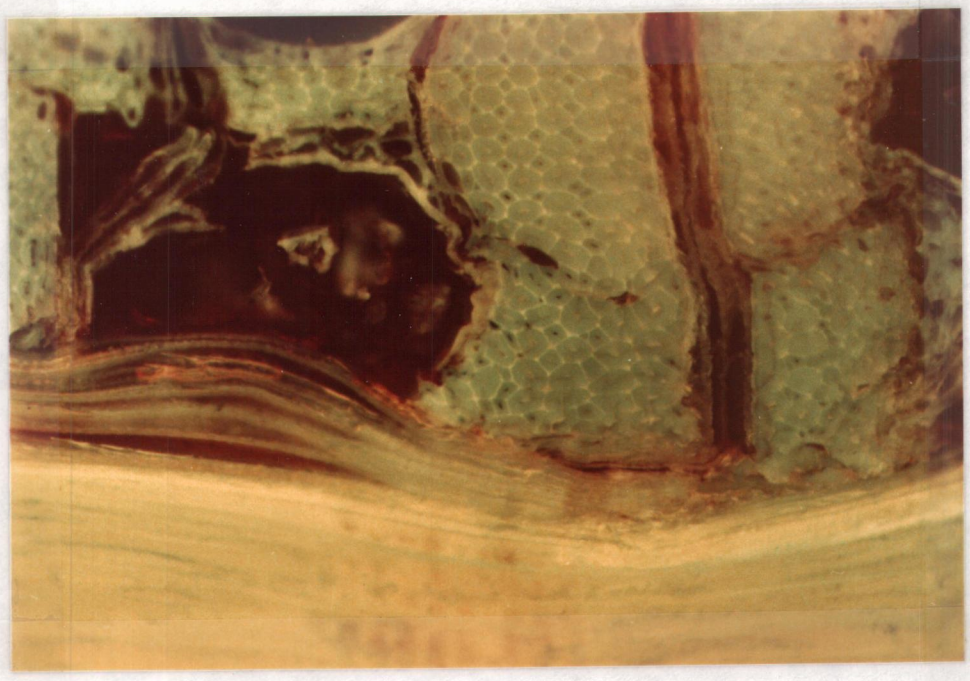


Figure 21A. Fluorescence picture of plywood glueline made of extracted Kapur veneer. 182X

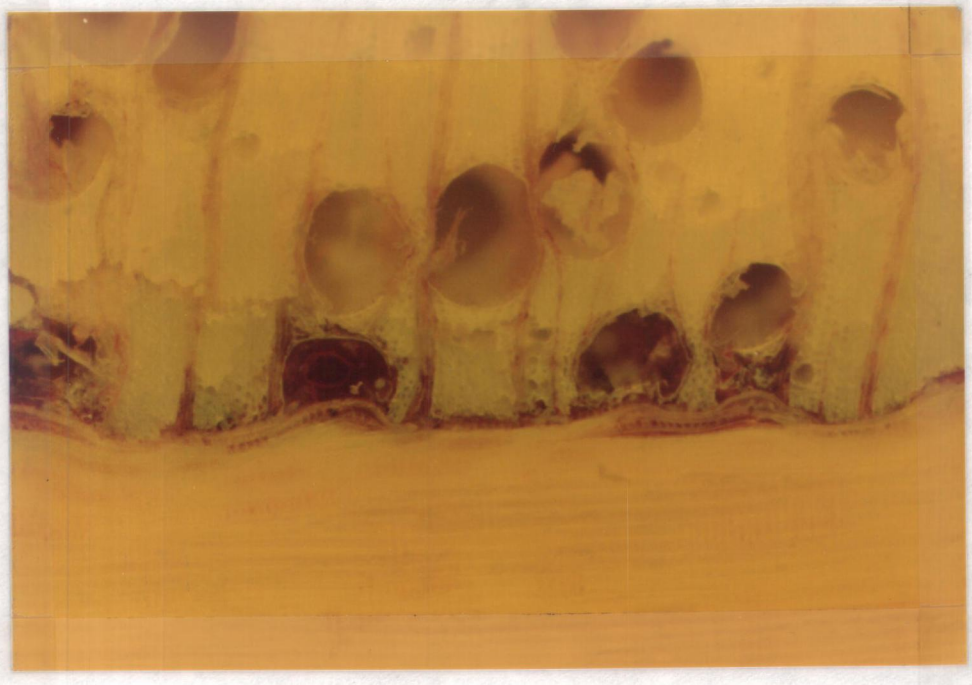


Figure 21B. Fluorescence picture of plywood glueline made of untreated Keruing-16 veneer. 60X

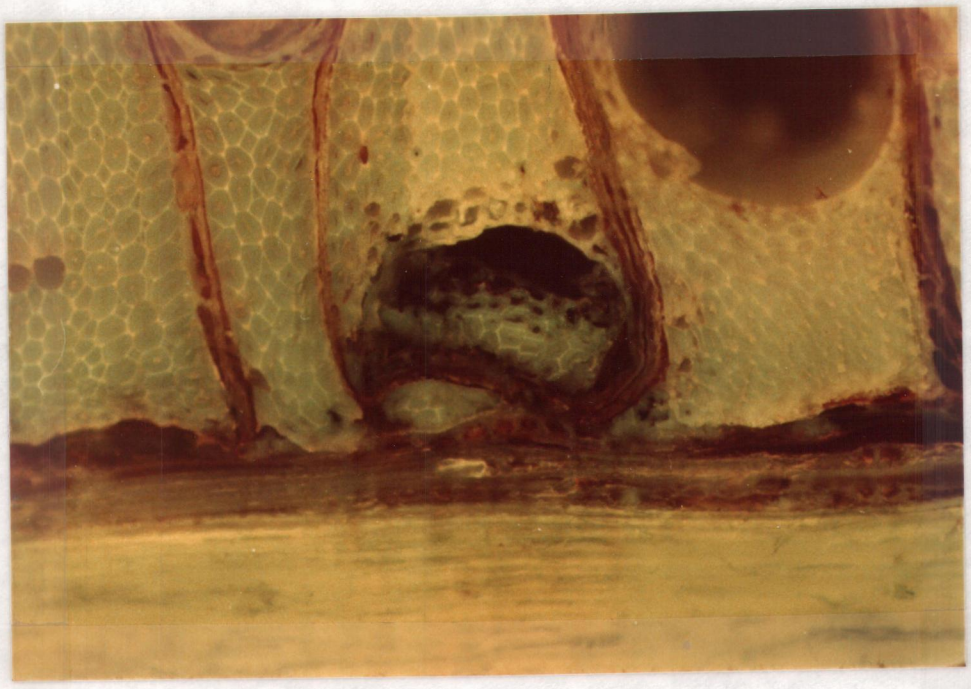


Figure 22A. Fluorescence picture of plywood glueline made of planed Kapur veneer. 182X

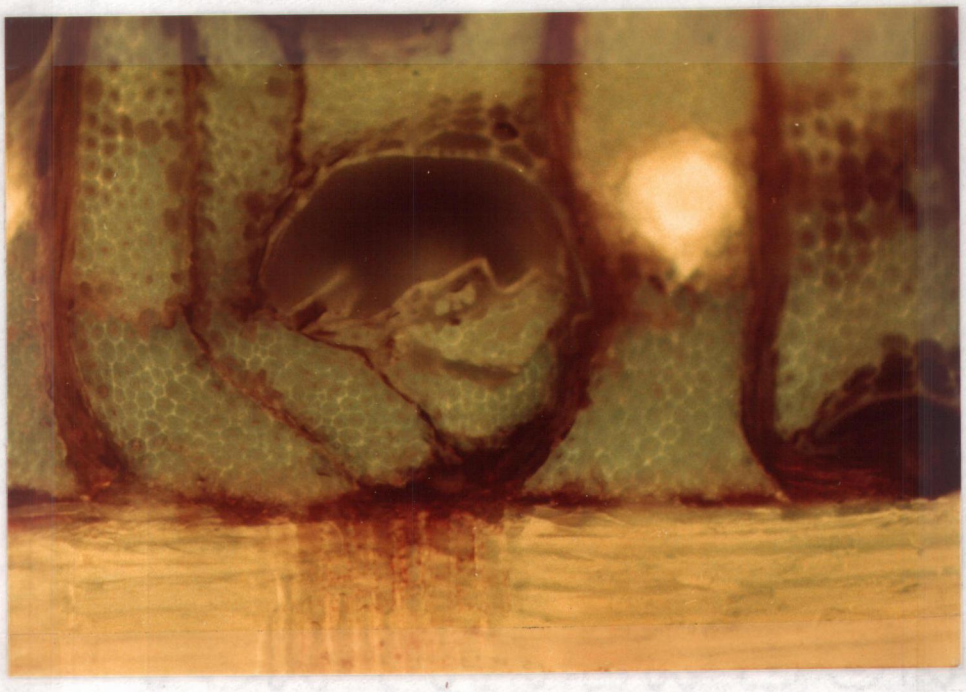


Figure 22B. Fluorescence picture of plywood glueline made of planed Balau veneer. 182X

are now "plugged" and adhesive apparently has not penetrated their lumina. Figure 22A and 22B along with Figure 23A and 23B illustrate the uniformity and evenness of the plywood gluelines made of planed veneers. The hardwood face veneer surface appears level and does not substantially crush or destroy the original configuration of the softwood core veneer. This flatness of the veneer surface in addition to the plugged vessels cause the adhesive to be evenly distributed in the glueline as is particularly evident in Figure 23A and 23B. This uniformity in adhesive distribution thus allows adequate adhesive to come into intimate contact with the recently exposed wall layers of the wood cell wall produced through planing. This in turn leads to a better bond and improved bond durability. Throughout Figures 22 and 23 there does not appear to be as much adhesive penetration into the fiber lumens as found in the gluelines made of untreated or extracted veneer in Figures 20 or 21. This is not surprising because in the gluelines made of untreated or extracted veneer, ample adhesive is forced into localized areas where deeper fiber lumen penetration is possible. In the gluelines made of planed veneer the adhesive appears more uniformily distributed with reduced localized zones of deep penetration. This observation leads one to believe that a good bond may not need excessive fiber lumen penetration but only a good physical and chemical adherance one or two cells deep. Thus, in summary, planing the veneer surface appears to cause the most effective use of the adhesive and appears to create an excellent surface for gluing.

River and Miniutti (30) reported than planing of hardwood blocks improves their gluability as long as their density is high enough. The

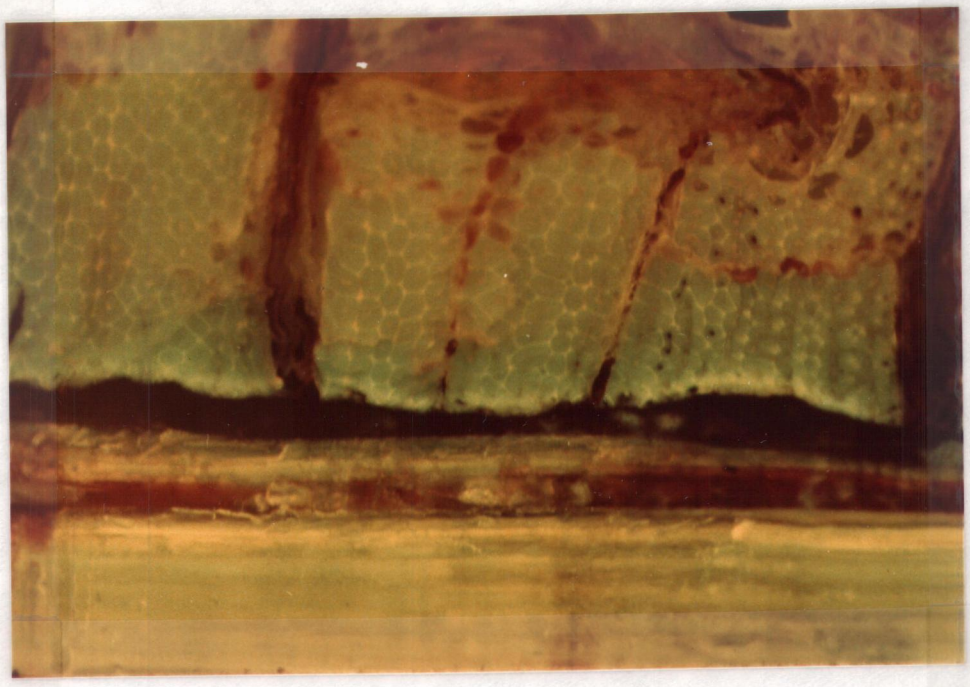


Figure 23A. 182X

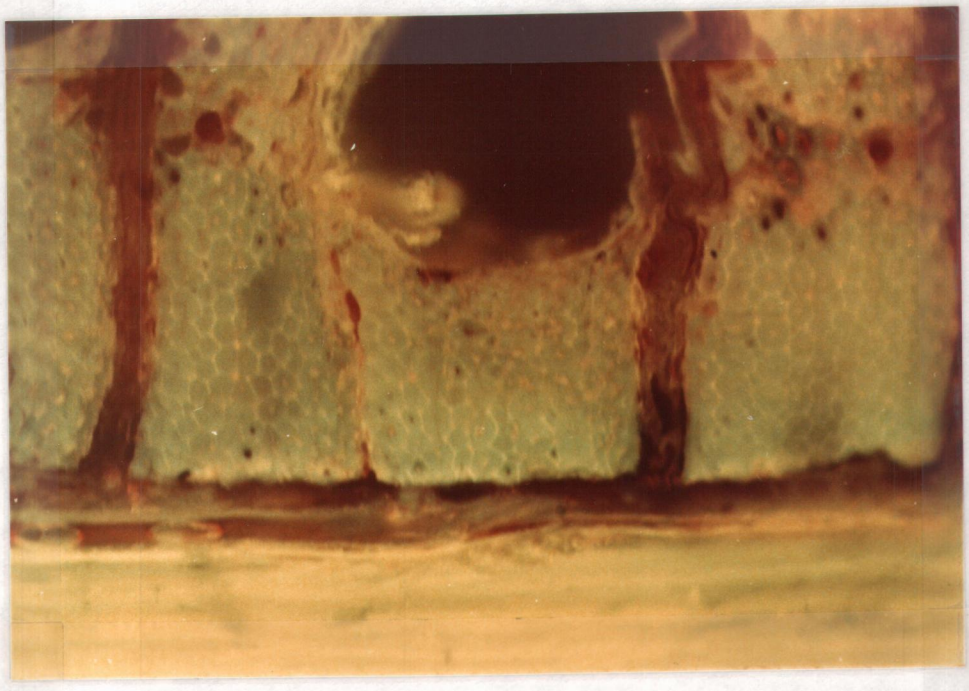


Figure 23B. 182X

Figure 23. Fluorescence pictures of plywood gluelines made of planed Kapur veneer showing uniformity of the glueline.

only low density hardwood used in this study was Red Meranti as noted in Table 1. Figure 24A is a plywood glueline made of untreated Meranti veneer and Figure 24B is a plywood glueline made of planed Meranti veneer. Fibure 24B shows a vessel partially filled with cellular debris which is keeping the adhesive from penetrating the lumen. Figure 24A shows a large amount of adhesive penetration into the fiber lumens as well as the vessel lumen. Although some of this penetration is due to a split in the wood, much of it is true fiber lumen penetration. The Meranti face veneer in Figure 24B has been planed and the cursching of the fibers at the glueline is easily observed. Although the fibers have been crushed because of the planing or pressing action on this low density Meranti veneer, the bond durability resulting from planing still showed great improvement as seen in Appendix B.

Variable Bond Durability Associated with the Keruings

The effects of planing and extraction have been described without reference to any specific species. The anatomical results presented for each treatment have been observed irregardless of species. Of particular importance in this study was the variable bond quality associated with the Keruings. The statistical results showed that planing the Keruing veneer surface prior to gluing eliminates much of the variability in bond quality. Anatomical results illustrated for all species of unacceptable bond quality why this increase in bond durability may have resulted from planing. When the gluelines made of untreated Keruings were observed individually no direct observations could be made connecting adhesive penetration or adhesive distribution

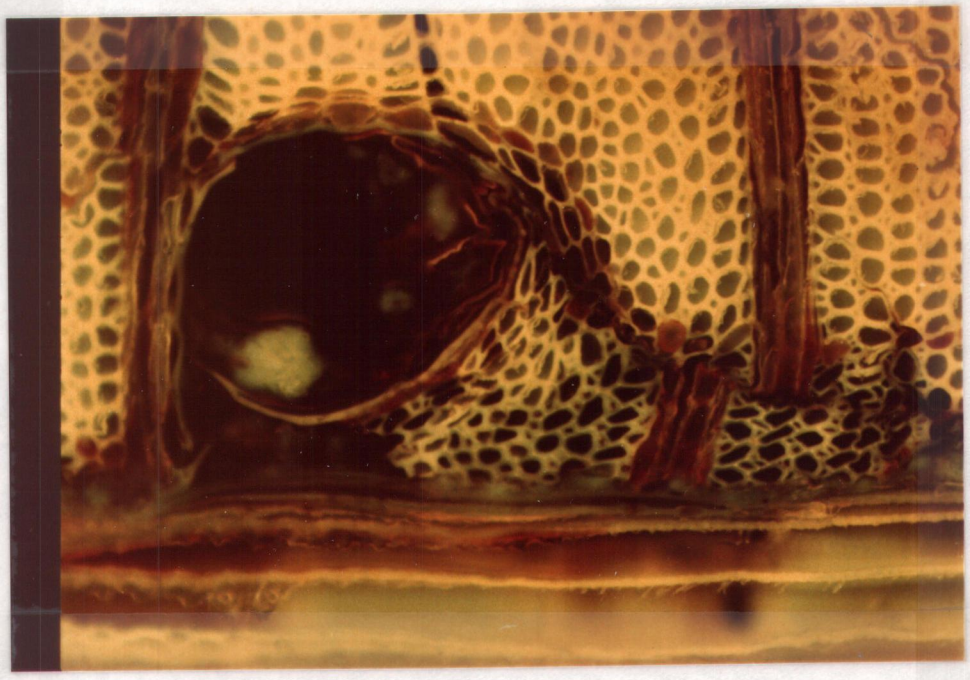


Figure 24A. Fluorescence picture of plywood glueline made of untreated Meranti veneer. 182X

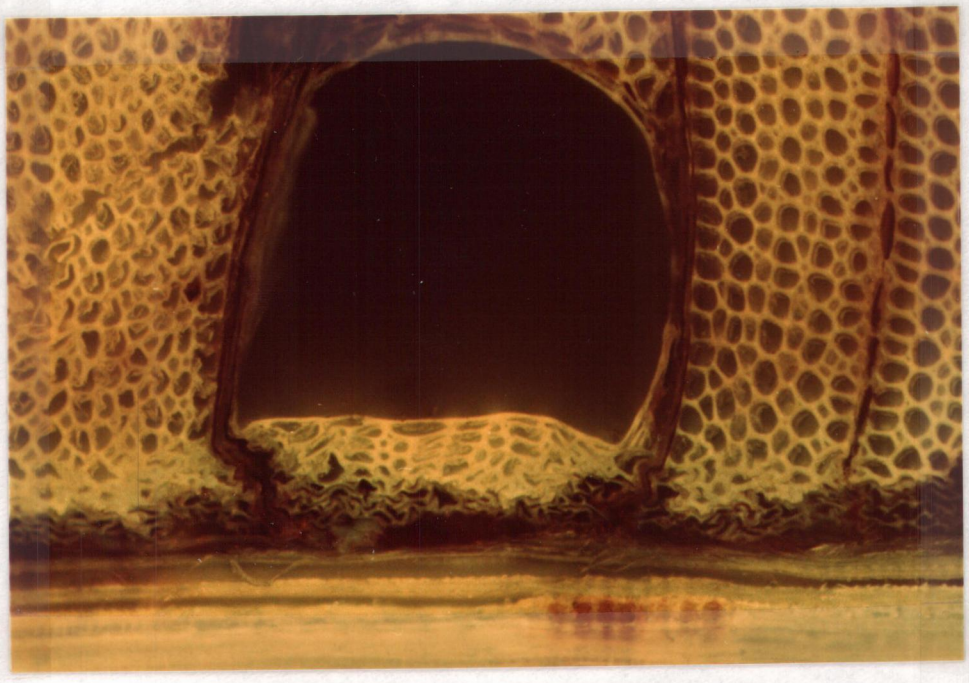


Figure 24B. Fluorescence picture of plywood glueline made of planed Meranti veneer. 182X

to how the panels performed when tested for wood failure. The anatomical observations made in describing the effects of treatment could not be carried one step further in describing for each Keruing specifically why it performed the way it did. The bond durability of all species, even Kapur, was increased because of planing. In Figure 7 we note that even untreated Keruing veneers having good bond durability performed better when the veneers were planed. This raises the question of why did these Keruing veneers perform well when untreated even though their glueline characteristics were not similar to gluelines made of planed veneer. It appears that a surface phenomenon is at work here. Perhaps the physical or chemical nature of the good gluing Keruing veneer surfaces when combined with an adhesive allows a good bond to form where for the poor gluing Keruings this situation does not exist. There appears to be a combination of factors at work that had to be accounted for before any explanation could be forthcoming. Density variation from specimen to specimen even within a species made penetration observations inconsistent. In some cases adhesive could be seen in fiber lumens while in others it could not. Cell wall penetration has not been defined using fluorescence microscopy. The caustic front reported by Nearn (24, 25) and Côté (7) was not always present and could not be used as a reliable indicator of adhesive penetration.

The investigation of the variable bond quality associated with the Keruings did not produce any definite answers, and it appears that in order to effectively evaluate this question many factors must be controlled. In some way the factor of density must be dealt with. The factor of extractive content and distribution in the wood must be

understood better from a physical and chemical point of view. Further investigation must be performed to determine if fluorescence microscopy can be used to locate and identify extractives in wood. Perhaps modifications in light intensity and excitation filters would enable one to identify better all the components present in the glueline. In summary, the anatomy of a glueline is a complex system. It is an interaction of many factors including density, anatomical elements, adhesive, extractives, surface exposed, surface chemistry, and so on. Thus, in order to effectively answer questions concerning wood failure differences of 20% between Keruings, these factors need to be controlled so that differences observed with microscopy can be connected to a factor which has been altered while the rest have been held constant.

CONCLUSIONS

The following conclusions can be made from the results of this study.

1. Planing Southeast Asian hardwood veneers prior to gluing resulted in a consistent increase in the percentage of wood failure when compared to the wood failure of the samples made of untreated veneers. This improvement raised some bonds from unacceptable or marginally acceptable bond quality to a highly acceptable bond quality. Planing treatment eliminated the variable bond quality associated with the Keruings.

2. Plywood gluelines of planed veneers showed uniform glueline thickness and an even adhesive distribution. Planing caused veneer surfaces to appear smoother than unplaned veneer. Cellular debris was packed in vessel lumens and ray ends were plugged because of crushing. Planed veneer appeared to exhibit larger amounts of intrawall surfaces while unplaned veneer showed more lumen surfaces.

3. One percent caustic extraction for 60 seconds followed by a 60 second rinse of the Southeast Asian hardwood veneers prior to gluing did not result in a consistent increase in the percentage of wood failure when compared to the wood failure of the samples made of untreated veneer. Some bonds of marginally acceptable bond quality were raised to an acceptable bond quality while others dropped from acceptable to unacceptable levels. Extracting treatment did not eliminate the variable bond quality of the Keruings.

4. Extracting the veneer caused the veneer surface to be darker colored than the untreated veneer surface. The extraction sequence appeared to further contaminate the veneer surface by causing extractive migration back to the surface of the veneer. The amount of extractive migration appeared to depend on the length of extraction and water rinse times. Plywood gluelines made of extracted veneers had areas of excessive adhesive penetration and areas of little adhesive penetration similar to untreated veneers.

5. Observation of variable adhesive penetration or adhesive distribution within a Keruing species resulted in no anatomical explanations for the variable bond quality associated with the Keruings. It appears that anatomical variables must be more closely controlled before the variable bond quality of Keruings can be explained.

6. The results stated above were found for both adhesives used in this study. Glueline failures still appeared to occur at the interface of the adhesive and hardwood surface while wood failure could occur in either the hardwood face veneer or the softwood core veneer.

LITERATURE CITED

1. Akaike, Y., T. Nakagami, and T. Yokota. 1974. The inhibitory effect of Kapur wood extracts on the gelation of urea resin adhesive. Mikuzai Gakkashi 20(5):224-229.

2. Ananymous. 1974. U.S. Product Standards PS1-74 for Construction and Industrial Plywood. National Bureau of Standards. Washington, DC. 32 pp.

3. Bodig, J. 1962. Wettability related to gluabilities of five Philippine mahoganies. Forest Products Journal 12(6):265-270.

4. Bryant, B. S. 1968. Interaction of wood surface and adhesive variables. Forest Products Journal 18(6):57-62.

5. Burgess, P. F. 1966. Timbers of Sabah. Sabah Forest Records No. 6. Forest Dept., Sabah, Malaysia. 501 pp.

6. Chen, C. M. 1970. Effect of extractive removal on adhesion and wettability of some tropical woods. Forest Products Journal 20(1): 36-41.

7. Côté, W. A. Jr. and R. G. Robinson. 1968. A comparative study of wood. Wood coating interaction using incident fluorescence and transmitted fluorescence microscopy. Journal of Paint Technology 40(525):427-432.

8. Fengel, D. and R. N. Kumar. 1970. Electron microscopic studies of glued wood joints. Holzforschung Bd. 24 (1970)H. 6 pp. 177-181.

9. Hancock, W. V. and F. L. Northcott. 1961. Undercured glue bonds in plywood. Forest Products Journal 11(7):316-319.

10. Harada, H., G. W. Davies and K. F. Plomley. 1968. Preliminary microscopic studies of wood structure and adhesion in plywood. Forest Products Journal 18(2):86-90.

11. Harada, H. and Y. Okuno. 1965. An electron microscopic investigation on the gluing of wood. Journal of the Japan Wood Research Society (Mokuzai Gakkaish) 11(6):240-244.

12. Hare, D. A. and N. P. Kutscha. 1974. Microscopy of eastern spruce plywood gluelines. Wood Science 6(3):294-304.

13. Horioka, K., A. Mishiro and Y. Chiba. 1969. Adhesion of tropical hardwood in Southeast Asia, especially contact angles and ability of adhesion. Bull. Exp. For., Tokyo Univ. Agri. and Technology. No. 8:9-30.

14. Imamura, H., T. Takahashi, M. Yasue, M. Yagishita, H. Karasawa and J. Kawamura. 1970. Effect of wood extractives on gluing and coating of Kapur wood. Bull. Gov. For. Exp. Sta., Meguro, Tokyo. No. 232:65-96.

15. Kaufert, F. H. 1943. Preliminary experiments to improve the gluing characteristics of refractory plywood surfaces by sanding. USDA Forest Service Research Paper. No. FPL 1351. Forest Products Laboratory, Madison, WI. 10 pp.

16. Koran, Z. and R. C. Vasishth. 1971. Scanning electron microscopy of plywood glue lines. Wood and Fiber 3(4):202-209.

17. Krahmer, R. L. and J. D. Wellons. 1974. Segregation and identification of Southeast Asian hardwoods. Research report to the Plywood Research Foundation, Tacoma, WA. 48 pp.

18. Kutscha, N. P. and R. L. Ethington. 1962. Shelling failures. Forest Products Journal 12(11):538.

19. Lehmann, W. F. 1968. Resin distribution in flakeboard shown by ultraviolet light photography. Forest Products Journal 18(10): 32-34.

20. Marian, J. E. and K. Suchsland. 1957. Experimental investigation of gluing and finishing problems through application of fluorescence microscopy in incident light. Forest Products Journal 7(2): 74-77.

21. Marts, R. O. 1950. Application of fluorescence microscopy and photomicrography to woody tissues. Stain Technology 25(1):41-44.

22. _____. 1955. Fluorescence microscopy for measuring fibril angles in pine tracheids. Stain Technology 30(5):243-248.

23. _____. 1955. Wood and fiber structure by incident fluorescence microscopy. Journal of the Biological Photographic Assoc. 23(4):151-155.

24. Nearn, W. T. 1965. Wood-adhesive interface relations. Official Digest Journal of Paint Technology and Engineering 37(485):720-733.

25. _____. 1974. Application of the ultrastructure concept in industrial wood products research. Wood Science 6(3):285-293.

26. Nguyen, D. 1975. Effect of wood extractives on cure of phenolic resin. M.S. thesis, Oregon State University, Corvallis, OR. 108 pp.

27. Nguyen, T. 1973. Wettability and gluability of Apitong (Dipterocarpus grandiflorus) veneer. M.S. thesis, University of Philippines, Los Banes. 141 pp.

28. Nguyen, T., F. S. Pollisco and R. C. Cosilla. 1976. Effects of sanding and surface aging on wettability and gluability of Apitong (Dipterocarpus gradiflorus Blanco). Pterocarpus 2(2):160-171.

29. Quirk, J. T. 1968. Fluorescence microscopy for detecting adhesives on fracture surfaces. U.S. Forest Service Research Note. FPL-0191. pp. 1-2.

30. River, B. H. and V. P. Miniutti. 1975. Surface damage before gluing--weak joints. Wood and Wood Products 80(7):35-36,38.

31. Schneider, M. H. and W. H. Côté, Jr. 1967. Studies of wood and coatings interactions using fluorescence microscopy and pyrolysis gas-liquid chromatography. Journal of Paint Technology 39(511): 465-471.

32. Sleet, G. T. 1975. Gluing and identification of Southeast Asian veneers. Research report of the American Plywood Association, Tacoma, WA. No. 133. 7 pp.

33. Suchsland, Karl. 1957. Influence of the roughness of surfaces on the strength of wood glue bond. Holz als Roh-und Werkstoff. 15 Jahrg. Sept. Heft 9. pp. 385-389.

34. Suchsland, Otto. 1958. On the penetration of glue in wood gluing and the significance of the penetration depth for the strength of glue joints. Holz als Roh-und Werkstoff. 16 Jahrg. Marz. Heft 3. pp. 101-108.

35. Villaflor, A. A. 1973. Water loss in resin adhesive systems as related to the wettability-permeability characteristics of wood substrates and to bond formation. Ph.D. thesis, University of Washington, Seattle, WA. 273 pp.

36. Wellons, J. D. 1977. Adhesion to wood substrates. American Chemical Society Symposium Series, No. 43. Wood Technology: Chemical Aspects. pp. 150-168.

37. Wellons, J. D and R. L. Krahmer. 1973. Characteristics of delaminated exterior hardwood plywood. Research report to the Plywood Research Foundation, Tacoma, WA. 20 pp.

38. Wellons, J. D., R. L. Krahmer, R. Raymond and G. Sleet. 1977. Durability of exterior siding plywood with Southeast Asian hardwood veneers. Forest Products Journal 27(2):38-44.

39. Wellons, J. D., G. Wilkie and R. L. Krahmer. 1977. Gluing Southeast Asian hardwood veneers to Douglas-fir. Summary report to the Plywood Research Foundation, Tacoma, WA. 8 pp.

40. White, M. S. 1977. Influence of resin penetration on the fracture toughness of wood adhesive bonds. Wood Science 10(1):6-14.

41. Wilkie, G. 1977. Determining appropriate accelerated aging tests for Keruing plywood. M.S. thesis, Oregon State University, Corvallis, OR. 89 pp.

42. Wilson, J. B. and R. L. Krahmer. 1976. Particleboard: Microscopic observations of resin distribution and board fracture. Forest Products Journal 26(11):45-47.

APPENDICES

APPENDIX A

PROPOSED STANDARD METHOD FOR EXTIMATING PERCENTAGE WOOD FAILURE ON PLYWOOD SHEAR SPECIMENS*

Scope

1. This method covers the determination of percentage wood failure of plywood shear specimens prepared and tested as outlined in ASTM D 906-64, "Strength Properties of Adhesives in Plywood Type Construction in Shear by Tension Loading."

Apparatus

2.(a) A dual element desk lamp equipped with one 15 watt Daylight and one 15 watt Cool White fluorescent tube shall be used for estimating purposes. Outdoor light interference should be avoided.

(b) A ruler or other measuring device calibrated to 0.1 inch is recommended as an aid to measuring the area of torn wood fibers.

Preparation of Test Specimens

3. Percentage wood failure shall be estimated with specimens in a dry condition.

Procedure

4.(a) Specimens will be hand held, tipped at a 45° angle to the desk surface, and the long axis of the specimen shall be parallel to the light tubes. A plane through the two fluorescent light tubes in the lamp shall be parallel to the desk surface and shall also form an angle of 45° to the surface of the test specimens. Very slight movement of the specimen (not rotation) is permissible to enable the eye to discern differences in color and texture which may exist.

(b) Wood fiber failure of each specimen shall be estimated to the nearest 5%, with a maximum of 100% based upon the one-inch-square test area.

(c) Both halves of the specimen are held to the light in the manner prescribed in 4.(a) to orient the estimator with relative positions of wood and glue failure. The estimator shall note bare areas in the glue spread which shall not be counted as wood failure.

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*From Wilkie (41).

(d) Solid wood failure within the test area shall be measured with the ruler or other measuring device. The estimator shall measure wood failure occurring on both havles of the specimen, taking care not to count wood failure from matching areas more than once.

(e) Scattered areas of fine fiber shall be counted by the estimator mentally grouping them into an area that can be estimated. Division of the test surface into measured areas with the aid of the ruler may be of assistance in this regard. With respect to hair-like or single cell fibers attached by one end, only the part actually in contact and adhered to the glueline shall be counted as wood failure. Loose fibers not adhered to the glueline shall be brushed or blown off prior to commencing the estimating process.

(f) Isolated wood particles (such as sawdust or slivers which fell onto the glueline during the gluing process) appearing as wood failure, but which have not actually been torn from a ply during testing, shall not be counted as wood failure even though glued in place.

(g) Evaluation of wood failure may be checked by estimating the amount of glue failure present within the test area. The total amount of glue and wood failure should equal 100%.

(h) Specimens containing localized defects permitted within the plywood grade (such as burls, core voids, etc.) in or adjacent to the test area, shall not be counted in the average. Any failing panel containing such defects in one or more specimens shall be subjected to a retest.

(i) By agreement between interested parties, other localized defects such as glue wipes, chips, core laps, etc. also may be a basis for discarding the test specimen.

(j) Test specimens showing glueline delamination in excess of 1/8 inch deep and one inch long in any area of the specimen shall be rated as 0% wood failure.

Calculation

5. The panel average percentage wood failure will be the total of the individual specimen values divided by the number of specimens tested from that panel.

APPENDIX B

TABLE OF MEANS FOR SPECIES BY TREATMENT INTERACTION LISTING TRANSFORMED AND UNTRANSFORMED WOOD FAILURE DATA

Treatment	Species	Mean of Yield Transformed	Mean of Yield Not Transformed
None	Douglas-fir	75.326	92.875
	Balau	67.880	83.469
	Meranti	69.825	86.406
	Kapur	39.313	41.375
	Keruing-10	65.761	81.313
	Keruing-28	73.382	91.938
	Keruing-15	75.052	91.938
	Keruing-26	54.355	63.781
	Keruing-16	67.902	83.656
	Keruing-14	73.067	89.688
Extracted	Douglas-fir	74.234	91.938
	Balau	66.997	82.687
	Meranti	62.293	77.000
	Kapur	35.606	35.719
	Keruing-10	69.676	86.188
	Keruing-28	74.821	92.063
	Keruing-15	73.211	90.344
	Keruing-26	55.731	65.563
	Keruing-16	69.573	86.688
	Keruing-14	68.343	82.313
Planed	Douglas-fir	74.934	92.406
	Balau	78.205	95.313
	Meranti	77.373	94.438
	Kapur	77.266	93.531
	Keruing-10	78.829	95.531
	Keruing-28	77.107	93.719
	Keruing-15	78.401	94.625
	Keruing-26	72.514	87.875
	Keruing-16	78.149	93.375
	Keruing-14	81.101	96.531