Wood Processing

(I)

Overseas Technical Cooperation Agency

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CONTENTS

FABRICATION OF GLUED LAMINATED WOOD

By

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Fabrication of Glued Laminated Wood

1. Preparation of Laminae*

(1) Wood species

The wood species is determined by the use of glued laminated wood (see photo), site condition of manufacturing plant, and gluing nature of each species (Fig. 2 and 3).

(2) Sawing and drying

Sawing and drying for manufacturing of board for laminated wood are the same with the case of materials for flooring and furniture and because the uneven thickness of board in sawing badly in fluences upon the yield percentage of the laminated wood and because normal moisture content in drying is essential to gluing (Fig. 4), the wood is dried up to 8 - 12 % of moisture content evenly by kiln drying and moisture content is measured by a moisture meter(oven dry method) and improper board is excluded.

(3) Grading and Selection

At present grading of sawn board is subject to the Japanese Agriculture and Forestry Standard of Sawn Timber and it is proposed that grading by appearance is to be replaced by that by strength.

When raminae consisting of one glued laminated wood have to be combined with boards in same grain, the board materials are classified in flat grain, straight grain and inbetween of these grains. For interior decoration of coniferous building material, no such classification is needed but required for ship-building wood of hardwood.

(4) Cutting out defects and decision of dimension

While dimension is decided by horizontal and vertical cutting, defects which is out of allowable limit are removed. Rough finishing planer makes these boards in a given thickness and rough finishing is sometimes done prior to grading.

(5) Patching

Those defects which affect gluing capacity or looks of the products are remedied by patching process.

(6) Edge joint

Narrow boards are made in a given thickness by edge joint.

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* Laminae means layers composing laminated wood.

(7) Assembling of boards

Boards which were under taken processes of (1) - (6) are assembled and composition of boards for each laminated wood is decided.

a. Assembling based on the requirement of strength. Board grading, defects (knots and cross grain), distribution of scarf joint and butt joint.

b. Safe bending radii of the board (in the case of curved laminated wood).

Ex.	White oak	Rs = 116t - 6
	Douglas fir	Rs = 126t + 10
	Mahogany	Rs = 124 + Lo

Provided, Rs = Safe bending jointing

t = Thickness of board

(8) Scarf jointing

The type of scarf is divided into plain scarf and deformed scarf and the strength effective percentage is shown in Figs. 5 and 6 and sufficient effective percentage is shown at plain scarf of 1/10 - 1/15 of gradient of scarf. Each type of scarf is decided taking consideration of use of laminated wood, place of distribution of composing board and yield percentage of the material.

The scarf is cut by a scarf machine (see photo) and jointed by scarf press.

(9) Final surfacing

Boards which are scarf jointed in a given length is planed for finishing by a planer before gluing. The precision of surfacing is 1.0 - 1.5 mm wide of knife mark and of defects arising from processing, attention is to be paid not to bring about concavity at the front or rear of the board.

2. Gluing

(1) Glues

(i) Kinds of glues

Followings are glues now being used for laminated wood.

a. Casein glue

b. Urea resin

c. Phenol resin

d. Melamine resin

e. Resorcinol resin

f. Melamine-urea-resin

g. Resorcinol-phenol-resin

h. Polyvinyle resin

In Japan, thermosetting resin such as urea resin is mostly used and the property and characteristics of commercial glues are shown in Table 1, Fig. 7 and 8.

(ii) Selection of glue

Glues to be used are selected taking consideration of environmental condition of glues used, durable years, cost, and proterty of wood when used. (see Table 1, Figs. 7, 8, 9 and 10)

(2) Gluing operation

(i) Mixing and preparing glue

It is convenient to use a small type mixer (5l - 10 l) for mixing resin, filler and hardner (Photo).

(ii) Spreading glue

For spreading glue, it is convinient to use a spreader with a doctor roller. The standard quantity of glue to spread is 250 - 350 g/m^2 per one glue layer for both surface spreading.

(iii) Assembling

Because the product of laminated wood is large in dimension and complex in form, the long time for assembling is required. Consequently, in most cases glues which can be used for long time are required.

(iv) Clamping

a. Clamping apparatus

Because a clamping apparatus requires an easy adaptation to the dimension and form of the product, jigs and screw clamp which are freely assembled are usually used (see photo).

b. Clamping pressure

The normal clamping pressure is 10 - 15 kg/cm^2 for hardwood such as Kaba (Betula spp.), Buna (Fagus crenata), Oak Kashi (Quercus spp.) and Yachidamo (Fraxinus excelsissima), and 5 - 10 kg/cm^2 for softwood such as Sugi (Cryptomeria japonica), Hinoki (Chamaecyparis obtusa), Akamatsu (Pinus densiflora), Ezomatsu (Picea jezonensis) Todomatsu (Abies Sacchalinesis), Momi (Abies firma) and Tsuga (Tsuga sieboldii).

c. Measuring gluing pressure

A torque wrench is used for measuring gluing pressure (see photo). The one way to measure by a torque wrench is to calculate by the following formula and the other way is to measure directly by compression meter.

$$FL = WR \frac{(\pi f D + K)}{(\pi D - fK)} = \frac{WD}{2} \frac{(\pi f D + K)}{(\pi D - K)}$$

Provided: F = Power on lever

L = Length of arm of lever

R = mean radius of screw

D = mean diameter of screw

K = Pitch of a screw

W = Total clamping pressure

f = Coefficient of friction

$\pi = 3.1416$

(v) Curing

For curing synthetic resin glue, when the glue is hardened, it is necessarily heated at normal temperature, medium or high temperature. The laminated wood is technically difficult to heat at over 100°C for its dimension and form but it can be done at normal or medium temperature.

a. Heating apparatus

As heating process, we have steam heating, electric heating, and high frequency wave heating, and the steam heating is most common (photo).

3. Finishing process of the product

   (1) Forming process (photo)

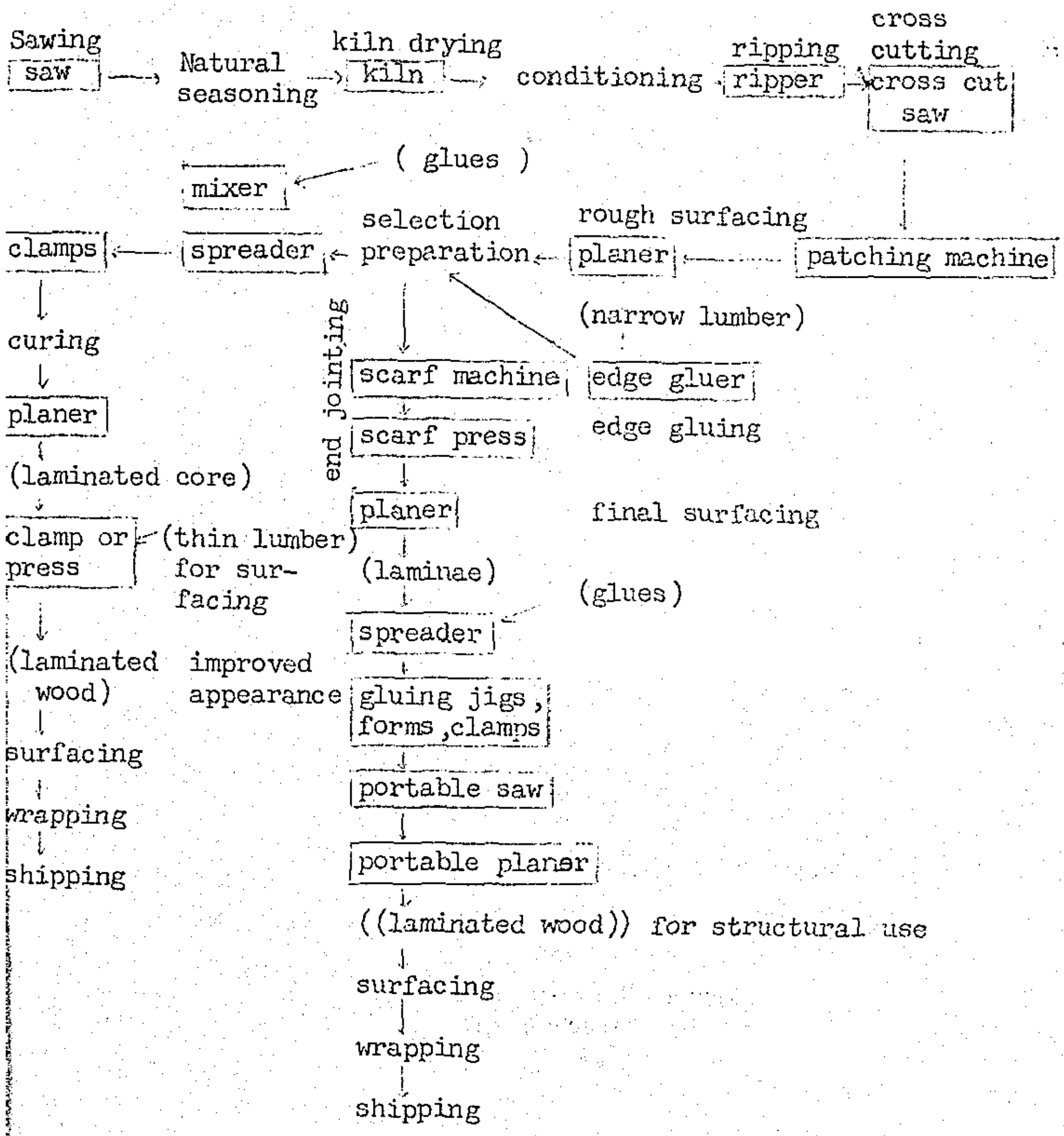
   (2) Planing process (")

   (3) Repair, painting and preservation

4. Inspection of the product

5. Packaging and Shipping

Fig. 1 Laminated wood manufacturing process



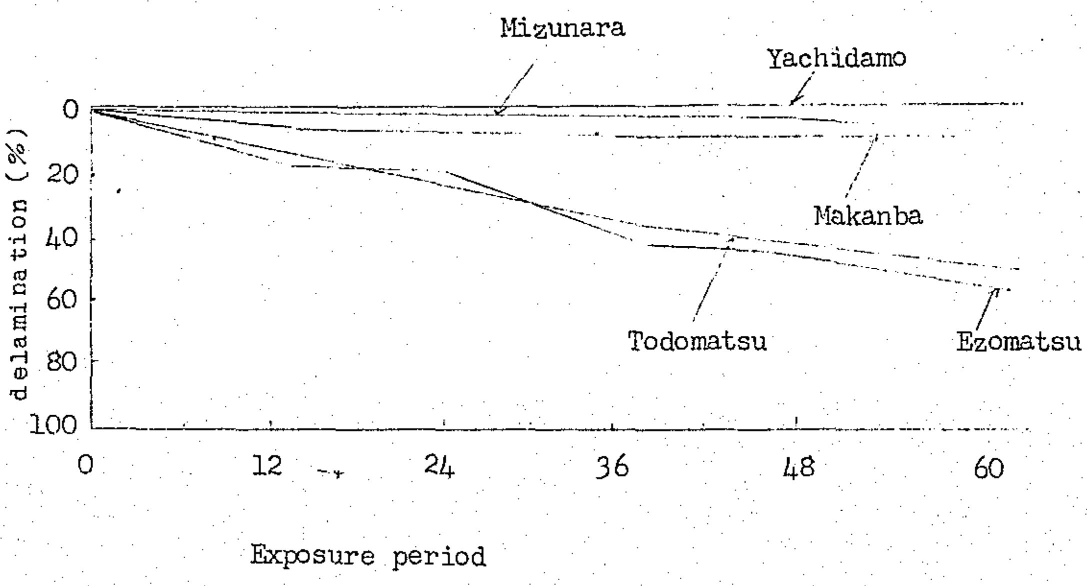


Fig. 3 Process of anti-climate test on laminated wood of various species glued with resorcinol resin

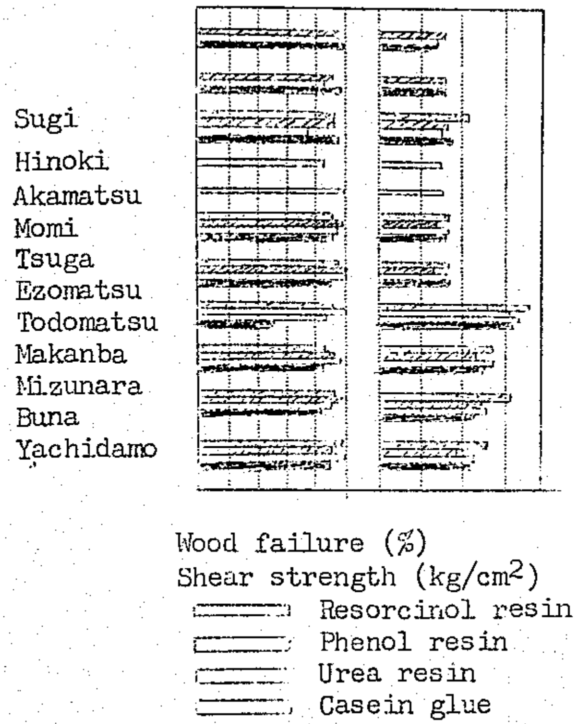


Fig. 2 Species, Adhesive and gluing capacity

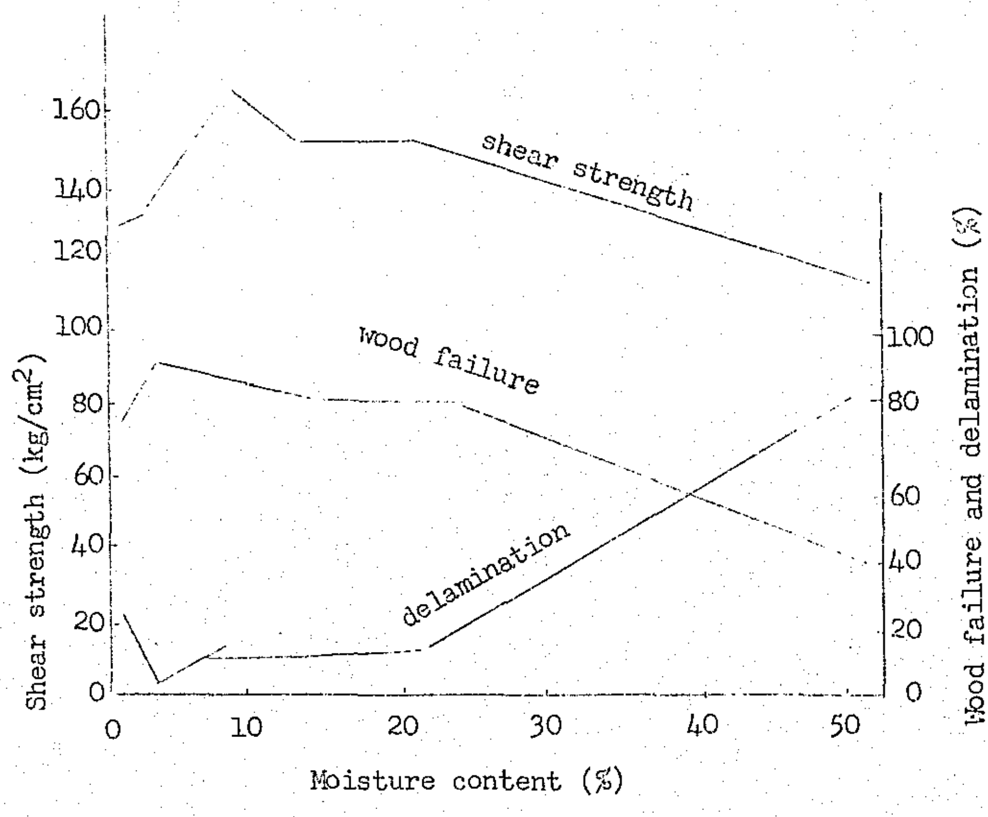


Fig. 4 Relation of moisture content of sawn board to gluing capacity.

Glue: resorcinol resin
Species of board: white oak

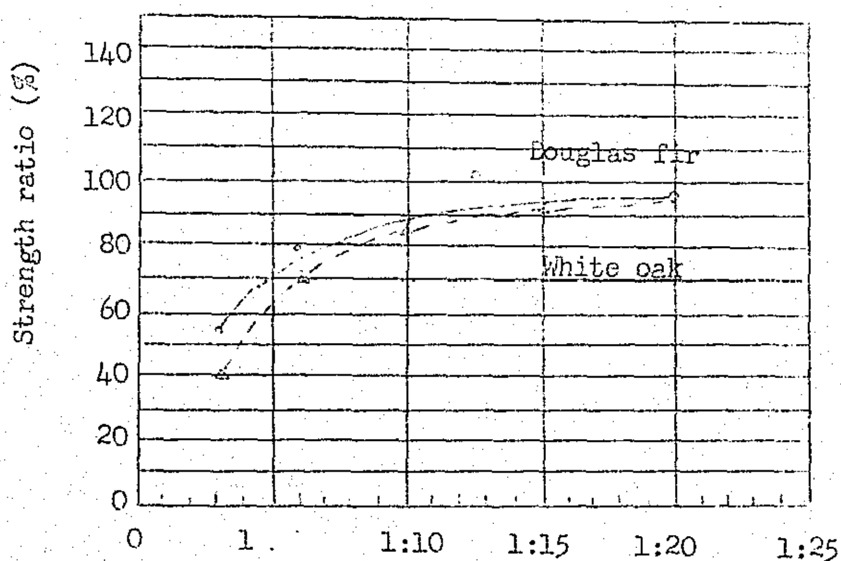


Fig. 5 Relation of slope of plain scarf of Douglas fir and white oak to the maximum strength ratio in paralell to fibre direction

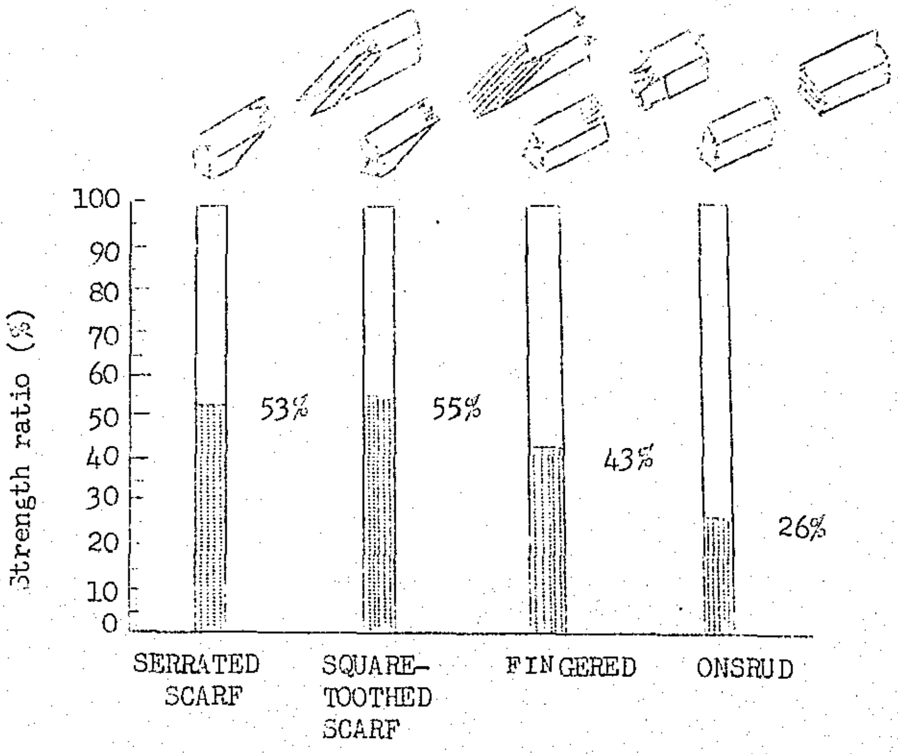


Fig. 6 Strength ratio of various scarf test piece paralelle to fibre direction against control test piece (white oak)

Table 1. Properties of adhesives

	Formulation				Viscosity	Specific	Curing	Gel time	Working	P.H	Resin
Adhesives	Resin	Hardner	Water	Alcohol	at 25°C	gravity at 25°C	time at 45°C	at 45°C	life at 25°C	at 25°C	content %
							hr min	hr min	hr min		
RA	100	15	–	–	8.3	1.122	1:45	.43	1:43	7:20	59.4
RB	"	15	–	–	8.6	1.140	1.16	.39	1.38	7.35	62.5
RC	"	15	–	–	13.54	1.153	1.59	.54	2.48	7.08	64.9
UD	"	5	–	–	10.50	1.290	2.30	.50	5.21	8.05	69.0
UE	"	5	–	–	5.8	1.255	4.55	.55	6.10	8.08	63.6
UF	"	5	–	–	24.7	1.320	.56	.26	1.20	7.98	76.3
UG	"	5	–	–	1.6	1.192	5.20	2.00	7	8.86	50.8
MM	"	10	–	–	3 - 3.5	1.234	3.26	48			
RH	"	10	–	–	7.2	1.102	5.55	.52	2.55	6.30	52.4
PI	"	10	–	15	2.7	1.249	1.50	.20	.55	6.91	74.9
PJ	"	10	–	15	8.3	1.214	5.13	1.05	5	3.55	74.8
PK	"	10	–	5	6.0	1.196	2.53	28	1.43	5.52	74.8
PL	"	10	–	–	5.0	1.220	2.11	34	57	7.05	75.5

R. Resorcinol resin
P. Phenol resin
M. Melamin resin
U. Urea resin

Fig. 7 Gluing capacity of laminated wood of Ezomatsu by each adhesive

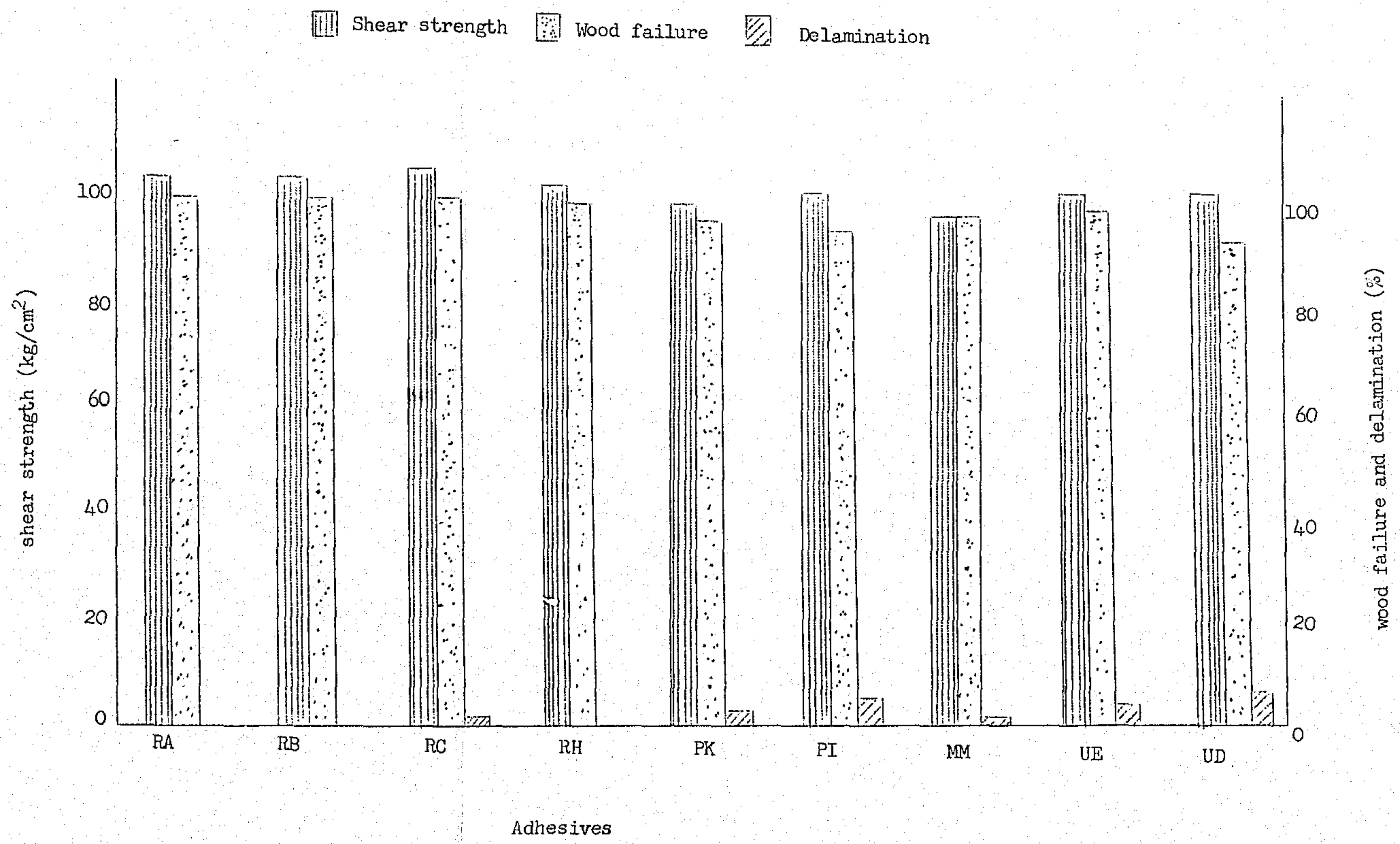
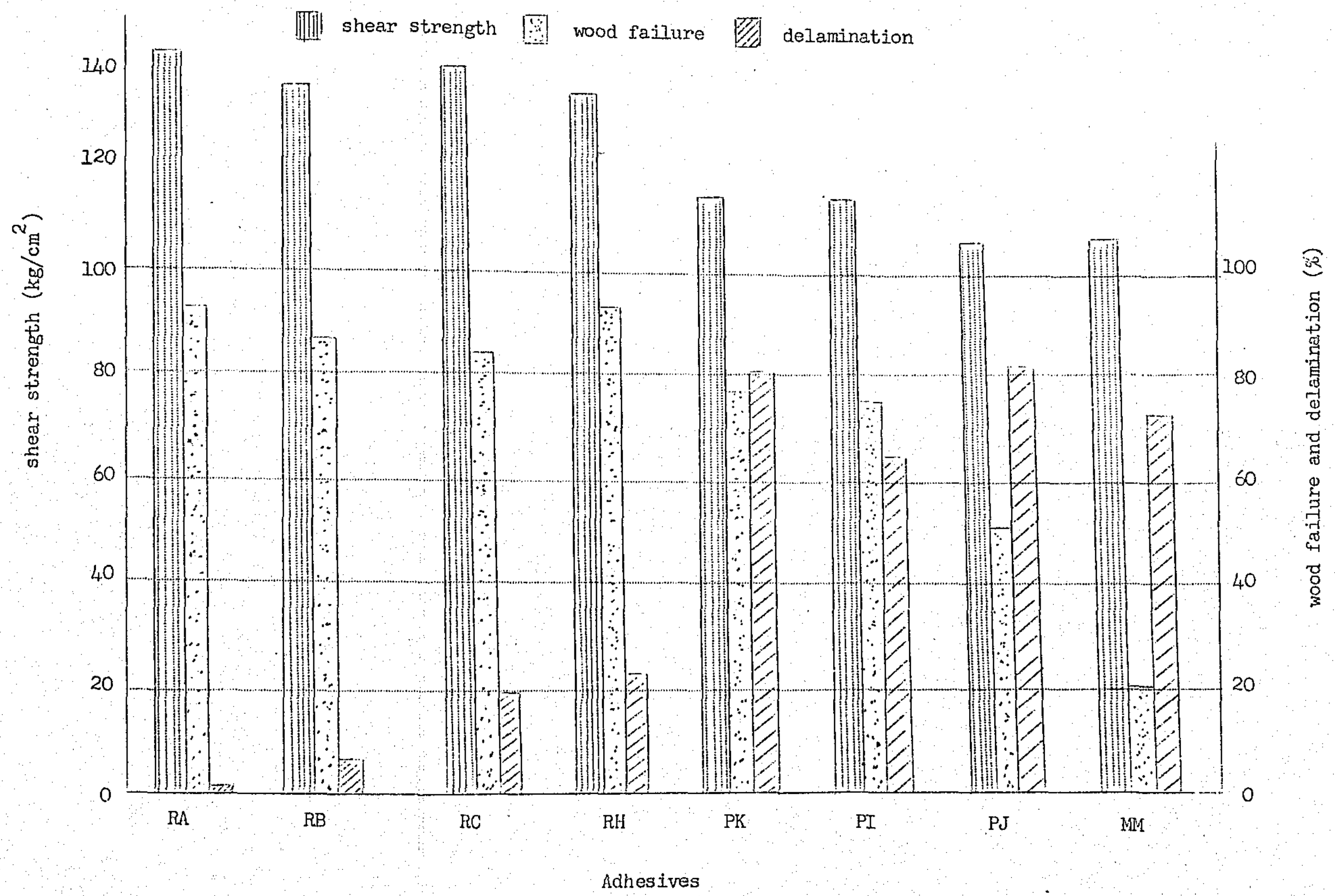


Fig. 8 Gluing capacity of Laminated wood of Mizunara by each adhesive



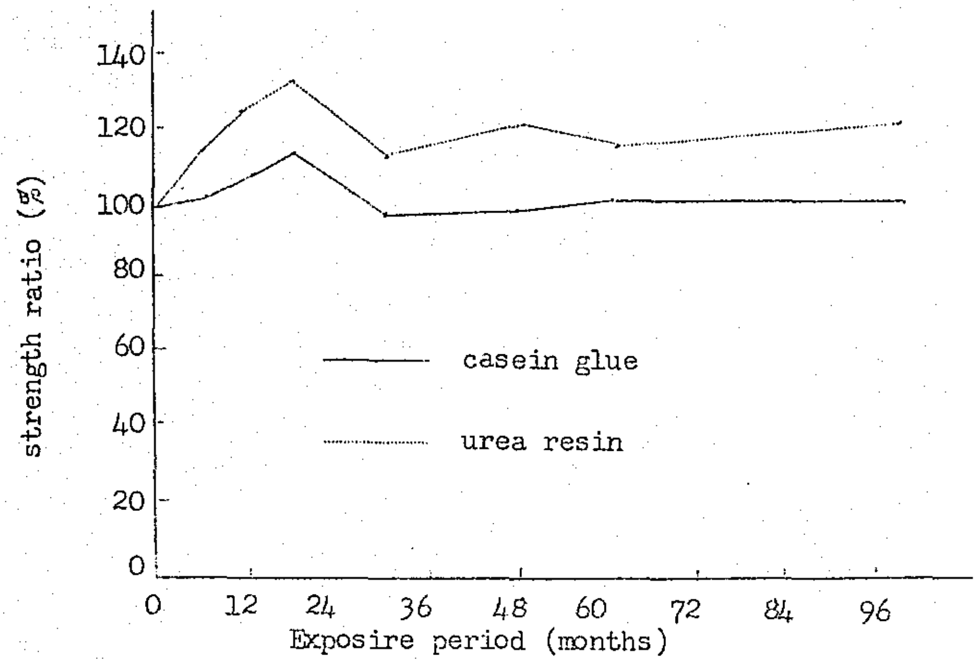


Fig. 9 Gluing durability of exposured and no painted laminated wood under eaves and without heating. (S.Yellow pine)

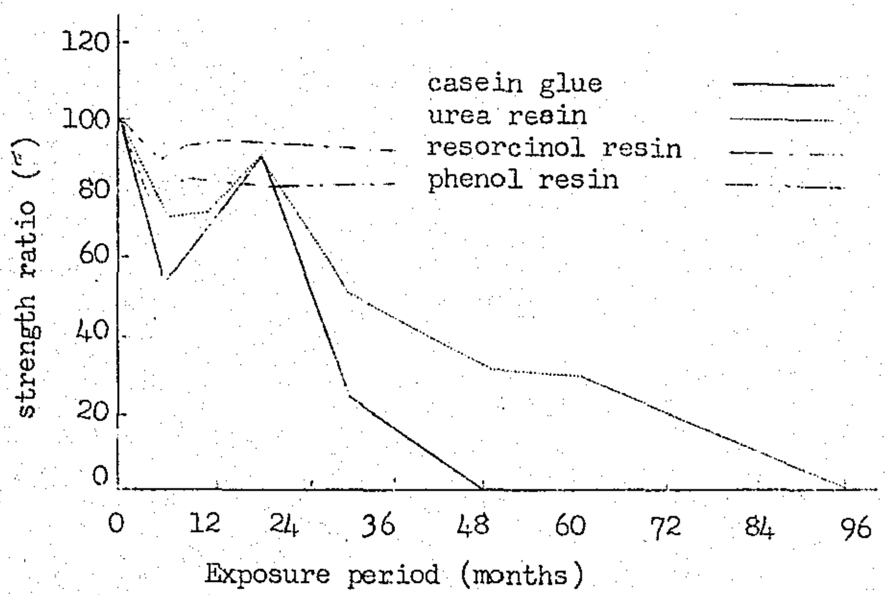


Fig. 10 Gluing durability of exposured and no painted laminated wood in the outdoor. (S.Yellow Pine)

WOOD PRESERVATION

By

SHOJI AMAMIYA

Wood Preservation

1. By what substance is the wood destructed?

Wood is mainly consisted of cellulose and lignin and other substances.

Of the above, the fact that wood keeps a given form shows various strength is due to the combination of cellulose and lignin like a building of ferro- concrete i.e., cellulose plays a role of ferro and lignin plays that of concrete and they form each cell and with orderly arrangement of these cells, they play a part of structural materials.

When wood is infested by a plant called wood destroying fungi, cellulose and lignin become a source of nutrition of these fungi and are decomposed and absorbed, and some fungi like cellulose as nutrient and others like lignin as nutrient. When wood is infested by these fungi, in the former case, wood becomes brown and in the latter case, it becomes white. In either case, because the skelton of wood is destroyed, wood is deformed and fragile and easily destroyed by touching with fingers. When wood is infected by wood destroying fungi, we call it decay. After all we can say that the cause of decay is wood destroying fungi.

In broad speaking, discoloring of wood by discoloring fungi belonging to mould can be considered as decay. In this case, when cellulose and lignin as structural substance are not decomposed, there is no remarkable change in strength but it loses beautiful looking and becomes susceptible to destroying fungi.

Destruction of wood by other than decay is by insects. They include larva of various insects which infest green wood or log soon after cutting, termites which damaged buildings and others or sea worms which affect wood ships and floating wood on the sea. Such damages can not be overlooked.

2. Where is the wood most susceptible to decay?

For explanation of this problem, if we know where the wood destroying fungin is most vigorously growing and propagating, we understand that wood placed under such condition is mostly rotten.

Since wood destroying fungi are living, it requires adequate temperature, humidity, air and nutrients for living and even if any one of them lacks, it can not live. Most fungi grow at 3 - 45°C and more or less 28°C is the best temperature for them.

The fungi grow well at over 85% of humidity and controlled at below 20 %.

Because oxygen is needed for growth of fungi, they do not grow where there is no air.

Considering the growth condition as above, summer is the best time for wood decay because humidity is high and temperature is more or less 28°C.

Consequently, those wood such as railway sleepers, tel. pole, pit props, buildings and other which touch the ground or cover water are seriously decayed from spring to autumn.

With the knowledge of growing condition of wood destroying fungi, if we give the adverse environment, wood is not destroyed. In other words, we have negative measures as to store in the high temperature or in low temperature, or to season well to 20% or less of moisture content or to store in water to suspend supply of air, i.e., timber storage in water.

In order to meet such situation, it is a principle and positive measure of anti-decay treatment to have a change in quality of source of nutrition undesirable for fungi which means to apply wood preservative.

3. How many chemicals (preservatives) are there to prevent wood decay?

The conditions which are essential to preservatives are as follows.

1) Strong resistance to fungi and insects.

2) Permeability.

3) Hard outflow.

4) Not to reduce the wood strength.

5) Not to corrode metal.

6) No harm to men and beasts.

7) No danger for fire.

8) Low price.

9) Availability and even quality.

10) Physical and chemical stability.

None of preservatives meets all of the above requirements and for some specific use, some conditions can be omitted.

Preservatives include oil preservative, oil soluble preservative, and water soluble preservative and any of them has merit and demerit and if we select preservatives according to use of timber, we can overcome demerits.

The following preservatives are being used in many countries.

Creosote

PCP (Pentachlorphenol)

Wolman salt (dinitrocresole + NaF + Na_2 Cr_2 O_7)

Cu So_4 Zn so_4

Na - PCP (Sodium - pentachlorophenol)

4. How to apply preservative?

The simple methods of preservation are painting, spraying and soaking and however these methods are temporary or partial, they are still effective in some cases to prevent decay but we can not expect full efficacy.

For the wood which requires long durable years, or is placed under disadvantageous conditions, the following treatments are recommended.

A.	Diffusion process:	To diffuse water soluble chemicals in the water of wood by means of green wood or wood with high moisture content.
B.	Hot and cold bath process:	After wood heated with solution of preservative, it is cooled and preserved.
C.	Boucherie process:	Putting solution of preservative on high place, preservative is applied by utilization of head to the green wood from the bottom to the top.

D. Pressure process:

1.	Bethel process.	Decreasing pressure + increasing pressure + decreasing pressure
2.	Lowry process.	Increasing pressure + decreasing pressure
3.	Ruping process	Air pressure + increasing pressure + decreasing pressure.

D_creasing pressure = 500 - 700 mm Hg 30 min.

Air pressure = 3 - 5 kg/cm^2 30 min.

Increasing pressure = 7 - 10 kg/cm^2 60 min.

Other process than the increasing pressure needs relatively simple facilities and the operation is easy but for the increasing pressure injection process requires various facilities as chemical application tank, pumps and boilers and installation cost is eventually high.

In order to select these processes, it is necessary to decide by the use of timber and environment, and the expected durable years.

5. How is the effect of preservative?

We can expect the extension of durable years from 1.5 to 2 times by painting, spraying and soaking of preservative and if we take other process, we can extend the durable years to large extent.

In case of the increasing pressure process, the durable years are extended greatly as follows.

Example: Railway sleepers

Species	Durable years	
	Log	Preserved wood
Miscellaneous wood	2 - 4 years	13 years
Beech	1 - 2 years	15 years
Pine	3 - 4 years	10 - 13 years

Telephone pole

Species	Durable years	
	Log	Preserved wood
Sugi	3 - 5 years	20 - 25 years

Pit props

Species	Durable years	
	Log	Preserved wood
Pine	1 year	2 - 3 years

As shown in the above, we can expect the extension of durable years at least triple or 8 times for larger wood.

For this reason, with the preservation the lesser usable wood can be utilized and unutilized wood is developed and the wood preservation helps wider use of resources. From the standpoint of economy, if we pay the cost of preservation at first, it can be paid because the durable years are greatly extended.

6. Where is the wood which has to be rotten?

Although the wood which is placed under the environment stated in 2 is to be preserved, we will show you the place where such wood is practically used.

They are railway sleeper, telephone pole, pit props, bridge timber, timber for salt sea water, wood in the ground as pile and column, building timber as foundation, bottom end of column, panel, siding, wainscot and wooden wall.

Generally speaking, wood which touches the ground, wood which is in water partly, wood in the sea or wood which is always wet and dry repeatedly are considered placed under the condition to be likely rotten and have to be preserved.

Of the above, wood which is now preserved is railway sleeper, telephone pole, a part of pit props and bridge timber and timber for salt sea water and others are preserved only by the interested but none by the uninterested.

7. Conclusion

As stated in the above, for the rationalization of timber use, extension of durable years is greatly important but in fact, we find in many cases wood unpreserved which has to be preserved from the viewpoint of the locality.

We should preserve such wood as much as possible to extend the durable years to help protection of timber resources and its conservation.

Veneer Cutting

1. Boiling (Cooking) and Steaming

The bolt from which veneer is cut is usually undertaken boiling and steaming. The purpose of this operation is to give elasticity and plasticity to get high quality veneer with lesser consuming power. For this purpose, cooking vat and steaming chamber are required. With this pre-treatment, (1) lathe check of veneer is reduced; (2) because initial moisture content and distribution of water become uniform, warping and crack at the time of drying are lessened; (3) partial hard portion of summer wood and knot are softened and cutting becomes easy; (4) easy barking; (5) dust and sand on the surface of bolt are washed out; (6) insects and eggs are killed. However the conditions of boiling and steaming have to change temperature and hours according to tree species and diameter, one example is shown in the reprint.

Practically, (1) it is desired that the difference of the temperature of wood and that of the initial treatment is less than 40 - 50°C; (2) rising speed of temperature is 10°C/hr.; (3) diameter class of bolt should be uniform; (4) because of high temperature, prevention of danger is taken into consideration. (5) caution is paid not to conduct excessive treatment. In Japan, generally this process of boiling and steaming is omitted for Lauan, Tilia japonica and Kalopanax pictum.

2. Cross - cut and Barking

Bolt is barked. The difficulty of this operation various with species, cutting time and presence of pre-treatment, and in case of small scale, barking is made by barking tool by hand. When the operation is on large scale, barking is made by a barker equipped with rotary lathe. The mechanism of this operation is shown in the picture. Lauan wood which is mostly used for plywood is peeled off already so that no barking is needed. Cross cut is to cut cross to meet the length of bolt with dimension of plywood and this operation is done by cross-cut saw and chain saw. (See Fig.)

3. Rotary lathe and rotary cutting

A roatry lathe is the most common machine for veneer cutting. This machine has two types as frame type and bed type. Its mechanism is that bolt equipped with main spindle revolves and knife carriage proceeds to a given thickness every revolution. Names of parts, major parts and their mechanism are explained in the illustration. Lathes are called according to the length of bolt to be cut as 4 - 11 ft. Recent improvement of rotary lathe is significant; (1) bolt is bound by oil pressure structure; (2) compressed air is used for adjustment of opening; (3) cutting speed is 100 ft/min. and revolution of spindle is 100 rpm for modern machine and direct current system to get stepless control is adopted; (4) for reeling of veneer, a reeling machine is being used.

The most important thing is how to adjust the relation of opening(between knife and nose bar)against the thickness of veneer. Angle of knife is also important. Relation of knife to nose-bar and names of various angles of knives are shown in the picture.

4. Half round cutting.

Because rotary cut veneer is flat grain, in order to get veneer near straight grain, half round cutting method is employed in which flitch from sawing bolt is revolved and veneer is produced with the same mechanism as rotary cut. In this cutting, the one method is to set chuck having large diameter to fix bolt at the ordinary rotary lathe to which flitch is set eccentrically to revolve and cut and the other method is to employ a stay log lathe.

The mechanism of this machine is shown in the picture. According to wood conversion, we can produce plywood of flat grain and straight grain and mixture of these grains.

5. Slicer and cutting.

Sliced veneer is manufactured by a slicer and it is cut from flitch but not from log. The type of slicer is roughly divided into vertical and horizontal. Operation starts either by knife carriage or flitch holder. In Japan the horizontal type is most common. The representative type, names of parts, and mechanism are shown in the picture. The specification of a slicer is to be referred to "Guide to woodworking machinery".

Because the objective of sliced veneer is to produce veneer for dressing, when cutting is made by method of sawing of flitch, cutting is to be done taking consideration of relation of annual ring to wood ray.

6. Grinding of knife

Knives of rotary lathe and slicer are straight on thee edge of blade and ground in a given angle. Then, in order to sharpen the edge of blade, final grinding is done by hand. Type and structure of the grinder is shown in the picture and the main parts are the grinding stone carriage which revolves grinding stone and the knife holder which a knife is set and usually when grinding, water is supplied in order to prevent over-heating. The specification of a grinder is referred to the catalogue. Final grinding is done by oil stone or water stone to grind and sharpen the blade evenly which require skill and experience.

7. Clipping.

The rotary cut veneer is cut in a given dimension and for this purpose a clipper is used. The clipper is usally operated by hand and for mass production an auto-clipper is used and optional cutting or set-cutting is done automatically. The auto-clipper is used as a series of machines from rotary lathe to reeling and unreeling.

The specification of a clipper is referred to the catalogue.

8. Quality of veneer

The quality of veneer is determined by (1) uneven thickness; (2) lathe check; (3) smoothness of cut surface. The veneer in high quality means with no uneven thickness, least lathe check and smooth surface. Uneven thickness is determined by micro-meter on several spots on fibre direction of veneer and right angle to this direction and this value determines the deviation to the required thickness. Lathe-check is determined by the method which ink is painted on the back surface and dried and then, the end surface is cut and the length of spot of ink on lathe check to the thickness of veneer in percent is expressed. Smoothness of cut surface is found to some extent by tactile sense or observation by naked eyes through incident light. For precise measurement, a rough tester is used. The most common rough tester is an apparatus which traces enlarges and records the profile curve of roughness of surface by a pointed end of a needle. Beside, a shadow tester and air micro-meter are used.

VENEER DRYING

By

T. Tsutsumoto

Veneer Drying

Veneer drying includes natural drying and kiln drying. The klin drying includes i) hot air drying, ii) hot plate drying, iii) infra-red drying. Of the above, the most common process is hot air heating, i.e., drying by means of dry kiln and drier, and others are special drying processes.

1. Drying rate

   a. Drying process curve (moisture content decrease curve); drying progress curve

      The curve which shows the process of drying veneer under a given condition, the relation between drying time and moisture content is the drying process curve (Fig. 1)

      From this curve, the drying quantity (drying progress) per unit time is calculated and shown in moisture content as Fig. 2 which is the drying progress curve.

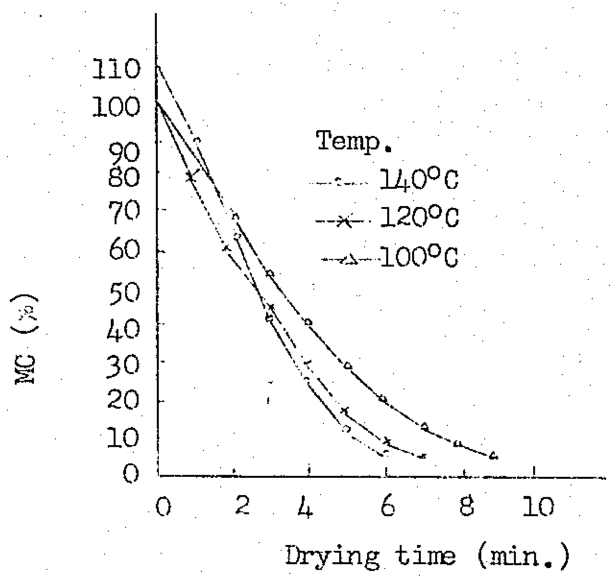


Fig. 1 Moisture content decrease curve
Beech sapwood 1 mm 20x20 cm
Air velocity 20 m/s

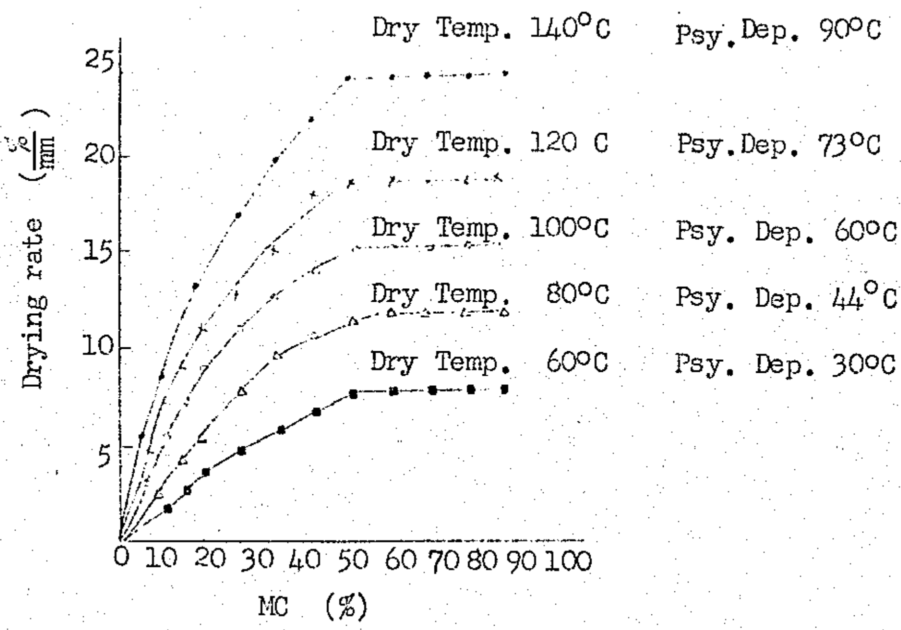


Fig. 2 Drying progress curve by drying temperature
Beech sapwood 1 mm 20 x 20 cm
Air velocity 20 m/s

b. Influence of drying condition on drying progress

i) Influence of drying temperature and humidity

A rise of drying temperature necessarily indicates physical depression (humidity lowers) and causes drying progress, particularly drying progress at high moisture content high (Fig. 2). In this case, the relation of drying temperature, physical depression and drying time is shown in Fig. 3 and the lower the temperature or the higher the initial moisture content, the more the influence of temperature is.

ii) Influence of air velocity

When air velocity increases, drying rate increases also but the lower the rate, the more the influence is and when it is over 3 - 4 m/sec, drying rate is not so high (Fig. 4)

Fig. 3 Drying temperature & drying time

Beech sapwood 1 mm
20 x 20 cm
Air velocity 20 m/s

0 60 80 100 120 140

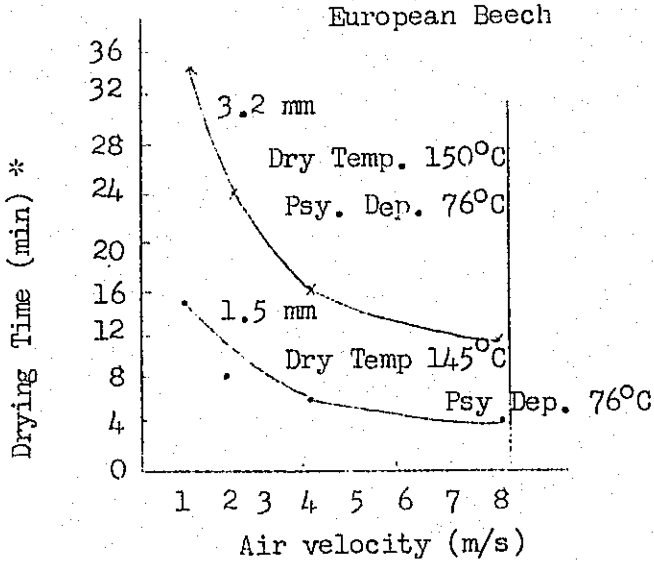
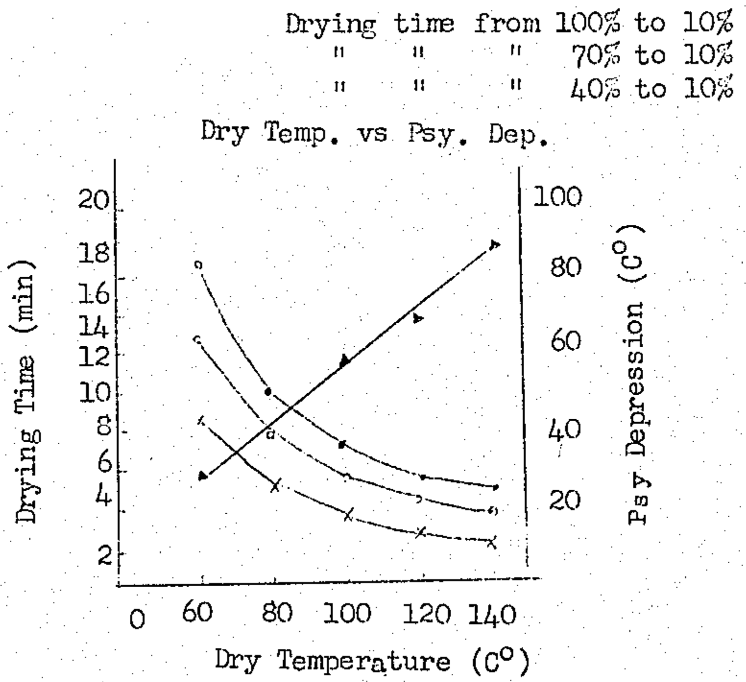


Fig. 4 Air velocity and drying time

* Time required for drying from 80% to 5 %.



c. Influence of veneer condition on drying rate

Influence of thickness on drying time is expressed in the following formula. $t = t_0 \left(\frac{s}{s_0} \right)^n$

In the formula, t is the time required for drying against s of thickness and to is the required time against s_0 of standard thickness. When s_0 becomes smaller, it goes near n=1. Drying time of beech sapwood of various thickness is shown in Fig. 5. However influence is large if width of board is less than 20 - 30 cm, but if it is over, drying time does not change significantly. It is natural that the initial moisture content if it is lower, drying time is short. (Fig. 3)

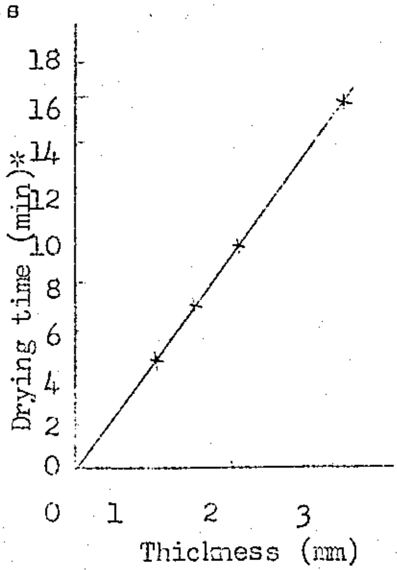


Fig. 5 Thickness and drying time

* Time required to dry from 70% to 10%

d. Irregularity of drying in direction of air flow

Even if veneer condition is uniform when the air flows in parallel with veneer surface to dry, the nearer windward, the sooner it dries and eventually that portion is inclined to shrink soon. (Fig. 6 & 7)

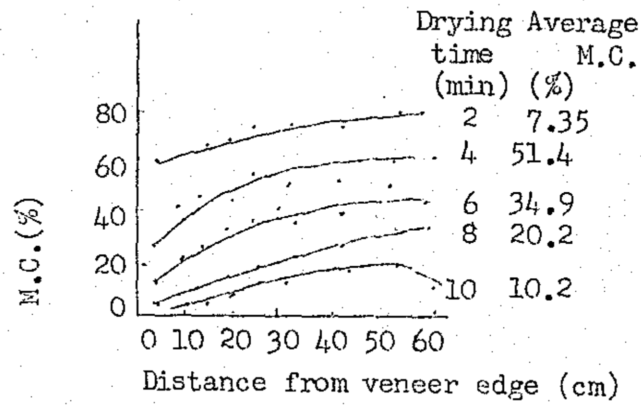


Fig. 6 Distribution of moisture content while drying

Air direction: parallel with fibre direction

Beech sapwood 1.5 mm x 20 x 60 cm
Initial moisture content 95 - 105%
Dry temperature 120°C air speed 1.8 m/s

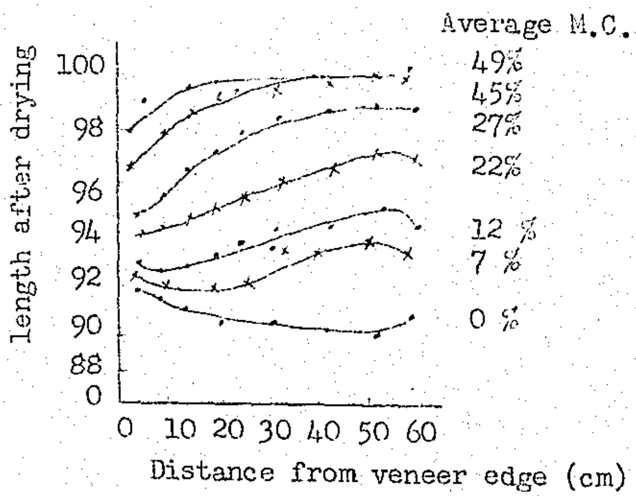


Fig. 7 Shrinkage while drying (wind direction-parallel with fibre direction)

Beech sapwood 1.5 mm 20 x 60 cm
Dry temperature 120°C Wind speed 1.8 m/s

2. Mechnical veneer dryer

a. Types of veneer dryer

Most common veneer dryer is that hot air is forcibly circulated in which veneers are sent successively to dry. Feeding process includes roller type and wire netting type. The latter type is used for drying thin veneer. When the dryer is classified by direction of hot air circulation,

Longitudinal circulation type (Coe Siempelkamp)

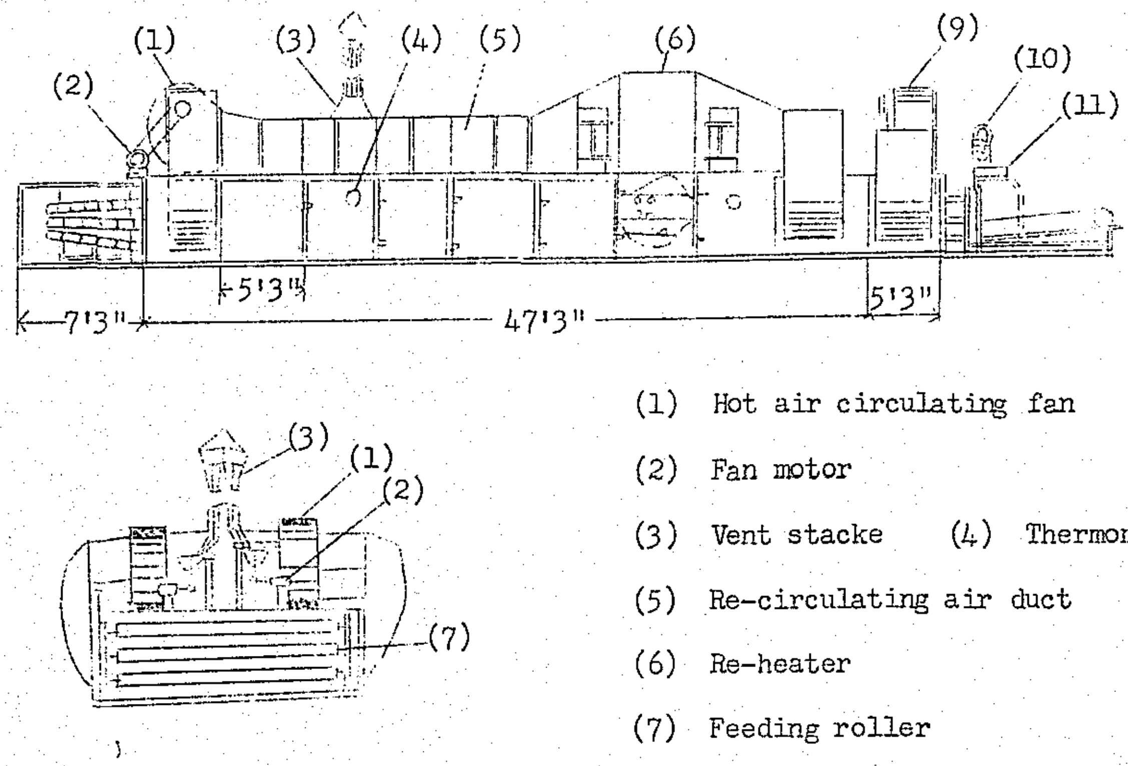
Cross circulation type:

Horizontal direction (Hildebrand Taihei S 50)

Vertical direction (Schilde Minami M M)

The dryer which is mostly used in Japan is the longitudinal circulation of Coe type which hot air circulating fan and heater are set on the top and hot air is circulated against the proceeding direction of veneer (Fig. 8).

As shown in Fig. 9, the cross circulation type dryer has hot air circulating fan and heater in each section and hot air is circulating right angle against the proceeding direction of veneer.



(1) Hot air circulating fan

(2) Fan motor

(3) Vent stacke (4) Thermometer

(5) Re-circulating air duct

(6) Re-heater

(7) Feeding roller

(8) Steam pipe (9) Cooling fan

(10) Drive motor (11) Speed meter

Fig. 8 Coe type Roller dryer

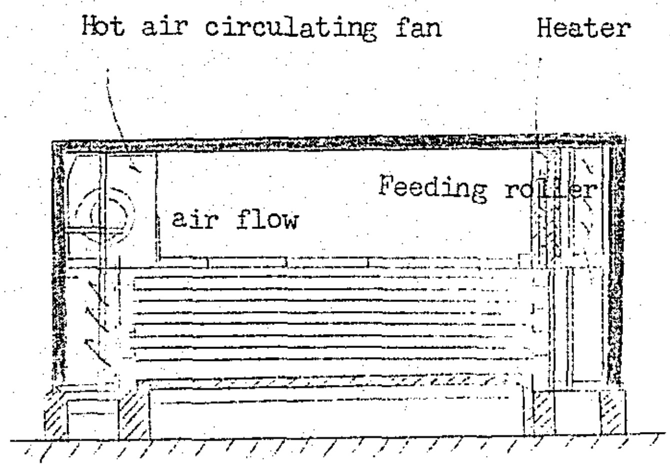


Fig. 9 Schilde type roller dryer

b. Drying time and drying quantity

The drying time by dryer varies with drying temperature and kinds of veneer and because of unevenness of initial moisture content and final moisture content, it is difficult to find it accurately. The following table shows examples of drying by various dryers. When drying time is determined, the drying quantity is determined as follows.

$$A = KWN \quad L/T \times 60$$

A = Drying quantity (ft^2 / hr) W = effective width (ft)

N = feeder L = Length of heated portion (ft)

T = Drying time (min)

K = a given figure determined by how to feed veneer

Drying time by various dryers

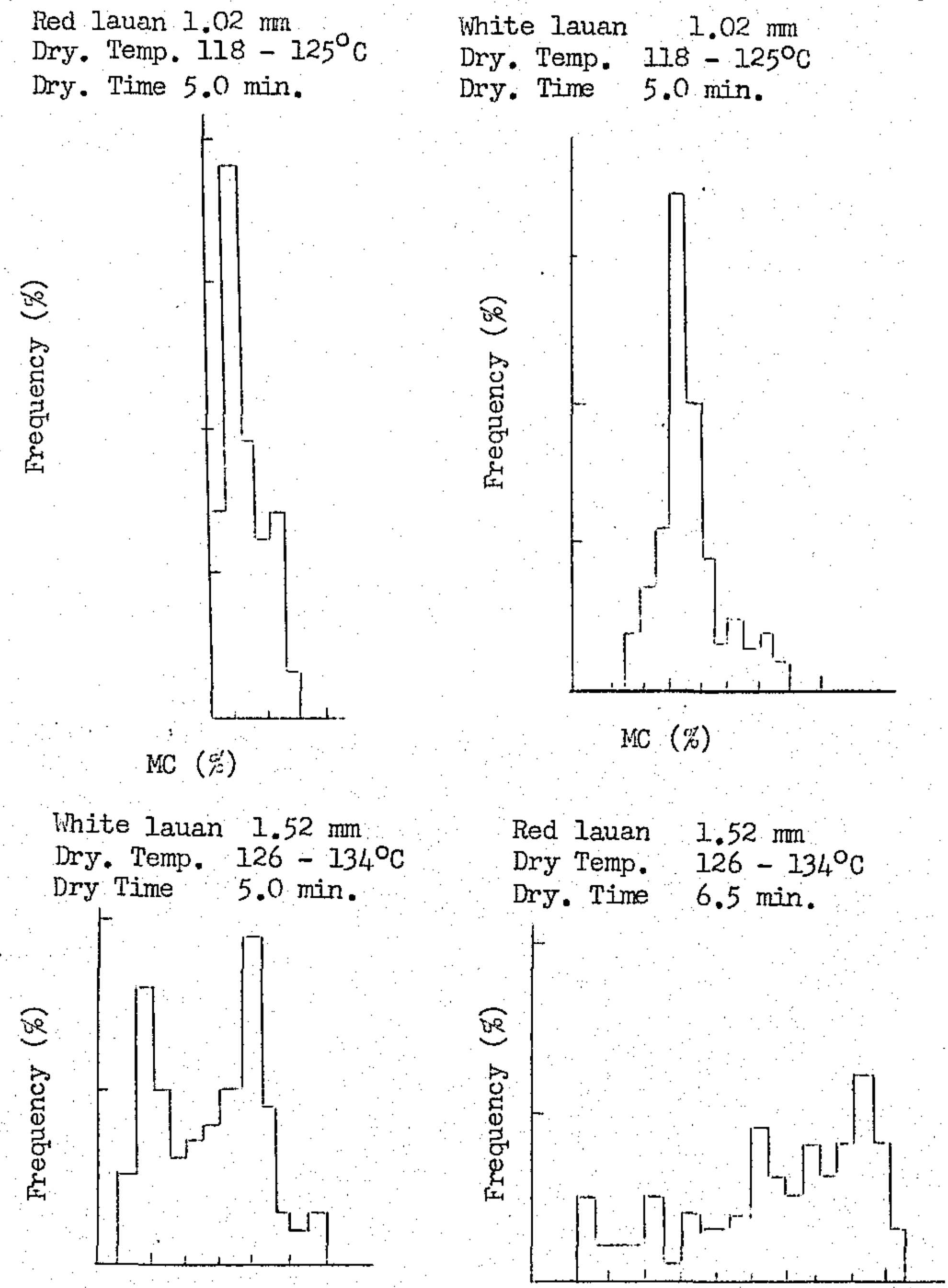
Type of dryer	Species	Thickness (mm)	MC before drying (%)	Drying time (min.)	Temp. in dryer (C)	Cond. of dampfer	M C after drying (%)
A) Coe	Red lauan	1.0	50 - 60	5.0	118 - 125	1/7	1.9
	White lauan	1.0	65 - 75	5.0	118 - 125	1/7	9.0
	"	1.5	65 - 75	6.5	126 - 134	1/7	3.4
	"	1.5	65 - 75	5.5	126 - 134	1/7	10.5
B) Coe	Sen	1.5	99	14	100	3/4	6
	"	1.5	99	16	115 - 125	3/4	1
	Kaba	1.5	74	15	115	½	3
	"	1.5	59	12.5	135 - 140	½	2
	Tamo	1.5	73	12.5	117 - 120	3/4	4
	"	1.5	73	12	120 - 123	3/4	10
C) Shilde	Red lauan	1.6	70.9	7	127 - 178	3/10	12.1
Roller	"	1.6	74.7	7	126 - 176	All open 6/10	11.3
	"	1.6	74.2	7	126 - 176	All open	9.9
D) Shilde	Red lauan	1.0	53.8	6.7	130 - 143	All close	9.9
Wire-netting	"	1.0	54.2	6.7	124 - 140	3/10	9.9
	"	1.0	55.5	6.7	119 - 136	6/10	10.4

A) 3 feeders effective width 4.6 m length of portion heated 14.5 m
B) 3 feeders " " 4.0 m " " " 14.5 m
C) 4 feeders " " 4.0 m " " " 20.0 m
D) 5 feeders " " 4.0 m " " " 19.0 m

c. Distribution of final moisture content

The moisture content of veneer after drying has much to do with warping of the product and gluing capacity and the most even moisture content is desirable but practically, unevenness to some extent in drying process can not be avoided. Examples of measurement of distribution of final moisture content are shown in Fig. 10. As a cause of such unevenness, uneven drying by locality of the dryer itself and uneven drying by mixing of veneers having specific drying property are considered. Consequently, in order to make final moisture content uniform, i) to make the temperature of dryer and air velocity even, ii) veneers are assorted as much as possible before drying according to species, sapwood and heartwood, and initial moisture content, iii) final moisture content is lowered to some extent.

Fig. 10 Distribution of final moisture content of Lauan veneer



d. Warp and split during drying

Warping of dried veneer varies with species and drying conditions and it is comparatively high for hardwood such as Buna, Sen and Tamo. This is due to unevenness of fibre direction in veneer and unevenness of moisture content during drying and when stress arising from uneven shrinkage exceeds strength of veneer, there is split. Fig. 11 shows warp of Beech veneer dried by roller dryer expressed in height pressed with a given load. As to the position of veneer, warp at the end is usually significantly larger than that at the center and the same with split. Such end waving and split are mostly brought about because the end par is dried earlier than the inside of veneer and some of such troubles can be prevented by following methods.

i) When drying, ends are overlapped. Table 2 (end waving)

ii) Before drying, kraft paper and S S tape are covered. Table 3 (end waving and end split)

iii) End is sewed by machine. Table 3 (end split)

Table 2 Quantity of end waving of Yellow Birch

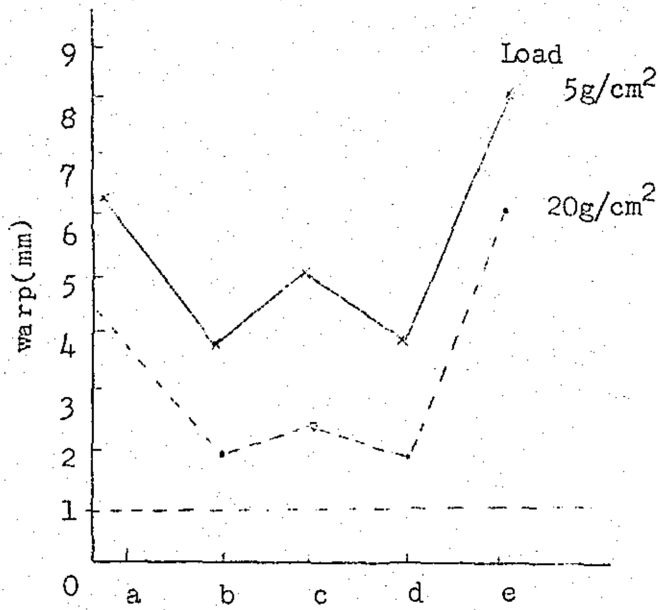
Quantity of lapping end	2 hr after drying	After humidity adjusted up to 8%
in	in	in
Open the end 1 - 2	0.16	0.28
Lap the end $\frac{1}{4}$	0.02	0.10
$\frac{1}{2}$	0.3	0.09
3/4	0.04	0.10

Mean height when load of 2 lb is applied.

Veneer condition: Yellow birch thickness 1/8" width 29"

Drying temperature = 163°C Drying time 20 min.

Final moisture content 2 %



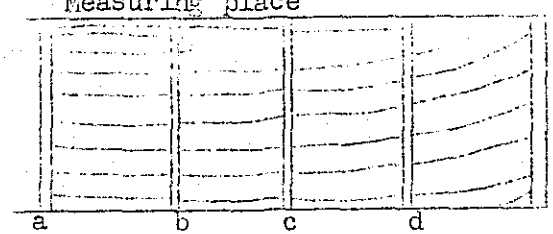


Fig. 11 Quantity of Veneer

Veneer condition: Beech sap and heart wood mixed 1mm

Drying condition: Coe type dryer
Temp. 118°C - 128°C
Drying time 7.6 min.
Final moisture content 5 - 10 %

Table 3 Lauan Veneer and face check of Veneer

1) Check after drying

Newly broken out check

Treatment	2 - 6 cm	6 - 10 cm	10 - 14 cm	14 - 18 cm	18 - cm	Total Number	Total Length
Non treatment	74	17	2	6	2	101	634
S S Tape	41	7	1	1	0	47	258
Veneer machine	34	73	16	4	0	127	1045

Check existed before drying

Treatment		2 - 6 cm	6 - 10 cm	10 - 14 cm	14 - 18 cm	18 - 22 cm	22 - 26 cm	26 - 30 cm	30- 34 cm	34 - cm	Total Number	Total Length cm	Extension total length cm
Non-treatment	Before drying	171	44	12	13	7	6	0	2	0	255	1785	
	After drying	155	51	14	15	7	7	3	3	0	"	1950	165
S S Tape	Before drying	62	53	21	15	4	1	2	0	1	159	1437	
	After drying	59	53	23	14	5	2	2	0	1	"	1469	32
Veneer machine	Before drying	57	55	19	16	10	1	3	1	0	162	1606	
	After Drying	48	54	25	16	10	4	2	2	1	"	1759	153

Remark: Total of 40 sheets of each group
Veneer condition: Tangile thickness 1 mm Width 84 cm
Drying condition: Coe type Dryer Temperature (put in) 128°C
(put out) 132°C
Damper 1/7 open
Drying time 4.5 min. Final moisture content 5 - 10 %

2) Check and overlap after cold press

Treatment		- 10 cm	10 - 14 cm	14 - 18 cm	18 - 22 cm	22 - 26 cm	26 - 30cm	30 - 34 cm	34 - cm	Total number	Total length cm	Total Width mm
Non-treatment	Check	11	7	9	6	2	1	1	0	37 (58)	540 (792)	63 (101)
	Overlap	14	3	3	0	1	0	0	0	21	252	38
S S Tape	Check	2	7	4	2	0	1	0	0	16 (29)	248 (381)	36 (60)
	Overlap	9	2	1	0	1	0	0	0	13	133	24
Veneer machine	Check	9	7	4	6	0	0	0	0	26 (32)	357 (426)	38 (49)
	Overlap	2	2	2	0	0	2	0	0	6	69	10

3. Special drying

a. Hot plate drying

The operation to dry green veneer (mainly core veneer) by hot plate is:

i) Drying by opening and closing the hot plate at an interval of a given times. (Interrupting drying)

ii) Drying with press all the time.

In either case, if the temperature of hot plate is over 120°C, the drying is more greatly reduced than hot air drying of the same temperature and the higher the temperature, the greater the difference is. Shrinkage and warping when dried with pressure all the time are shown in Fig. 4 and shrinkage percentage of width direction is low comparing with those dried with dryer and flat veneer is obtained and on the contrary, shrinkage of thickness direction is high and check is easily broken out. Final moisture content unless dried up to 0 - 5 % of mean moisture content can not be uniform.

Table 4 Shrinkage and split of veneer dried by hot plate

Drying method	Thickness mm	Temp. °C	Press kg/cm^2	Shrinkage Width	Shrinkage Thickness	Split & warp
Hot press	3.0	125	2.5	1.94	10.47	Many and small splits evenly distributed
"	"	"	5	1.91	12.97	"
"	3.0+3.0	"	2.5	2.22	10.30	"
Dryer	3.0	"	-	10.33	5.46	No split, large warp especially end waving is significant.

Hot press for plywood is used

Veneer Beech(sapwood) size 3 x 3 feet
Initial moisture content 70 - 80 %
Final moisture content 0 - 2 %

b. High frequency wave drying

A high frequency wave drying method is applied for drying of sliced veneer. This is the drying which sliced veneers are piled and pressed from the above to dry and few warping is found in dried veneer and it is convinient to make grains uniform.

c. Infra-red drying

Although application of infra-red to veneer drying is still in experimental stage, the features of this method are as follows.

1) No need to dry air as medium

2) Easy operation and sanitary.

3) Light weight and movable.

4) Comparatively less expensive installation.

On the other hand, consumption of electricity is high and cost of drying is relatively high.

Drying time by infra- red and consumption of electricity are shown in Table 5 and this method is applicable to simple druing of very thin veneer.

ADHESIVES IN THE WOODWORKING INDUSTRY

By

Yasuo Matsumoto

9. Adhesives in the wood-working industry By Yasuo Matsumoto

9.1. Adhesives in common use.[1] (See Table 1 & 2)

(1) Natural materials

a. Animal glues

Animal glues have the distinction of being the oldest adhesives employed for bonding wood, and evidence is available that they were used over 3,000 years ago.

There are several grades of animal glue depending on the source of raw material and processing conditions, but those obtained from hides are usually employed for bonding wood, preparation of the adhesive consists of soaking the dry glue, which is supplied in cake, powder or flake form, in water, during which time a gel is formed. This gel is melted preferably at a temperature of 50 - 60°C before application, and maintained at this temperature during use. Setting of these adhesives after application consists initially of "gelation" on cooling, and finally of loss of water due to evaporation or migration into the wood pores.

The set glue can be softened by water or by the application of heat, and this property can be utilized where it may be necessary to re-open a joint.

(b) Casein glues

Casein glues are prepared by dissolving casein in water containing lime and other alkaline agents. For convenience, the adhesives are often supplied as powders already containing the lime, and require only the addition of water before use. Casien glues have a limited pot life ranging from approximately one hour to one day, and and setting of the adhesives results from chemical reaction between the casein and the alkali and loss of water into the wood pores.

These adhesives are usually employed for cold press work and are reputed to be less sensitive to temperature variation than other glues.

(c) Albumin glues

These adhesives are usually supplied in powder form. They are similar to casein glues in that they are set under alkaline conditions, but are normally employed under hot pressing conditions. They are still used extensively in the Baltic States and other countries for the manufacture of plywood, and have received attention in America as extenders for phenolic adhesives.

(2) Synthetic adhesives

(a) Urea-formaldehyde adhesives

These resins are supplied as viscous syrups in the form of dispersions or solutions in water or as spray-dried powders which, after reconstitution with water, may be used in the same manner as the syrups. (The urea resins have also been supplied as glue films but have a limited use due to their poor storage stability.)

Urea-formaldehyde resins can be set at temperatures ranging from approximately 15-100°C by the incorporation of a suitable "acid-producing hardener," and by suitable formulation hardeners are available which will result in a large range of pot lives and setting times.

The main disadvantage of urea-formadehyde adhesives is their poor "gap filling" properties as thick films will craze and cause reduction in bound strength. Methods of overcoming this defect which have been proposed include the addition of approximately 10-20 % of suitable fillers to the resin and at the same time modi-- fying with benzyl alcohol or the use of formic and as a hardener in conjunction with a filler.

(b) "Extended" urea-formaldehyde adhesives

One of the advantages of urea-formaldehyde adhesives is that they can be cheapened by the addition of fillers such as china clay, walnut shell and coconut shell flour and starch. Addition of fillers increases the viscosity of the resin, enabling additions of water to be made so that the final glue cost is appliciably reduced. The increase in viscosity may also be utilized technically in order to prevent excessive penetration of the adhesive into the wood.

(c) Fortified urea-formaldehyde adhesives

Improvement in the water resistance of urea-formaldehyde resins is made possible by the addition of melamine or phenols or resins made from the latter materials and formaldehyde. Such modifications are usually carried out by adding the modifying agents to the resin, together with the acidic hardener. The most commonly used modifying agent is melamine and the resultant adhesive can only be used at elevated temperatures - usually at 95 - 100°C.

(d) Phenol-formaldehyde adhesives

There are four main types of phenol-formaldehyde adhesives :-

(i) Hydrophobic resins to which acid hardeners are added to effect setting at room temperature. Such adhesives can also be used at elevated temperatures provided that suitable fillers are incorporated to prevent penetration which can result in a starved glue line.

(ii) Hydrophilic resins usually supplied as aqueous solutions containing a high proportion of alkaline catalyst. These adhesives can only be used at elevated temperatures.

(iii) Powders which are usually obtained by spray during the hydrophilic resins. These are dissolved in water before use and are again employed at elevated temperature.

(iv) Glue films which comprise tissue paper impregnated with the hydrophilic resin.

Rolls of such material only require cutting to size before use and are set at elevated temperature.

(e) Resorcinol-formaldehyde adhesives

These adhesives are supplied in liquid form and consist of resorcinol novolacs which are set by the addition of further formaldehyde added as a hardener. Their main advantages are their ability to set under neutral to slightly alkaline conditions which may be desirable in certain applications and their improved storage stability compared with the phenol-formaldehyde resins. They have not been used extensively in this country, probably due to their high cost.

(f) Miscallaneous adhesives

The adhesives which have been discussed are those which are mainly used for bonding wood, but as materials other than wood itself are employed in the industry, adhesives, in addition to those previously described, have been utilized for special applications. Many of the adhesives which are recommended consist of mixtures of rigid and flexible materials. The rigid component is usually a phenolic resin, and the flexible component a poly-meric material such as polyvinyl formal[4] or natural or synthetic rubber. Most of these are set under hot conditions, but some can be employed at room temperature.

Casein-rubber latex adhesives are also employed bonding non-porous surfaces to wood and these can be set at room temperature.

Table 1

Table 2

9.2. Setting of adhesives and hardner (See Table 1 & 2)

(1) By loss of water only. (Starch glue, polyvinyl-acetate resin emulsion.)

(2) By loss of water accompanied by some chemical change. (Casein and vegetable proteins.)

(3) By a change from liquid to solid on cooling accompanied sometimes by loss of water or solvent. (Animal glues and some thermo-plastic adhesives.)

(4) By the action of heat at a particular temperature. (Blood albumin.)

(5) By chemical reaction at normal or elevated temperature (Thermo-setting synthetic resins.)

A hardener (or catalyst) is a reagent that accelerates a chemical reaction, with or without heat. In the case of resinous adhesives, it accelerates setting or hardening.

9.3. Extenders or fillers

Extenders and fillers are additional ingredients incorporated in liquid resin mixtures for one or more of several reasons. In general, fillers are inert (for example, walnut shell flour) and extenders usually exhibit minor adhesive qualities (for example, wheat flour or dried blood). Examples of such combinations are as follows:

In the case of urea resins, large ratios of wheat, rye or tapioca flour may be added for the primary purpose of cost reduction.

Walnut shell flour may be added in limitted quantities either phenolic or urea resins to add to the bulk or body of the mixture, as a filler, for purpose of regulating flow characteristics.

The use of fillers up to 10% of the dry resin (by weight) will show very little reduction in durability, but will gine more reliable and uniform results.

9.4. Durability of adhesives (See Table 1 and Fig. 1)

(1) Weather-proof adhesives. (Examples: Phenolic,

resorcinol and possible melamine resins.)

(2) Moisture-resistant -- mould-proof. (Examples: Normal and fortified urea resins. Heavily extended phenolic glues.)

(3) Moisture-resistant -- mould-susceptible. (Examples: Casein, soya, blood, heavily extended urea resins.)

(4) Interior adhesives. (Examples: Animal, starch, polyvinylacetate resin emulsion.)

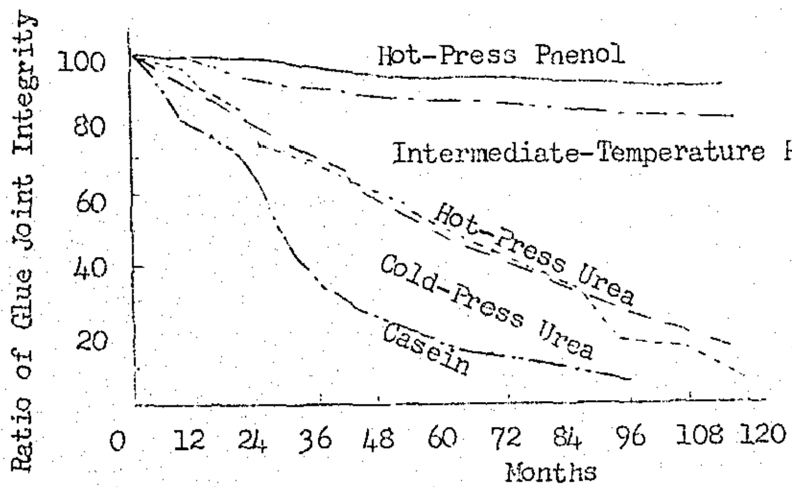


Fig. 1 Relative durability of glued joints in unprotected plywood panels subjected to weathering (madison)[4]

9.5. Japanese Industrial Standards of Synthetic resin adhesives for wood.

As Table 3.

9.6 Types of the adhesion strength test piece (see Fig. 2)

(1) D.V.L. Tension type adhesion strength test piece

(2) Lapjoint tension type adhesion strength test piece

(3) Abrasion type adhesion strength test piece

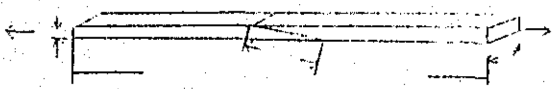
(4) F.P.L. shear type adhesion strength test piece

(5) Tension type adhesion strength test piece

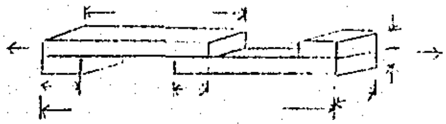
(6) Adhesion strength test piece by the bending strength

(7) Adhesion strength test piece of plywood

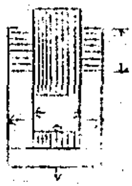
1. D.V.L. tension type adhesion strength test piece



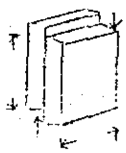
2. Lap joint type adhesion strength test piece



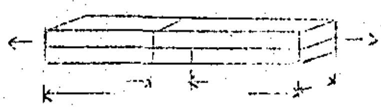
3. Abrasion type adhesion strength test piece



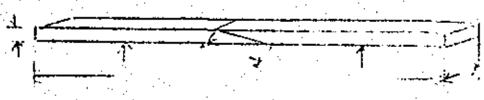
4. F.P.L. shear-type adhesion strength test piece



5. Tension type adhesion strength test piece

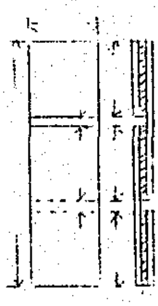


6. Adhesion strength test piece by the bending strength



7. Adhesion strength test piece of plywood

A



B

Fig. 2 Types of the adhesion strength test piece

9.7. Some mixing for mulas of adhesives and their adhesion strength.

As Table 2.

9.8. Experimental work

Testing of a urea resin adhesive in accordance with Japanese Industrial Standard (JIS K6801).

Reference

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Table 1. Summary of the Properties and Applications of Wood Adhesives [1), 2)]

Adhesives	Natural materials		
	Animal 1	Casein (Prepared) 2	albumin 3
Form usually supplied to user.	Powder or flake.	Powder.	Powder.
Storage life (month)	-	-	-
Preparation before use.	Soaked in cold water followed by warming.	Mixed with cold water.	Mixed with cold water.
Method of setting	Gelation and loss of water.	Chemical reaction with alkali and loss of water.	Coagulates and Chemical reaction with loss of water.
Pot life.	Extended if preserved but necessary to maintain temperature preferably at 50 - 60°C.	1 hour to 1 day.	Several hours to several days.
Pressing Temperature and time.	Room temperature 12 - 24 hours.	Room Temperature 1 - 24 hours.	100 - 120°C 5 - 10 minutes.
Resistance rating. Water	P	F - M	F - M
Weather	P	P	P - F
Fungus	P	P	P
Heat	P	M	F - M
Principal Uses.	Veneering and joinery.	Joinery, assembly and some plywood.	Plywood.
Special features.	Joint may be re-opened. Little tendency to cause splitting of decorative veneers. Good tack.	Setting less critical to temperature Variation as compared with other adhesives. Joint-if not stressed regain strength after immersion in water.	Cheap plywood adhesive with moderate durability and water resistance.

* E: Excellent, G: Good, M: Moderate, F: Fair, P: Poor

Synthetic adhesives				
Thermo - setting resins				
Urea formaldehyde 4	Extended urea formaldelyde 5	Melanine fortified urea formaldelyde 6	Melamine - urea formaldelyde 7	Acid setting 8
Liquid or spray-dried powder	As Col. 4.	As Col. 4, the melamine being supplied in a powder hardener	As Col. 4,	Liquid.
V: 6 - 8 S: 3 - 4	As Col. 4.	As Col. 4.	W: 4 - 8 S: 2 - 4	W: 4 - 5 S: 1 - 2
Powder: Dissolved in water and hardener added. Liquid: Hardener added.	Extender and water (if necessary) added to resin followed by herdener.	As Col. 4	As Col. 4.	Addition of hardener.
Acid hardening accelerated by temperature rise.	As Col. 4.	Acid hardening at elevated temperature.	As Col. 6.	As Col. 4.
Less than 1 hour to 1 day.	Several hours to 1 day, depending on degree of extention.	As Col. 4.	As Col. 4.	1 to several hours.
20-25°C 12-24 hr. 30-60°C 10-40 min. 80-100°C 5-10 min.	As Col. 4.	90 - 100°C 5 - 10 min.	60-80°C 3-10 min 90-110°C 3- 6 min	20-60°C $\frac{1}{2}$ -12 hr. 60-110°C $\frac{1}{4}$ -2 hr.
E F - M E M - G	G - F F - P E - F M - G	E G E E	E G E E	E E E E
Most applications.	Veneering and plywood.	Veneering and plywood.	Veneering and plywood.	Constructional work and joinery.
Versatility. Ease of handling. Ideally suited for modern practice, involving strip, and R.F. heating.	Cheap adhesive for veneering and plywood.	Superior water-resistance to natural and urea formaldehyde resins.	good hot water resistance.	Excellent gap filling properties and weather resistance. Can be used with strip and R.F. heating.

			Thermo-plastic resin
Phenol formaldehyde Alkali seting		Resorcinol formaldehyde	Polyvinyl acetate
Liquid 9	Film 10	11	
Liquid or spray dried powder.	Rolls of impregnated paper.	Liquid with hardener containing formaldehyde	Emulsion.
As Col. 8.	As Col. 8	10	12 - 24
Powder dissolved in water: addition of small quantity of filler to liquid may be necessary.	Cutting to size.	Addition of hardener	If necessary, slightly diluted with water
Heat hardening under alkaline conditions.	As Col. 9.	Chemical reaction between fomaldehyde and resin accelerated by temperature rise.	Loss of water.
Usually about 1 day due to loss of water on glue spreader.	Equivalent to storage life.	1 to several hours.	Equivalent to storage life.
130 - 150°C 5 - 60 minutes.	130 - 150°C 5 - 60 minutes.	25 - 40°C 10 - 12 hr. 40 - 60°C 3 - 4 hr.	Room temperature 12 - 24 hours.
E E E E	E E E E	E E E E	F - M P - M E P
Plywood.	Plywood.	Constructional work.	Veneering and joinery. (Sometimes mixed with urea resin.
Excellent plywood.	Exdellent plywood. No pot life considerations.	Setting under approximately neutral conditions. (no heating)	Ease of handling. Flow at elevated temperature. Piles retain flexibility.

Table 2. Some mixing formulas of adhesives and their adhesion strength[3)]

Kinds of adhesives	Soy - bean glue	Milk casein	Extended urea formaldehyde resin	Urea formaldehyde resin	Room temperature setting phenol formaldehyde resin	High temperature setting phenol formaldehyde resin
Formula	Soy-bean flour 360g Sodium silicate 50g water 900 - 1000g	Milk casein 300g Sodium hydroxide 25g Carcium hydroxide 45g water 900 - 1000g	Urea resin 400g wheat flour or Soy-beam flour 150g water 250g 10% NH_4Cl aq. soln. (hardener) 40g	Urea resin 800g wheat flour 50g water 100g 10% NH_4Cl aq.soln. (hardener) 40g	Phenolic resin 800g Hardener (β- naphthalene-sulfonic acid or β- benzene-sulfonic acid 50% soln.) 80g	Phenolic resin 800g
Plywood adhesion strength (kg/in^2) birch	70 - 90	100 - 140	80 - 110	110 - 140	110 - 130	110 - 130
oak	50 - 70	80 - 120	80 - 100	100 - 140	100 - 130	110 - 130
Shina (linden)	40 - 50	60 - 80	60 - 75	70 - 90	60 - 80	60 - 80
lauan	50 - 60	60 - 80	60 - 80	70 - 90	70 - 90	70 - 90
Water resistance	Poor	Fair	Moderate	Good	Excellent	Excellent
Mixing Temperature (°C)	20 - 25	20 - 25	15 - 25	5 - 70	10 - 30	-
Mixing Time (min)	20 - 30	20 - 30	30 - 30	5 - 10	5	-
Pot life (hour)	2 - 3	2 - 3	2 or less	2 or less	1 or less	Unrestricted

Table 3. Japanese Industrial Standards of Synthetic resin adhesives for wood

Standard NO		JIS K6801	JIS K6802			Summary of test methods	
Terms of testing \ Kinds of Adhesives		Urea resin adhesives (with hardener)	Phenolic resin adhesives 1 Room temperature setting (with hardener)	2 High temperature setting	3 High temperature setting (resin impregnated Paper)		
Viscosity (Poise)		150 or less	150 or less	150 or less	-	Lawaczeck viscometer, at 20 ± 0.5 C°	
Gelation time (hour)		1 - 5	2 - 7	-	-	Gelation time after mixing the resins and hardeners in accordance with instructions of the manufacturer followed by keeping 20 ± 0.2°C	
Storage test (hour)		20 or more	20 or more	20 or more		Gelation time when kept 70 ± 2°C (urea resins) or 80 ± 2°C (phenolic resins).	
Adhesion Strength (kg/cm^2)	Normal	60 or more	80 or more	80 or more	80 or more	Birch D.V.L. tension type test piece. Pressing presume: 10 - 15kg/cm²	3 or more test specimens for each tests
	After soaking in water	45 or more	-	-	-	50 ± 1°C water, 8 hours and cold water, 10 minutes.	
	After boiling	-	50 or more	50 or more	50 or more	100 C water, 3 hours and cold water, 30 minutes.	
Crack test		-	Pass	-	-	Adhesive, which is mixed with hardner, spread on a dried birch wood, cuyed for 48 hours at 25 ± 2°C and thickness of 2 ± 0.5mm, is heated for 1 hour at 60 ± 2°C, soaked in 20 ± 5°C water for 5 hours, boiled for 1 hour and then dried for 17 hours at 10 - 30°C, at that time, the resin should not have any cracks.	

STRUCTURE OF WOOD

By

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1. Structure of Wood

1-1 The growth of the tree

It is very important for understanding the properties of wood to know its structure which is far different from that of any other material, like a piece of iron, which appears to be practically homogenous under the microscope. A piece of wood appears as network with openings of various shapes and sizes.

The end grain of a piece of wood under the microscope shows various openings which are the cavities of the different types of cells which are formed during the growth of the tree. Each type of cell has its own particular function in the growing tree.

Before entering to study the details of the structure, it will be helpful to know the outline of various parts of a tree and how it grows.

In the center of the end grain of wood is the pith which shows rather distinct contour and around it is the wood of which inner part is heart-wood and of which outer part is sap-wood. And outer most part is the bark.

Moreover, in both sap-wood and heart-wood there are layers which are called growth rings.

Between the outermost part of the sap-wood and the bark is a very thin layer, not visible to n.e., called the cambium layer.

These various layers above mentioned have their own significance. It is very interesting to know their origin and their functions in their living condition.

a) Growth in height

The increase in the height of tree is originated by the division of numerous special cells which are very active at the top of the tree. These special cells which give riseto growth in height are thin walled, and, in themselves, do not produce woody tissue. When the tree is young, vertical growth is rapid but in accordance with its maturity the growth slows down considerably and may be considered to cease comparatively early in the life history of the tree.

As shown in Photo., under the growing point are cells which have definitely changed. Some cells on the outerpart go to form cambium layer which conducts very important roll in the growth of trees.

b) Growth in girth

Corresponding to the growth in height, growth in girth is originated by the division and the growth of the cells of the cambium layer which can not be observed by nacked eyes. The cells which are member of cambium layer are very thin walled. These cells are found between bark and wood and cover all round the tree cone except tip. The photo. shows how these cells transist as time goes on.

The cambium layer produces outerportion of wood inside of it and innerportion of bark inside of it.

As time goes on, the stem gradually increases in thickness by the addition of new wood cells on the outside of those already formed. The cambium layer functions in the laying down of both the wood and the bark on the stem and branches.

In conclusion it is to note that growth in height occurs only at the growing tip by the division and growth of the special cells located there, while growth in girth is the special function of the cambium layer.

Neither the wood cells, laid down on the inside, nor the bark cells laid down on the outside of the cambium layer, influence growth in height.

1-2 Outline of wood structure

(a) Structure of Soft Wood

Tracheids

a. Tracheid length

Its variation in regard to pulp quality
Sanio's law

b. Thickness and cell lumen

Ray

a. Cross field pitting

Piceoid
Taxodioid
Cupressoid
Pinoid
Window like

b. With or without ray tracheid

Parenchyma

a. Resin cells and its arrangement

b. Idio blast

Resin canal

a. Vertical

Normal and traumatic canal and their arrangement

b. Horizontal

Normal and traumatic canal
Ephiceliusm cell, it's number per-canal,
thickness of wall.

(b) Structure of hard wood

Vessel

1. Arrangement on the end grain surface
2. Size, thickness, shape
3. Perforation. Pitting. Tyloses.

Tracheid

1. Distribution
2. Shape and size

Libriform wood fiber

1. Length and it's relation to pulp quality.
2. Thickness and lumen
3. Transisional form from tracheid

Parenchyma

1. Distribution, its Type
2. Crystalliferous cells

Roy

1. Type
2. Volume percentage with regards to physical properties. (Shrinkage)
3. Crystalliferous cells

Miscellaneous

1. Oil cells
2. Horizontal and Vertical resin canal, Normal and traumatic.

1-3 Identification of wood

In this Forest Experiment Station, the work to arrange card sorting key for providing simple means for identification of timber in this country is almost completed.

Diagnostic features taken by authers are as follows. (Table I, II)

Table I.

List of features of sorting card for Softwood

General

1. Heartwood and softwood indistinguishable
2. Heartwood distinctively colored
3. Boundary of heartwood and sapwood clear
4. Growth rings comparatively indistinct
5. Late wood conspicuous
6. Odor pronounced
7. Taste
8. Lustre pronounced
9. Greasy to the touch
10.
11. Comparatively heavy and hard
12. Comparatively light and soft

Tracheids

13. Bordered pits alternate
14. Bordered pits multiseriate, opposit
15. Margin of tori scalloped
16. Border with thickenings
17. Lenticularaperature frequently present in early wood
18. Spiral thickenings present in earlywood

19.

20. Intercellular spaces conspicuous

21. Crystal present

Resin canol

22. Normal, mostly solitary

23. Normal, solitary or 2 - several continuous

24. Traumatic, vertical or horizontal

25. Normal, horizontal

26. Epithelial cells thick walled

27. Number of epithelial cells per canal mostly 5 - 6

28. Number of epithelial cells per canal mostly 7 - 12

Parenchyma

29. Present

30. Abundant

31. Transverse walls nodular

32. Crystalliferous idoblast

33. Tangential arrangement

34. Zonate

36. Terminal arrangement

37. Evenly diffused all over the ring

Cross field pitting

38. 1 - 3, simple or nearly so.

39. Piceoid

40. Cupressoid

41. Taxodioid

42. 1 - 6 pinoid

Rays

43. Ray tracheid

44. Ray tracheid dentate

45. Ray tracheid with spirals

46. Horizontal walls thin

47. Horizontal walls unpitted

48. strongly pitted

49. Indenture

50. End walls nodular

51. Crystalliferous cells

52. Sciadopity type cells

53. Cells approximately iso-diametric

54. Cells elongated

55. Cells angulated

56. Less than 15 cells high

57. Sometimes more than 30 cells

58. Biseriate rays comparatively abundant

59. Cells with dark content

Color reaction

60. Flavone

61. Fluorescence

62.

63.

Family

64. Ginkgaaceae

65. Taxaceae

66. Podocarpaceae

67. Araucariaceae

68. Cephalotaxaceae

69. Pinaceae

70. Taxodiaceae

71. Cupressaceae

Locality of native wood

72. Hokkaido

73. Honshu

74. Shikoku

75. Kyusyu

76.

Locality of foreign wood

77. North America

78. South America

79. Australia, New Zealand

80. Filippines, Indonesia

81. Formosa, China

82. Korea, Manchuria

83. Sakhalin etc

84. Europe etc

85 - 92 Characteristics for utilization

93 - 100 Mechanical properties

101 - 116 Use

Table II

List of features of sorting card for Hardwood

General

1. Distinct color
2. Whitish
3. Brown
4. Yellowish
5. Red, Pink tint, Red Brown
6. Other colors
7. Streaky
8.
9. Distinct odor
10. Growth ring
11. Whitish zone in growth ring boundary
12. Whitish zone (except (11))
13. Waxy

Soft tissue

14. Distinct (to n.e.)
15. Absent
16. Associated with pones
17. Surrounding pores
18. Predominantly independent of pores
19. Diffuse

20. Banded, Fine lines

21. Brood conspicuous bands

22. In regularly spaced bands

23. In irregularly spaced bands

24. Winglike, Confluent

25. Reticurate

26. Terminal

27. Crystals

28. Pores

29. Absent

30. Very small, invisible (to n.e.)

31. Small

32. Medium

33. Large

34. Very large

35. Few

36. Moderately numerous

37. Numerous

38.

39. Tyloses

40. Deposits

41. Diffuse porous

42. In chain

43. Flamelike arrangement

44. Tangential arrangement

45. Ring porous

46. Pore zone uniseriate

47. Pore zone multiseriate

48. Diffuse except pore zone

49. Radial or flamelike except pore zone

50. Tangential, wavy oblique except pore zone

51. Predominantly solitary

52. Radial multiples 4

53. Radial multiples 5

54. Clusters

55. Simple perforations

56. Multiple perforations

57. Spirals common

58. Spirals only in small vessels

59. Scalariform pits

60. Numerous small pits

61.

62.

Rays

63. Conspicuous luster

64. Barly visible with lens

65. Fine

66. Medium

67. Broad & Conspicuous

68. < 1mm in height

69. 1 - 2 mm height

70. > 2 mm height

71. Teterogenous I

72. " II

73. " III

74. Homogenous

75. Uniseriate Heterogenous

76. " Homogenous

77. Aggregate

78. 1 - 2 or 2 cells wide

79. 2 Distinct widths

80. > 5 cells wide

81. > 10 cells wide

82. Crystals

83.

84. Horizontal canals

85. Storied

86.

Other features

87. Vessel-ray pits small, medium, opposite alternate

88. Vessel-ray pits scalariform

89. Vessel-ray pits palisade-like

90.

91. Vertical canals

92. Vertical canals concentric

93. Traumatic vertical canals

94. Secretary cells

95. Included phloem

96. Pipple mark

97.

98.

99.

100.

101.

102.

Fibers

103. Spirals common

104. Storied

105. Septate

106. Bordered pits

107.

Weight

108. Light

109. Moderate

110. Heavy

111 - 118 Locality

1-4. Fine structure of wood by H. Harada

1. Submicroscopic structure of cell wall.

The physical and mechanical properties of wood, which bring many influences on wood technological methods, result from the chemical components and the structure of wood, especially the cell wall structure of it. The study on the cell wall structure of wood gives us the basic knowledge on which the immense field of wood technology is based.

In the past thirty years, a large amount of structural and microchemical work has been carried out on softwood tracheds, in part, because of their technological importance, but also because in many ways they provide material particulary suitable for the study of the plant cell wall.

In this short paper, the present state of investigations, into some aspects of the structure of tracheids is discussed.

1.1 Wall and layer

Each cell is separated from neighbouring cells by an isotropic "cementing" layer of intercellular substance, the intercellular layer. The cell wall of the mature tracheids consist of the following two structure: that is the primary wall and the secondary wall. The primary wall is the envelope initially surrounding the cell following cell division. The secondary wall which is formed subsequently consists of three layers - on outer layer S_1, a middle layer S_2, and an inner layer S_3, which are distinguishable of the difference in their optical properties (Fig. 1).

And this difference of the cell wall layers was recognized more clearly by the electronmicrograph of thin section (Fig. 2).

1.2 Microfibril and micell

Qualitatively the primary wall and the secondary wall of the mature tracheids and fibres are similar in composition each consisting of cellulose, lignin and noncellulosic polysacharides. Cellulose forms the structural frame work material whereas lignin and noncellulosic substances constitute the encrusting substances.

The state of aggregation of cellulose, the frame work component of the cell wall, differs considerably from that of the encrusting constituents. X-ray methods have shown the existence of crystalline units, termed micells, which measured 50 - 70 A in width and at least 600A in length. On the other hand, some workers have shown that cellulose molecules are extremely long, much longer than the crystalline regions revealed by X-rays.

To complicate the matter further, the advent of electron microscopy and its application to cell wall studies revealed the presence of well defined units called microfibrils which in different cellulosic materials average approximately 200A in breadth and about 100 A in thickness (Fig. 3). These microfibrils are of indefinite length and apparently somewhat rectangular in cross section. This led to the suggestion by Frey-Wyssling that a microfibril with a cross section of 100 x 200 A consisted of four so-called elementary fibrils with a diameter of about 50 x 100 A each containing a crystalline core surrounded by a paracrystalline sheath, the crystalline core being about 600A in length (the micells) separated from each other by regions of lower order of crystallinity. Between microfibrils are occupied by the encrusting substances.

1.3 Microfibrillar orientation

As shown above, the basic structural element of the cell wall is the microfibril. It could be resolved by the use of electron microscopy.

<u>The primary wall</u>: The primary wall is a thin layer, generally a few layers of microfibrils thick, more lignified than the secondary wall, but less than the inter

cellular layer. The primary wall is formed during cell division at the cambium. Typically, the primary wall has a woven or net-like structure which lacks the distinct orientation found in the secondary wall layers (Fig. 4).

The secondary wall: The outermost layer of the secondary wall, the S_1 is a relatively thin layer. It is composed of a few lamellae in which the microfibrils are arranged completely and oriented in a flat helix at an angle of about 70 - 90 degrees to the axis of the cell. This was the orientation through to be most probable from polanigation microscopy studies. The middle layer, the S_2, is the thickest layer and forms the major portion of the cell wall. Many properties of a given wood can, undoubtedly, be related to the organization and characteristics of this layer. The microfibrils of the S_2, exhibit greater parallelism than the S_1 or S_3. The orientation of the microfibrils in this layer is in the form of a steep helix, nearly parallel to the longitudinal axis of the cell, usally is an angle of about 20 degrees in earlywood 5 - 10 degrees in latewood (Fig. 5). There is lamellation in the S_2 also, and each lamella has about the same thickness.

The innermost layer of the secondary wall is designated as the S_3 layer. It forms the lining of the cell lumen when a warty membrane is absent. The S_3 is a very thin, loose-textured layer of microfibrils. As in the S_1, the microfibrils usually follow a flat helical pattern, forming a large angle to the tracheid axis (Fig. 6). It is generally about 70 - 90 degrees, but much variation can be found in different species. Parallelism within the layer is low as microfibrils, singly or in small bundles. Because there is apparently less lignin in this layer, it is easier to observe this condition in a natural state than is possible in the S_1 or S_2.

The wart structure: The tracheids of many softwood have the inner surface of the cell wall covered with a so-called wart structure. This structure appears to consist of warts and amorphous material. Though it develops during the death of the protoplasm, it is to be regarded as a real part of the cell wall(Fig. 7). This structure is also shown on the border of the pit. The presence of the wart structure in softwood tracheids has been found to be one of the features about every individual genus except Pinus genus. So the presence of the wart structure in softwood tracheids have a role for the identification of softwoods. For instance the genus such as *Ginkgo*, *Arancaria*, *Agathis*, *Sciadopitys*, *Cryptomeria*, *Cunninghamia*, *Taxodium*, *Sequoia*, *Chamaecyparis*, *Thuja*, *Thujopsis*, *Juniperus*, *Cupressus*, *Abies*, *Tsuga*, *Cedrus*, and *Diploxylon Subgenus* of *Pinus*, have the wart structure, but *Taxus*, *Torreya*, *Cephalotaxus*, *Podocarpus*, *Pseudotsuga*, *Picea*, *Larix*, *Psendolarix* and *Haploxylon subgenus of Pinus* have not the wart structure.

1.4 Distribution of chemical components.

As is well-known from numerous analyses, the cellulose fraction of softwood tracheids constitutes 50 - 60% of the dry weight of the cell wall. The lignin fraction is 20 - 30% of it. The distribution of these constituents in the cell wall has been studied by the methods such as microchemistry and ultra-violet absorption measurements. It has been shown that the cellulose content increases from the primary wall towards the cell lumen, and that the lignin content which is greatest in the primary wall decreases towards the cell lumen.

2. Structure of pit

It is well known that the pits in different woods show considerable variation in size, shape and distribution, and that these features have been useful for the identification of species with the light microscope. In spite of of these variations, electron micrographs have shown that there exists a striking similarity in the fine structures of the pits. However, two distinct classifications of bordered pits can be made, those found in softwoods, and those which are typical of hardwood species.

2.1. Pits of softwood

A pit is a recess in the secondary wall of a cell, together with its external membrane. The pit membrane is composed of the protions of the primary wall of adjoining cells and the intercellar layer between them. There is a central thickening called torus and the closing membrane. The perforated membrane which surrounds the torus is made up of microfibrils arranged in a radial pattern from the central thickening outwards (Fig. 8). The real openings in the membrane vary in size, but there are often openings of 0.1 - 0.2 permitting water to moue freely from one tracheid to the adjoining one. When wood is dried, aspiration of softwood pit membranes frequently takes place and the torus covers the pit aperture, thus effectively blocking the movement of free liquids.

2.2 Pit of hardwood

In the case of hardwood, the electron micrograph has shown that this simple membrane resembles the primary wall in microfibrillar organization. No opening, resolvable with the electron microscope, have been found in hardwood pit membrane (Fig. 9). Water movement between cells separated by such membranes occurs only through the mechanism of diffusion. The pits which connect parenchyma cells, and those which are found between parenchyma and vascular elements, have simple imperforated membranes which resemble the bordered pit membranes of hardwoods.

3. Experimental work of electron microscope.

Theoretically, the electron microscope could provide one hundred times better solution and at least one hundred times greater magnification than the light microscope. As will be pointed out in later discussion, electron microscopy is limited by the physical design of the instrument as well as by the preparation methods which must be followed before a specimen can be viewed.

In light microscope the critical factor is the wave length of the illumination being used. The electron microscope uses radiation of extremely short wave length, such that 20 Angstrom unit resolution can be achieved as compared with 2000 Angstrom units with a good light microscope.

One of the most serious limitations to be faced in using the electron microscope is that the specimen must be placed in vacuum. Another factor that can be viewed. It varies with different instruments, but an area fifty by fifty microns is an average figure. A third critical limitation is the thickness of the specimen. While wood section for light microscope are seldom less than ten microns, but for electron microscope they should be less than 0.1 micron.

Preparation

(1) Sectioning method: One way of producing thin specimens is through the use of ultra-microtomy, a technique commonly employed in biological and medical research. Very briefly, small piece of wood is a plastic material such as methyl-methacrylate and normal Buthyl-methacrylate which becomes quite hard upon polimerization. The sample in the matrix is mounted in one of a number of Ultra microtomes designed for cutting thin sections. Glass or diamond knives are generally employed in preparing the ultra-thin sections.

(2) Disintegration method: Another approach to the

preparation of suitable specimens has been mechanical disintegration in a homogenizer or blender. The isolated tissure is processed in a liquid medium, small fragments are collected on specimen grids to be dried, and then the specimens are shadowed with a heavy metal to improve contrast in the electron microscope. Suitably thin material has been prepared and valuable information obtained through the use of this technique.

(3) Replica method: Replica techniques have been shown to be more practical and have been more widely used for investigating wood. This method involves the production a facsimili of the surface of the sample which is more stable than wood in the electron beam. The facsimili is covered with a very thin layer of evaporated material, such as carbon or Alminum, shadowed at a small angle with a heavy metal such as Cromium or platinum to enhence contrast.