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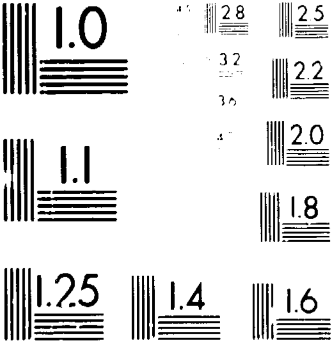
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DP/ID/SER.A/534
17 August 1984
English

13947

RESEARCH AND DEVELOPMENT FOR THE UTILIZATION OF
RUBBERWOOD AND COCONUT WOOD

DP/SRL/79/053

SRI LANKA

Technical report: Manufacture of glued laminated timber*

Prepared for the Government of Sri Lanka
by the United Nations Industrial Development Organization,
acting as executing agency for the United Nations Development Programme

Based on the work of C. R. Francis, Timber Engineer

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Vienna

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V.84-89251

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1. INTRODUCTION

Glulam, the common contraction for "glued laminated timber" is manufactured in many countries in large quantities. There are many variations possible in all stages of manufacture, but the process consists essentially of glueing several boards together face to face to make a large piece of timber.

The act of laminating changes the properties of the timber in various ways, all of them beneficial. A piece of glulam is therefore a different article from a piece of wood of the same species, with different properties and end uses. Some of these are now briefly considered.

Size

The most obvious difference, and perhaps the most important is the ability for glulam to be made in large sizes. Lengths over 30 m, depths of 2 m and widths of 0.5 m are not uncommon. Now that the virgin forests of the world are rapidly becoming cut out this ability to manufacture in large dimensions becomes increasingly important to the glulam industry.

Shape

The bulk of glulam is manufactured in straight rectangular sections. However, thin boards can be bent to quite sharp curves without breaking and glulam may be produced in a variety of curved shapes for use as arches, ship stems, etc., all with the grain in the length of the member. The only alternatives are naturally grown knees for boats, hewn out of suitably shaped branches or steamed shapes as used in bentwood furniture. Both these are severely limited in size.

Most timber is produced in rectangular sections, and any other shape involves cutting wood to waste. Glulam may be produced in I or T sections without waste, the section being built up of boards of the appropriate widths. One such large volume product is tongued and grooved decking made from three equal width boards glued together, with the middle board offset.

Strength

Sawn timber contains defects, particularly knots and sloping grain which reduce its strength. Very rarely can large sizes be found which are completely free of defects. The result of laminating a large piece from a number of small pieces is that a major defect in any one piece is unlikely to be adjacent to a defect in another piece. Still less likely is that three major defects should be adjacent. As a result, the strength of glulam approaches the strength of defect free timber, or its "basic strength" in structural design terminology.

Stiffness

For the same reason as described above, stiffness of glulam is equal to that of defect free timber. A practical consideration is that lamination must be dried to quite low moisture contents for satisfactory glueing. Consequently glulam is not subject to the excessive creep exhibited by green timber, nor is it necessary to wait the very long times (which in large sections could be over one year) for equivalent sized sawn sections to dry.

In the majority of timber structures, stiffness is a limiting consideration rather than strength, and this property of glulam is most significant.

Preservation

Glulam may be pressure treated with creosote after fabrication, but current practice in many countries is to treat the individual laminations with waterborne salts by diffusion or pressure impregnation before laminating. The depth which a preservative will penetrate is limited to a very few centimeters and it is very difficult to completely impregnate timber much thicker than 5 cm. A glulam member which is composed of laminations treated before fabrication will, therefore, be completely impregnated. It may be sawn, drilled, etc., on site without any fear of exposing untreated wood to fungus or insect attack.

Dryness

As explained above under "Stiffness", glulam is uniformly dry throughout its cross section. Consequently glulam is free of the shrinkage, warping and splitting which would inevitably occur should equivalent sized sawn timber be used.

When large section timbers are dried, stresses are developed in the wood. If such a large timber is subsequently sawn along its length the release of the internal stresses will cause the timber to curve both lengthwise and crosswise. Glulam may be resawn with impunity.

Cost

Glulam is more expensive than sawn timber. A rough guide is twice the price of sawn timber presented to the same degree of processing (dried, treated, planed) for straight members and three or four times as expensive for curved members - which are practically unobtainable in sawn timber. On the other hand, glulam is manufactured to order, in length as well as cross section. The 15% to 20% waste factor normally allowed for sawn timber is thus eliminated. Also, much expensive work, and extra dimensions and components required for joining sawn timber to long lengths are eliminated. In place, in large structures glulam compares more than favourably with sawn timber. If this were not the case, it would not be so widely used in countries which are well supplied with sawn timber.

A more interesting comparison is with the cost of alternative materials: structural steel or reinforced concrete. A recent cost comparison for a large 4,000 m^2 four storey office building, complete, was:

Reinforced concrete	-	NZ $ 628 per m^2
Glulam	-	NZ $ 578 per m^2*

Construction

Quoting from reference* the architect stated: "Added to this, the construction period for the building in 50 working weeks compared to a predicted construction period in reinforced concrete construction of around 80 weeks".

The site foreman for the Carter Holt building referred to in the same article was experienced in reinforced concrete high-rise buildings. He stated to the expert that he was amazed at the simplicity and speed of construction and the cleanliness of the building site, when compared with reinforced concrete construction.

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*Huskin, Phillip: "Heavy timber construction making a come back". New Zealand Engineering, Vol. 37, No. 7, Aug. 1982.

However there is a price to be paid for this speed. As with any prefabricated construction, architects must learn to detail and dimension completely and accurately, to an extent not commonly done in masonry construction. To hide behind the instruction "Contractor to check all dimensions on site" is irresponsible when site and factory may be separated by hundreds of miles, and orders for components placed weeks or months before delivery.

2. WOOD PREPARATION

The expert once asked an elderly glulam factory foreman what were the essentials for making good glulam. The reply was:

"You must have the wood dry and flat.
You must put the hardener in the glue.
You must clamp up tightly.
All the rest is easy."

This chapter covers the first essential.

To obtain good bonds, wood must be below a moisture content (M.C.) of about 18% preferably below 15%. In humid climates this will require the use of heated drying kilns. Kiln drying is not covered in this report. The actual moisture content to be aimed at depends on the equilibrium moisture content (E.M.C.) of the location in which the Glulam is to be used.

Wood exhibits a degree of hysteresis in reaching equilibrium with constant temperature and relative humidity conditions, depending on whether it is becoming dryer or wetter as it approaches the equilibrium. Wood which is drying down to an E.M.C. of say 15% will remain at about 16.5% whereas wood increasing in M.C. will reach about 13.5%. These figures are only indicative and the exact differences depend on various factors.

Different pieces of timber respond to drying differently, also there are always slight variations in drying conditions even in the same kiln or timber stack. Consequently there will always be slight variations in M.C. between pieces in a single kiln charge or air drying stack. If good practice has been followed these variations will seldom exceed about 3% M.C. between the wettest and dryest pieces unless wood containing incipient decay is present.

Since it is necessary to ensure that all wood is dryer than 18% the maximum average M.C. to be aimed at will be (18-3/2)% or 16.5%. In practice an average slightly dryer than this should be aimed at, unless a very much lower E.M.C. will exist for the wood in service, in which case it should be dried to within about 2% of E.M.C.

Dry wood is stiffer and stronger than wet wood, and also has to absorb more water to reach the M.C.s at which insect or fungus attack can commence. Because of the hysteresis effect described above, it is better to dry to about 2% dryer than E.M.C. than 2% wetter (assuming that the latter figure is less than 16.5%). Either end of the range will minimise shrinking and swelling with seasonal E.M.C. variations but the lower figure will result in a superior product.

For exterior structures such as bridges, power pylons etc. the E.M.C. will probably be around 20% and the preceeding recommendations will not apply. They are important considerations for interior structures particularly where the glulam will be exposed to view.

If two pieces of timber of very different moisture contents are glued together and then brought to E.M.C. severe shear stresses will be developed in the plane of the glueline perpendicular to the grain direction. These stresses increase with increasing width of timber and may easily exceed the shear strength of the wood. In such a case cracks will appear at the glueline. (Note that such cracks are not bond failure, and can be distinguished from bond failure by the step which occurs at the crack). Shear stresses will also be developed parallel to the grain. In themselves these cannot cause failure, but in a member subjected to heavy external shear stress they may contribute to failure if acting in the wrong sense.

In order to limit the development of shear stresses arising from this cause, the M.C.s of individual laminations in a single member should all be close to the same value, with a permissible range of about 3%.

Measurement of Moisture Content

It will be apparent from the preceeding section that knowledge of the M.C. of numerous pieces of timber is required in glulam manufacture. The ideal method of determining this is with a resistance type moisture meter. This instrument is rugged and quick to use, and also determines M.C. at some depth below the surface. The type with electrodes formed on the head of a hammer is most convenient.

Resistance moisture meters are subject to various errors, arising from temperature, wood species and presence of treatment salts. Most models offer a degree of correction. Calibration on new species of wood by testing a piece of wood with the meter and determining its M.C. by the oven drying method is recommended. The ability of a resistance moisture meter to measure quickly and consistently far outweighs any criticism of its lack of accuracy in extreme conditions.

Other methods of determining wood moisture content include radio-frequency power loss meters and oven drying. R.F. power loss meters are also small and portable but are more a surface M.C. instrument. Field repair is not possible.

Oven drying consists of:

1. Weighing a sample of the wood
2. Drying the sample at 102°C to 105°C to constant weight
3. Cooling the sample in a dessicator
4. Reweighing
5. Calculation of M.C. from $M.C. = \frac{\text{Wet wt.} - \text{dry wt.}}{\text{dry wt.}} \times \frac{100}{1}$

This procedure is time consuming. However, if the heating is done in a domestic type microwave oven and a direct reading balance is used, step (3) can be omitted and the whole determination can be completed in less than 5 minutes. However, microwave ovens and direct reading balances are expensive and not portable.

Preservation

Preservation against insect, fungus or mollusc attack may be an essential part of the preparation of wood for glulam manufacture. In general for the reasons described in the introduction preservation before laminating is preferred. It must therefore be completed before drying.

Wood preservation is a complex process in its own right and will not be covered further in this report.

Planing

Planing performs several important functions in the preparation of timber for laminating. It provides smooth flat clear surfaces which are essential for good glue bonds. It shows up undersize timber caused by variations in sawing. It permits much more accurate grading than can be performed on sawn timber.

A preliminary rough planing operation known as "blanking" 1/ is frequently necessary. Blanking is required:

- Before pressure treatment. It effectively increases penetration in oversize wood and limits the volume of treated shavings to be disposed of

- Before defecting, in order to assist grading and to show up undersized wood

- Before fingerjointing to provide accurate working surfaces.

Blanking also makes the final surfacing easier since only light cuts are required. Irregularities due to oversized wood jamming in the planer and resulting scorch marks from feed rolls are eliminated

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1/ Also known as "regularizing" and "hit or miss" planing.

Blanking is only a preliminary sizing operation and the quality of surface produced is immaterial. Feed speeds may be as high as desired and there is no limitation on the spacing of knife marks. Light skips are acceptable on blanked surfaces provided that they are not so deep that they will not be removed in final surfacing.

Surfacing should be done immediately before gluing, with a maximum time interval of 24 hours.

Minimum delays between surfacing and laminating are specially important when treated timber is used. After quite short periods treatment salts may efflorsce on the surface of the wood. The salts may be invisible but still sufficient to prevent a satisfactory bond being formed.

In untreated wood the principal hazard is dust which can prevent satisfactory bonding.

The quality of surfacing is important. Except for minor local occurrences, gluing surfaces should be free of raised grain, torn grain, skips, burns, glazing or other deviations from the plane of the surface that might interfere with the contact of sound wood fibre in mating surfaces of the laminations.

Variations in thickness across the width or along the length of any piece should not exceed plus or minus 0.008 in. (0.2 mm) and cup should not exceed 1/32 in. for each inch (0.3 mm per cm) of width for timber nominal 1 inch (25 mm) and less in thickness and should not exceed 1/64 in. for each inch (0.15 mm per cm) of width for timber over 1 in. (25 mm) in thickness. In no event should cup and warp exceed that which can be straightened out by pressure applied during gluing.

The feed speed of the machine should be set to give not less than 20 knife marks per inch. The depth of cut on each face should not be more than 1/16 in. (1.5 mm) but should be sufficient to give a definite cut, avoiding any polishing or glazing which would result from the knives rubbing the surface.

Maintenance of these standards of precision requires the use of thickness "go" and "no-go" gauges. These can be cut from bandsaw steel and precision ground in a universal tool grinder. A suitable form is shown in Figure 1 (see page 37).

Machines

The best type of machine for blanking and surfacing is a medium to high speed five head planer. This type of machine can produce accurately blanked timber at high production rates. The arrangement of the feed rolls well in advance of the cutter heads avoids the possibility of cup resulting from cupped boards being flattened by the feed rolls, as can happen in a short bed thicknesser.

When surfacing blanked timber only the top and first bottom head need to be used. This assumes that end joints are accurately aligned.

Before surfacing operations commence, freshly sharpened knives should be fitted and carefully jointed.

A machine with 12" x 4" throat capacity will cope with almost all requirements.

The layout of the infeed and outfeed areas of the machine should be carefully planned taking into account the length of fingerjointed stock which may be fed through it. Suitable tables and skids to handle the very long lengths will be required.

3. DEFECTING, FINGERJOINTING

Timber received at a glulam plant will require upgrading by the removal of defects and the ends require to be accurately squared. A cross cut saw will be required for this work. This should be equipped with roller benches on both sides and an accurately aligned fence.

For high production rates the most suitable type of saw is a rising spindle machine with top and side clamps. This should cycle automatically from a foot or knee switch. With suitable handling and waste disposal this type of saw is capable of very high production rates but its degree of versatility is limited.

Slower in use but more flexible is a radial arm saw or the very similar pendulum horizontal saw. These machines have a larger cutting capacity and can also cut at an angle. A radial arm saw may therefore be used for other purposes such as finishing small glulam components, as well as defecting.

A means of end jointing timber is essential. It is not possible on a commercial scale to glue end grain to carry any tensile stress. It is possible to make glulam with butt joints. This weakens the resulting member in excess of the unjointed area. Also it is very difficult to lay up a member using random length butt jointing.

The first end joints used in glulam were scarfs. These require a very flat slope, from 1 in 8 to 1 in 12 to develop appreciable strength. Scarfs are difficult to machine and hold in alignment while the glue cures and are very wasteful of timber. A wastage of 15% to 20% in timber will be experienced if scarf joints are used.

Modern glulam practice is to use fingerjoints exclusively. The trend has been to use smaller and smaller fingers. The length has appeared to have stabilised at a minimum of 10 mm. Shorter fingerjoints are manufactured, as short as 4 mm. However, these exhibit lower strengths than 10 mm or longer joints. This appears to be due to the fingers being shorter than the wood fibres.

Fingerjoints may be cut parallel to the wide faces of the boards - "horizontal" joints, or perpendicular - "vertical". Horizontal joints are easier to cut and glue and machines for making them are cheaper and simpler than machines for making vertical joints. Also, fewer cutters are used.

Vertical joints exhibit strength advantages over horizontal joints, particularly in thin boards. They are also easier to align so that the faces on either side of the joint are level.

Fingerjoints receive the pressure necessary for good bonding from the wedging action of the fingers being pushed together. Very high end pressures are required for good bonding and the splitting action of the fingers wedging open the opposite groove is high. The outermost few grooves in fact do split slightly and little lateral pressure is developed. These zones of low lateral pressure are not strongly bonded. In a horizontal joint these zones of weakness constitute a higher proportion of the cross section of the timber than in a vertical joint.

The expert considers that 10 mm vertical fingerjoints are most suitable for glulam manufacture, followed by 10 mm horizontal joints. These joints regularly develop 65% of the clear strength of the wood in tension. With care in machining, glueing and clamping, strengths of 80% are regularly achieved. These values are ample for glulam manufacture.

Fingerjointing machines will work on sawn or planed timber. Planing permits examination of the ends for defects such as small knots, splits and sloping grain. Planed surfaces also allow the timber to be more precisely aligned and clamped in the machine.

After glueing and clamping, fingerjoints must be left undistrubed until the glue has cured. This will take several hours, depending on temperatures and the glue used. One of the advantages of the mini-fingerjoint is the very high wet strength which is developed from the high end pressures used in clamping. This makes mini joints less sensitive to rough handling after glueing than other longer types. All the same, freshly fingerjointed timber must be handled carefully and provision made for gently moving and storing uncured stacks.

There will be some squeeze out of glue at each joint. To avoid packets of fingerjointed timber sticking together, layers of boards in a packet should be separated by fillets. Fillets made of reinforcing steel are best as these do not stick as wooden ones do. Wooden fillets may be machined to an X or H section to provide minimum contact area and dipped in water repellent solution to prevent sticking.

Fingerjointing presses and outfeed conveyors quickly become covered in glue. To minimise the problem of glue build up these areas must be cleaned regularly and should be kept liberally coated with an anti-seizing agent. Wax is good but needs to be melted on. Reject peanut oil has been found satisfactory. Silicones are not recommended. They are so effective that traces carried over to other parts of the factory can seriously affect bonding in the lamination process.

Fingerjointed timber will have glue smears and slight misalignments at the joints and needs to be replaned before laminating. Even if alignment is perfect, synthetic resins do not bond well to themselves and consequently the smears must be planed off.

One manufacturer produces a line of fingerjointing machinery in which the planing is done immediately after clamping. This does not damage the joints. However experience with a similar operation was that the planer became covered with glue and proved a very difficult machine to clean. For this reason the expert does not recommend this practice.

Besides permitting elimination of strength-reducing defects through defecting, fingerjointing allows the reduction of crook and bow. Crooked boards may be sawn through in the centre, then both ends so formed should be re-squared. A single cut like this will reduce crook by a factor of four.

Twist is not reduced to any extent by fingerjointing.

4. GLUE SELECTION, MIXING AND APPLICATION

Only a few types of glue are suitable for glulam. Many types of glue are unsuitable for various reasons. PVA ("White") woodworking glue is subject to creep under sustained loads, as are epoxies. Gelatine glues are insufficiently durable.

Consideration in choosing a glue should include:

- Cost
- Storage life
- Ease of use
- Durability

Casein Glue

Casein was the first glue used for glulam and is still used to a limited extent. It is interesting that casein glued joints made by the ancient Egyptians thousands of years ago have been preserved in serviceable condition.

Casein is relatively cheap, easy to use and has a good storage life when kept dry and cool. It is not durable except under dry moderately cool conditions and is not suitable for use in humid climates or where it is exposed to the weather.

Synthetic resin glues

The synthetic resin glues used in glulam are all compounds of formaldehyde.

They are:

- Urea formaldehyde (UF)
- Melamine formaldehyde (MF)
- Phenol formaldehyde (PF)
- Resorcinol formaldehyde (RF)
- Tannin formaldehyde (TF)

Combinations of these are also available, e.g:

- Melamine - urea formaldehyde (MUF)
- Phenol-resorcinol formaldehyde (PRF)

Synthetic resin glues are usually supplied in two components, the liquid resin and a powder (sometimes liquid) hardener. UF resin may be supplied as a powder to mix with water. Their setting reaction starts when the resin and hardener are mixed. This reaction is accelerated by high temperatures and slowed or stopped by low temperatures. It may be desirable to chill the resin to give a conveniently long working time, then heat the glued up assembly to hasten its curing. Storage life of the unmixed components will also be shorter at high temperatures and longer at low temperature.

Because of the variety of formulations and degrees of reaction available from manufacturers, it is not possible to do more than describe the general characteristics of these glues.

U.F.

Short to intermediate storage life. Easy to apply and clean up. Cures at ambient to medium temperatures. Low durability in high temperatures or humidities. Relatively cheap.

M.F. and MUF.

Medium storage life. Easy to apply but sticky and messy to clean up. Cures at medium to high temperatures. Moderately resistant to high temperatures and moderate humidities. Not completely suitable for exterior use. More expensive than U.F.

P.F. - R.F. - P.R.F.

Medium to long storage life. Easy to apply and clean up. Curing temperatures range from low, to glues only suitable for hot pressing, depending on formulation. All are completely unaffected by high temperatures or moisture and are the most durable of glues used for glulam. Characteristic dark red-brown glueline. Costs range from moderate, for the hot press types to fairly high (about US$ 3.00 per kg. FOB).

T.F.

Tannin is a naturally occurring phenolic compound and can be reacted into glues similar in performance to P.F. This is being done on a commercial scale in Australia, Brazil, New Zealand and South Africa. The use of T.F. may allow local manufacture of exterior type glue, provided a moderately capable chemical industry exists, thus saving on imports. T.F. glues may suffer from relatively short working lives. In any particular case a R+D programme by an experienced chemist would be necessary to establish the technical suitability and viability of such an operation.

Durability

In Britain, glues are classified into:

- Interior (Int)
- Moisture resistant (MR)
- Weather and boil proof (WBP)

The tests required for such classification are described in British Standard 1204.

In commencing a glulam operation, advice on suitable glues should be sought from manufacturers. Requests for quotations should include information on:

- Species to be glued - send samples if possible
- Climatic conditions - average, maximum and minimum temperatures; relative humidities; rainfall
- Proposed end uses - interior or exterior
- Storage conditions
- Proposed curing methods

Names and addresses of glue manufacturers may be obtained from the commercial sections of the embassies of major industrial nations.

Storage

For the reasons mentioned above special consideration should be given to storage in tropical countries. This is particularly the case if purchasing policy, shipping etc. requires that glue must be ordered a year ahead.

Possibilities for cool storage include:

- Choice of a high country location for bulk storage
- Leasing of cool store space. Note: Synthetic resin glues are poisonous and may not be acceptable to food cold stores
- Air conditioning of glue store. Air conditioners must run continuously
- Chilling of drums with cooling elements inserted through the bungs, the stack of drums being insulated with locally available fibre

Any of these measures will extend the storage life of resins and hardeners.

Mixing

Intimate mixing of glue and hardener is essential. Hand mixing with a stick is not reliable. Mechanical mixing at 120 r.p.m. for 5 minutes is ideal. High speed mixing will entrain bubbles of air in the glue and may shorten the pot life of the glue. An electrical timer in the mixing motor circuit is useful, otherwise a clockwork timer or a large clock on the glue room wall will suffice.

To extend pot life, the resin may be chilled overnight in a refrigerator. It should be weighed into plastic buckets in a sufficient quantity to cover the following day's glueing programme. If a standard mix size is used, the hardener may also be pre-weighed into paper or plastic bags which simplifies the mixing operation. This practice is strongly recommended with PRF glues whose reaction is exothermic. With PRF glues failure to chill the resin will result in seriously reduced pot life.

A 'T' shaped mixer about 8 cm x 4 cm on the end of a vertical shaft has been found satisfactory for mixing glue in plastic buckets. The bottom of the shaft should be 50 cm from the floor. The bucket containing the resin and glue is placed on a stand so that the mixer is about 5 cm from the bottom of the bucket. After mixing the bucket is placed on the floor for a few minutes to collect drips, then carried to the glueing area.

Pot life, open assembly time, closed assembly time

When hardener is mixed with resin, the chemical reaction which leads to the glue setting commences. A while after mixing, the reaction proceeds to a state where the glue gels and becomes so thick that it can no longer be spread on the wood. The period from mixing to commencement of gelling is the "pot life" of the glue. It is shorter at high temperatures - hence the chilling of the resin before mixing. Some glue spreading machines have refrigerant jacketed glue pans to extend pot life. Glue manufacturers' brochures contain tables or graphs of pot life and temperature.

After the glue is spread on the timber, solvent evaporates from the glue, and the glue soaks into the surface of the wood. The evaporation of the solvent (water and/or alcohol) causes the glue to thicken. This is not the same action as gelling, although the setting reaction is proceeding at the same time. Because of the thickening of the glue, a **maximum** "open assembly time" is given. This is the period which elapses after the spreading of the glue, and before the board is laid up against another glued surface.

When glueing hardwoods, very liquid glues are often used to permit the glue to soak into the surface of the wood. In order to allow this to happen, and to allow the glue to thicken slightly, a minimum open assembly time is frequently specified.

After the boards are glued and laid up face to face a period elapses before the clamps are tightened. During this period the glue may become fairly thick, but not so viscous that the glue cannot be squeezed out to a uniform thickness by the clamping operation. The "closed assembly time" is the period between laying up and clamping. A **maximum** time limit also exists for closed assembly time.

Pot life, open and closed assembly times are all affected by temperature. In addition, a long total assembly time is advantageous in order that evaporation of solvent should not be excessive, and the pot life of the glue not exceeded before clamping is completed.

Because of the number of variables involved specific recommendations cannot be given to cover all cases. However the glue manufacturer's brochure will give recommendations for his particular glue. Experience in particular operating conditions, and quality control tests on glue lines will soon indicate practical limits.

Spreading

Spreading may be done by hand, by roller spreader or curtain coater. All methods are capable of resulting in good quality glulam.

Single or double spreading may also be used, depending on circumstances. In single spreading, only one face at a joint is spread with glue, as when a postage stamp is stuck on an envelope. In double spreading, both faces are spread with glue.

Single spreading may be used satsifactorily in absorbent woods, where there is little or no warping in the timber, and when layups can be completed well within the limits of assembly times. Unless all these conditions are met, problems of adhesion may arise with single spreading.

Double spreading will give good results in much more adverse circumstances than single spreading, but except when a double sided roll spreader is used twice the amount of work is required for double spreading.

Hand spread glue may be levelled with serrated blades e.g. pieces of power-hacksaw blade, or spread with rollers. Paint rollers with a short stiff pile are suitable.

A superior tool for hand spreading consists of a small reservoir of glue over a rubber roller. The amount of glue fed on to the roller can be adjusted and a single firm stroke with the tool leaves a uniform spread on the surface of the wood. See Figure 2 (page 37).

A curtain coater consists of a horizontal tube containing a row of fine (1.5 mm dia.) holes at about 8 mm centres. Glue is pumped into this at a constant rate and streams down onto the timber which travels on a powered conveyor. Glue not caught on the timber falls into a funnel placed over the pump inlet, which serves as the glue reservoir.

By suitable choice of conveyor speed and pump discharge accurate spreads in the form of parallel beads are achieved. Coarse adjustment of the spread rate is achieved by changing the vee belt drive to the pump. Fine adjustment is achieved by varying the angle of the discharge head with respect to the direction of the timber.

A curtain coater can only spread on one side. If double sided spreading is required, two machines in line or a second pass through the same machine are necessary. In this case, the conveyors should consist of slats spaced at about 1 m centres running between parallel matched chains to minimize glue loss.

Roller spreaders consist of a grooved steel roller running in a bath of glue, with the quantity of glue being fixed by an adjustable "doctor" knife. The doctor knife scrapes off excess glue from the roller surface. Roller spreaders come in a variety of designs, both single and double sided, and are self feeding. They are rugged machines but expensive, and relatively difficult to clean up.

Glue spreads are quoted as "pounds per 1000 sq. ft. of glue line" or "Grammes per sq. meter". 100 lb. per 1000 sq. ft. = 489 gm per m^2. Glue spreads range from about 40 to 80 lbs. per 1000 sq. ft. of glueline. The lower end of the range is associated with single spreading, non-absorbent wood, high quality surfaces and short assembly times (not all of these are compatible). Higher spread rates are associated with absorbent wood, imperfectly planed surfaces and long assembly times.

Glue spread rates are checked by attaching a piece of paper or thin cardboard to the timber and passing it through the glue spreader, or rolling glue over it to typical thickness. The paper is weighed and measured before the test and weighed again afterwards, and the weight of glue per unit area calculated.

This procedure is surprisingly difficult to carry out in a roller spreader. The cardboard should be firmly attached to the timber at its leading edge with rubber cement. On most occasions this will prevent it lifting off the timber and warping itself round the roller. A balance with a precision of 0.1 gm or less is required for this test, which should be carried out regularly.

5. CLAMPING EQUIPMENT

The application and maintenance of adequate pressure on a glued joint is essential for the development of the strong reliable bonds required in glulam. The pressures required are high, ranging from 100 psi to 250 psi (700 KPa to 1750 KPa) and the forces involved are correspondingly large.

For example, if 8" wide boards are being laminated with pairs of bolts spaced at 16 inches at a required pressure of 250 psi, then the tension in each bolt is 250 x 8 x 16 x 1/2 = 16000 lbs.

Screw clamps of one type or another are the most commonly used means of applying glueing pressure. Pneumatic or hydraulic jacks or rams are also used, but usually only in mass production machines where heating by radio frequency energy or other means is employed.

The jig shown in Figure 3 (page 38) is designed for the use of tee headed bolts to provide the clamping pressure. Some side pressure is also required to align the edges of the individual laminations to a flat surface on the finished laminate. This force is provided by J head bolts which hook round the channel sections forming the base of the jig and pull bars down on the side of the laminate.

The bolts and nuts are production tools and should be carefully manufactured. Ideally hardened alloy steel should be used since this will give the longest service life. Also the ideal thread form is an Acme thread. Unfortunately Acme threads are difficult and expensive to manufacture, especially in the absence of sophisticated light engineering industry.

In practice, V form threads (Whitworth, UNC, DIN) carefully cut in mild or medium tensile steel will be adequate, although replacement will be more frequent. Threads should be cut in a lathe and finished with a full form die nut or chaser. The quality of thread produced in a threading machine is generally not good enough.

If obtainable, full height hardened nuts should be used. Otherwise double height mild steel nuts machined from hexagon bar stock may be used. These may have integral faced washers welded to them. Clamping bolts and nuts are shown in Figure 4(a) (page 39).

Tightening Equipment

In a jig of this type there are a large number of nuts to be tightened to a high controlled torque in a limited time. Also, the length of thread which the nuts must be run down may be quite long. The best tool for this purpose is a pneumatic impact wrench, these being capable of high torque, high running down speed, yet still being relatively light.

Unfortunately the large sizes of wrench required for final tightening consume large volumes of air when running free, while smaller sizes with less air consumption do not have sufficient torque. Unless a very large air compressor and receiver are available it is advisable to have a pair of smaller wrenches for initial spinning down and tightening the alignment clamps and also one or two large wrenches capable of exerting an equivalent torque of 500 ft. lb. If a large compressed air supply is available, then the running down of the clamping nuts may be done by the large wrench, but even so it is desirable to have a smaller one for tightening the alignment clamps, since less force must be applied to these. If the alignment clamps are too tight, it will not be possible to exert full glueing pressure.

Sockets

The length to which the nuts are run down is much greater than in ordinary engineering practice and it is necessary to adapt normal impact sockets for this purpose. A deep impact socket is cut in half a little behind the ends of the internal flutes. The front and back halves are then welded to a piece of heavy walled tube 12" (30 cm) long. Chromium plating or oxide finish on the sockets should be ground off before the welding, and the tube should be machined to give an accurate line up of the two pieces of socket. Since sockets are made of high alloy steel, this work should be done by a competent engineering organization which can also heat treat the lengthened sockets after manufacture. A suitable socket fitted to an impact wench is shown in use in Figure 4(b) (page 39).

Compressometer

While it is easy to tighten nuts to a controlled torque, what is actually required is a controlled tension in the bolts. With continued use, the friction characteristics of the threads in both nuts and bolts will change.

A compressometer is a device for measuring the force between a nut and an adjacent surface and hence the tension in the connecting bolt. A hydraulic device is shown in Figure 5 (page 40). This is completely filled with hydraulic brake fluid through the automotive bleeding valve. It is important that all cavities, including the Bourdon tube of the pressure gauge are filled with liquid, otherwise the travel of the piston will be excessively long at the high pressures involved.

The device should be calibrated in a testing machine, and at annual intervals thereafter.

In use, the compressometer is placed between a clamping block and a nut in a laid up assembly. The air pressure is reduced below the expected value for the tension required, then gradually increased with the impact wrench held on the nut. The air pressure is noted. This is repeated five or six times on different bolts and an average air pressure determined which will result in the bolt tension required. This should be repeated at about two-weekly intervals, or when new nuts or bolts are purchased, or if nuts are run down to less or more than their usual positions on the bolts.

Note that in this procedure the torque on the nuts is not determined. The operating air pressure is related directly to the required bolt tension.

Note: The dimensions shown are for 'Caterpillar' hydraulic seals, but any reputable brand seal may be used. It is recommended to buy the seals first, then detail the compressometer to suit.

6. LAMINATION

The key process in the manufacture of glulam is the laminating operation. This consists essentially in applying the glue to the timber, assembling this in its final form and applying the necessary pressure while the glue sets. The exact actions carried out will vary somewhat depending on the equipment available. This section is written around the use of the jig shown in Figure 3 (page 38) and pneumatic impact wrenches. However, the operations are basically the same with all types of equipment and orientation of laminations.

Preparation

Preparation for laminating is very important. Once the glue is mixed and spread, nothing will stop it from setting, and mishaps and hitches which delay the operation must be avoided at all costs.

The materials, the machines and equipment should all be assembled and checked as thoroughly as possible.

Timber

The timber should be assembled adjacent to the glue spreader. In all but small repetitive jobs each component should have its constituant laminations stacked in separate piles. If different grades are used for interior and exterior laminations, these should be numbered consecutively on one edge near the end, on the edge which will be visible in the final lay up in the jig.

Glue

The type and quantity of glue required should be advised to the glue mix operator, and the times when it will be required. The glue spreader should be checked for correct reassembly after the last cleaning and turned over for a few seconds.

Test strips of cardboard should be weighed and if necessary glued to the first piece to be spread, then to pieces which will give a test about every half hour of glueing.

Jig

The tee head bolts should be laid in position in the jig over a length sufficient for the length to be laminated, with their nuts started. Corresponding bolts should be stood in position behind the jig each with a clamping block. Any cauls required should also be placed in readiness. The J head bolts and hold down bars should be assembled and placed adjacent to their required positions. The threads of all bolts should be checked for cleanliness and lubrication as the bolts are positioned and any doubtful ones rejected for clean up with the die nut.

The air pressure for the impact wrenches should be adjusted to the value appropriate to the width, species and spacing to be used.

Some additional equipment may be required, particularly trestles for holding spread boards if a long minimum open assembly time is specified. These should be positioned adjacent to the jig or the glue spread outfeed or both.

Assembly

When everything is checked and workmen positioned, assembly may commence. The first batch of glue is mixed, the glue spreader filled and started and the first board passed through. The cardboard test strip is weighed and the glue spreader adjusted if necessary. The boards are carried to the jig and laid flat for the expiration of the open assembly time. Towards the end of this time the first board to be glued is stood up against the back of the jig, then the next and so on. These workers should time their work by the timber passing through the glue spreader so that the same rythm is maintained. As each board is positioned in the jig, the workman at the end should check that the numbers on the edges are in consecutive order.

When the last board has been spread all the workmen who have been glueing move down to the jig for the clamping operation. Meanwhile the man in charge of glue mixing commences cleaning up of the glue spreader, buckets etc.

When the last glued board is placed in the jig any necessary cauls are positioned and two pairs of men start placing the clamping bolts, starting at the centre of the assembly and working towards the ends. Each pair is followed by a third man equipped with the small impact wrench. He spins the nuts down on both T and J head bolts.

If warped timber is being used, the loose assembly may be very much larger than its clamped up size. It may be necessary to start compressing the assembly with long bolts, then following these by shorter bolts in the adjacent position.

When the nuts have been run down with the small wrenches, the large ones are used to tighten the nuts to their final torque. Again this operation should start at the centre of the assembly and proceed towards the ends, or in short assemblies at one end working towards the other. This allows the laminations to slide over one another and avoids a restrained warped piece from separating adjacent lamination.

Squeeze Out

After clamping is completed, each glue line should show a uniform bend of squeezed out glue. Excess glue, or its absence, or lack of uniformity can indicate various problems to an experienced eye.

The following are some faults and their indications:

- Lack of squeeze out: Insufficient glue, pot life exceeded, open assembly time exceeded
- Excess squeeze out: Excess glue spread, no hardener added to resin, insufficient open assembly time

- Squeeze out adequate on last boards, inadequate in first boards - Overlong closed assembly time

Multiple layups

More than one component may be fabricated at a time. The principle limitation to the volume of glulam produced at a time is likely to be shortage of clamping bolts and nuts. Several beams of the same thickness may be made simply by leaving a dry joint between adjacent beams and laying up as for a single very deep member.

If an even number of narrow members is to be made, it may be more convenient to lay these up one on top of the other, separated by a single row of clamping bolts. This gives only half the number of nuts to be tightened than if pairs of bolts are used.

If several large members are required such as bridge beams, these may be laid up on top of each other. In such cases, the side clamping bars should be checked for alignment with a string. This will show up any which are not properly seated.

Unclamping

After the time required for the glue to set, the clamps may be removed. In practice it is best to leave the clamps on as long as possible, since in low temperature (less than about 40°C) curing is not completed until after several days. Unclamping should also proceed methodically The nuts should be run right off the bolts, dipped in oil and stored in pails with an elevated bottom through which the oil can drain.

Bolts should be scraped clean of glue, oiled, and if glue has become lodged in the threads it should be removed as soon as possible with a die nut. Other components should be scraped clean and stored and the jig itself scraped clean and oiled. If these details are not done on every occasion, the jig and other components become so encrusted with glue as to become useless.

Teamwork

The key to successful laminating is a well drilled team of key workmen. A nucleus of about six is sufficient. On very large jobs each of these may have one or two labourers attached to him to expand the size of the team.

7. FINISHING

There are two distinct stages in finishing glulam components: clean up and carpentry.

Cleaning up glulam components as they are removed from the jig consists of removal of squeezed out glue and levelling the surfaces. Depending on the finish required some patching or filling may also be undertaken.

Clean up should start as soon as possible after removal of the component from the jig. With time the glue becomes harder and harder and more difficult to remove. Initial removal of excess glue is done with spade type tools. These can be made from lengths of heavy section planer knife brazed or welded to a handle about 2 ft. long made from 1/2" water pipe. Further work is done with power tools or machines. A heavy duty floor sander used with coarse sandpaper is a good tool for low or medium production levels and in skilled hands it can produce good quality surfaces. This tool must never be kept still or a deep gouge in the surface will result. An open coat abrasive belt should be used. This is less prone to clog with glue than a close coat sandpaper.

Conventional planers and thicknessers are also used if they have the throat capacity. Some speciality manufacturers make thickness and surfacing planers up to 2.6 ft. wide for the glulam industry. If long runs of the same profile are run through planers it will be found that the hard abrasive glue lines will wear notches in the planer knives. To eliminate the need for frequent grinding it will be found advantageous to fit adjustable fences so that the glue line may be varied relative to the knives.

Sanding machines, either drum or belt are excellent for cleaning up and finishing glulam. Multiple belt machines have stock removal rates as good as planers and are not affected by hard gluelines. Wide beltsanders require less frequent replacement of abrasive than drum sanders and are faster. However the cost of belts is high and the belts are easily torn by a projecting knot or badly aligned finger-joint. When using a wide belt sander it is wise to do a preliminary cleanup by hand to remove any such hazards.

Handling

A major problem in glulam manufacture is handling the large and heavy components. For example a beam 30 ft. x 3 ft. x 6 in. would weigh about one ton.

A compromise between cost and flexibility is the installation of 1 ton capacity hand operated monorails running transverse to the factory directing and the provision of three wheeled dollies running on swivelling castors, also of one ton capacity. This will allow movement of heavy components without too much effort. Pairs of monorails should be installed at about 20 ft. centres:

- Over the jig
- In the centre of the finishing area
- Over the truck loading area

A gantry length of 16 ft. will give sufficient sideways movement. The loading gantries should have their trolleys permanently fixed, but the same hoists as are used in the finishing area may be used there when production levels are low, since the finishing gang will also be responsible for loading.

Details of handling equipment need to be designed with care. A suitable dolly is shown in Figure 6 (page 41). A number of sturdy trestles is required. Note that the height of these is 1" lower than the height of the dollies. This allows the trestles to be placed under a beam which is resting on the dollies. The beam can be lifted up one end at a time, a 2" thick packer placed on the trestle, the beam may then be lowered and the dolly wheeled away.

Handling through machines

A particular problem is handling heavy members through thickness planers or wide sanders. Not only do they have to be moved lengthwise through the machine but moved sideways, returned and turned over for second pass. To complicate matters, the bed of many thicknessers rises and falls to accommodate different thicknesses, so any conveying system must also be variable in height. If fixed bed height machines are installed this problem does not arise and this should be considered when deciding machine purchases.

A relatively low cost solution to the problem is to build the machine foundation in a pit so that the bed of the machine is at the same height as the transport dollies, or half an inch higher. The dollies then serve as the infeed and outfeed conveyors. In the case of variable bed height machines the height should be at the level of the deepest opening. Thin sections to be planed with the bed higher are packed up on the dollies. If this solution is adopted, it is essential that an efficient shavings exhaust system should be installed, with a flexible hose to clear out the pit. Also, the floor in line with the machine must be smooth and level where the dollies will run.

Finish Carpentry

Completing glulam members will certainly involve square cutting the ends and may also include drilling bolt holes, including counterboring for concealed bolt heads, cutting notches etc. These are basic carpentry techniques but because of the size of the timbers conventional techniques may not provide sufficient accuracy. For example a 5° error in boring a hole through a 1" board will put the emerging point less than 1/8" out of position. In a 10" thick member the same misalignment will produce an error of nearly 1" and would make the fitting of a bolt impossible.

Accurate measurement and setting out are essential. Measurements should be done by steel tape and a rafter square should be provided for marking out.

Portable electric power tools are generally used. Pneumatic tools are preferable since they come to no harm if stalled, but they are up to twice the price of electric tools of similar capacity. Pneumatic tools available include drills, circular saws and chain saws.

Saws

Cuts up to 4" deep may be conveniently made with portable circular saws carrying 10" diameter blades. Above this size portable circular saws become heavy and dangerous. A 6" depth capacity saw weighs about 30 lb.

For deeper cuts chain saws mounted on a base plate and with a depth of cut of 12" are available. Such a tool weighs only 24 lb. Figure 4 (page 39) shows an example of an electric, vertical chain saw.

Drilling

A heavy duty 3/4" (steel) capacity drill should be available, with a stand which can be clamped to the timber to guide the drill perpendicular to the surface. The usual type of portable drill press stand is unstable if the drill is overhung to the rear of the stand. It is more satisfactory to cut a hole about 4" square in the base, and place the unit over the hole centre with the drill in its usual position.

Drill bits should be double twist double spur (Jennings) pattern for quick chip removal. For counterboring, multispur machine bits which are available in diameters up to 4" are most suitable.

Routing

Patching of the sides of members finished to architectural standards may conveniently be done, with the assistance of a router. This can quickly sink rectangular holes to a uniform depth.

With a rounding over cutter, the corners of members, which are particularly prone to damage, can be smoothed to a uniform radius. This is particularly useful in identifying to site carpenters the soffit of cambered straight beams. This helps to avoid the installation of cambered beams upside down.

Water Repellent Finish

Glulam members with their planed or sanded finish are frequently exposed for architectural effect. Protection from rain wetting during storage, transport and erection is required to avoid water staining short of varnishing in the factory, the most effective protection is given by a water repellent finish.

The "Madison" formula developed by the Forest Products Laboratory, United States Department of Agriculture, consists of:

- Solvent (mineral spirits, turpentine)	79 %
- Pentachlorophenol concentrate 10:1 (40 %)	11 %
- Boiled linseed oil	9 %
- Parafin wax	1 %

The wax and linseed oil waterproof the surface of wood against the ingress of water. The pentachlorophenol inhibits unsightly mould growth. Stains and pigments may be incorporated if required. Instructions for the preparation of "Madison" formula water repellent finish are given in the Annex (page 44).

"Madison" formula WRP may be applied by mop, broom or brush and dries quickly. It gives protection against water staining for several months and may be painted or varnished over with oil based paints. It cannot be painted over with water based emulsion paints. Note that it will not prevent staining from exposed steel nails or bolts if these become wet.

8. RECORDS AND QUALITY CONTROL

Maintenance of adequate records and of an adequate quality control system is vital for the continued production of good quality glulam. Determination of quality of glue bonds cannot be done by mere visual inspection and physical testing is required. The quality of joints is also affected by a number of factors, any one of which may adversely affect joint strength.

Apart from compliance with any regulations which may be imposed, records and quality control serve two important commercial functions. They protect the manufacturer against invalid claims arising from incorrect use of members. They are also a valuable promotional tool. Either of these can easily repay the cost of quality control.

The aim of quality control is to maintain a minimum level of quality. To do this, simple tests on a routine basis must be carried out. Daily tests to a low order of accuracy are far more useful than weekly or monthly tests to a high level of accuracy. A 10% precision is adequate for routine quality control. This will indicate that a sample is well within requirements or well outside. Either is usually the case. In border line cases a few more samples and tests will indicate whether the process is in control.

All quality control tests should be logged for future reference, with sufficient identification for correlation with production records. Production and sales records should be sufficient to trace back any major component to its manufacture date and to quality tests not necessarily performed on that member, but at least bracketing it.

Glue

Records should be kept of manufacturers batch numbers and any compliance certificates he may issue. The issue date of each drum of a batch to the glue room should be recorded. This will enable the source, quality and date of manufacture of the glue in any component to be narrowed down to one or at most one of two sources.

Results of glue spread tests should be logged. The information required is:

- Date
- Glue type
- Timber size and species
- Time sample taken single/double spread
- Dry weight
- Wet weight
- Spread rate

Timber

Before fingerjointing, moisture content tests should be taken at random through the packet and the results noted. If the timber has been treated then the packet number should be noted so that it can be related back to the treatment charge sheet.

As a minimum, the date time species size and M.C. results should be noted. Also note any particular feature e.g. numerous skips in blanking, lower than average grade appearance etc. The mere fact that such deficiencies have been noticed and recorded will frequently be sufficient incentive for them to be rectified. Otherwise continued less than normal quality may require investigation to put matters right. This might show up the need for further training of new operators, investigation into kiln operating practices etc.

Mechanical Tests

The two important mechanical tests are bending strength of finger-jointed specimens and block shear tests on gluelines. When a factory has settled down one per day of standard production should be sufficient. A balance must be struck between the cost and effort of testing and the volume of production, which may have to be checked in detail and possibly condemned in the event of substandard quality emerging.

Fingerjoint Tests

Since there is very little effort involved in taking samples, and since samples cannot be tested until the glue sets, it may be advantageous to take fingerjoint samples more frequently than at the minimum level, say twice a day, and then test both samples first thing the following morning.

For fingerjoint quality control an adequate test is to break a 40" (1 m) long sample on the flat under a central load. The load may be applied by a 3 ton hydraulic jack equipped with a pressure gauge and calibrated in a testing laboratory. A photograph of a suitable apparatus is shown in Figure 8 (page 42). Stock widths up to 4" (100 mm) can be tested in this. Wider stock will require ripping back to 4".

Since the zone of failure is known, there is no point in the additional complications arising from insistence on the uniform loading and shear free zone resulting from four point bearing.

The modulus of rupture is calculated also the proportion of wood failure is estimated in the tensile stress zone. The MOR should be such that:

(1) The rolling average from the last 10 tests should be at least 3.15 times the highest allowable bending or tension stress value for normal conditions of loading being used in design.

(2) No value shall be less than 2.36 times the highest allowable bending or tension stress value as above.

Lamination Tests

The principal mechanical test used for checking lamination bond strength is the block shear test. The sample size and shape are shown in Figure 9 (page 42) together with a suitable test apparatus. The same calibrated hydraulic jack used for the fingerjoint test may be used in this apparatus.

Samples are cut from the trimmed off ends of members. It is in the laminator's interest to ensure that members are made long enough to ensure that the sample has been under direct pressure from a clamping bolt, and not from an unclamped end. In the latter case pressures are likely to be too low, and gluelines too thick for good bonding, and erroneously low test results may emerge.

9. FACTORY LAYOUT

Laminations are awkward to handle because of their length and finished members are heavy. Layout of a glulam factory is of vital importance in maintaining an efficient operation.

Up to the fingerjointing stage only ordinary length timber is handled, but after the fingerjointing stage very careful layout is required. Ideally a glulam factory should be long and narrow with work progressing from one end to another. Changes in direction of material flow where laminations or members must be turned through 90° should be avoided at all costs. Sideways shifts of materials are acceptable and provide convenient buffer storage areas.

It must be remembered that most glulam operations involve passing laminations through a machine or process e.g. planing, glueing, clamping. The infeed and outfeed areas must be long enough to accommodate the longest laminations ever handled. The factory layout shown in figure 10 (page 43) complies with these conditions. It will be noticed that the infeed of the planer is opposite the outfeed of the fingerjointer, and the infeed of the glue applicator is opposite the outfeed of the planer. Laminations thus move in a zig-zag fashion down the factory. In this case a jig 40 ft. (12 m) is installed. Clear areas of this length are therefore provided.

With some awkwardness this factory could handle member up to 80 ft. (24 m) long should the need ever arise. It would not normally be economic to relocate all the machines to cope with such lengths since normally there would be little requirement for them. Spacing machines out would greatly increase unproductive transport distances for the normal 20 to 30 ft. (6 to 9 m) lengths which constitute the bulk of production in most factories.

If a square shaped building must be used, the same general effect as described above may be obtained by arranging the main machines in a line across the centre of the building, feeding in alternating directions. An example of the material flow in such a layout is shown in Figure 10 (page 43).

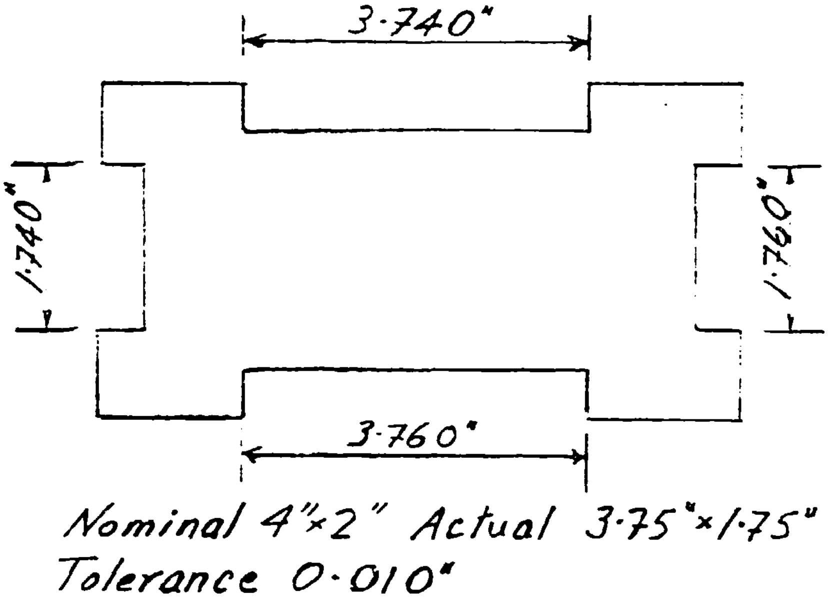


Figure 1. "GO - NO GO" gauge

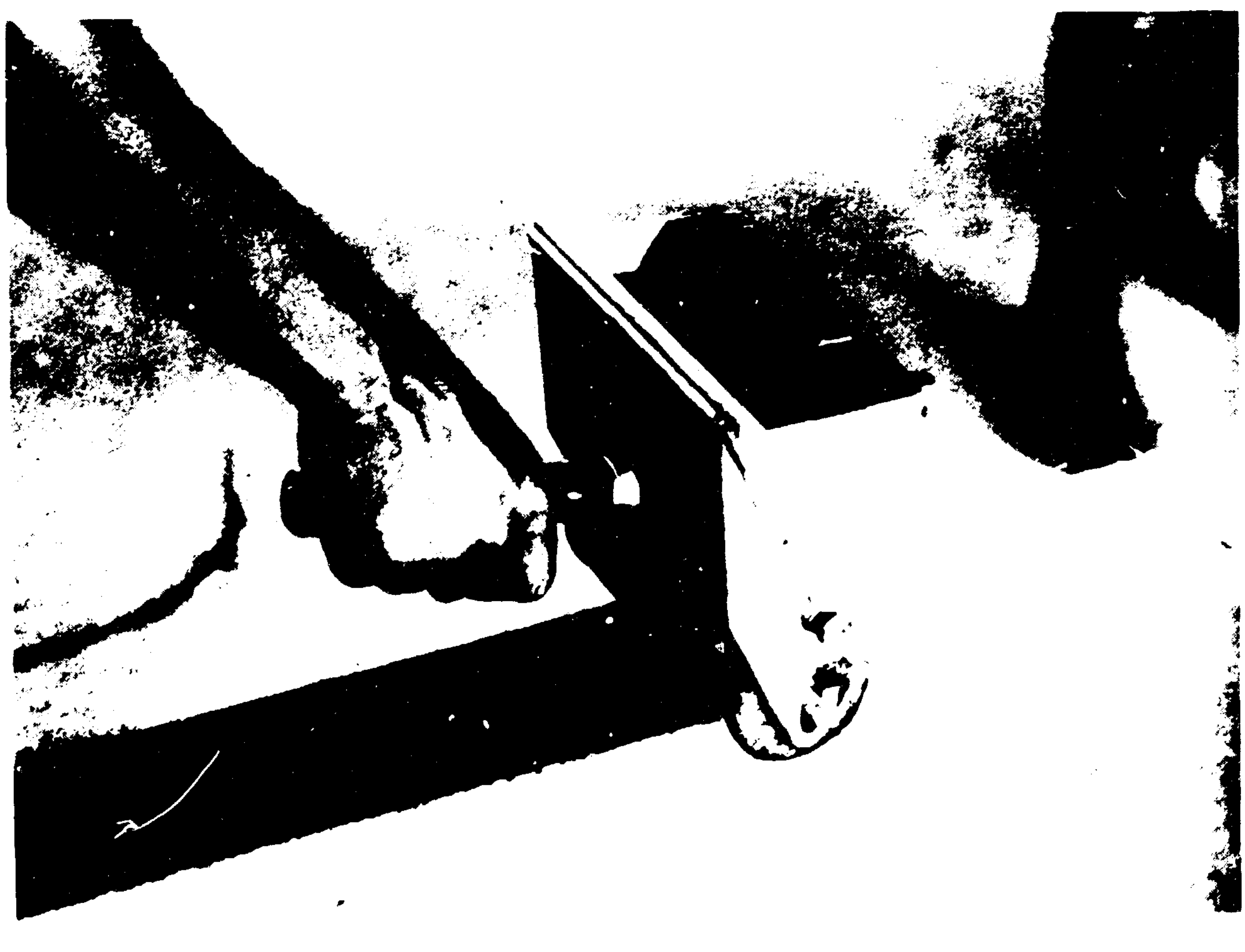


Figure 2. Glue spreading by hand

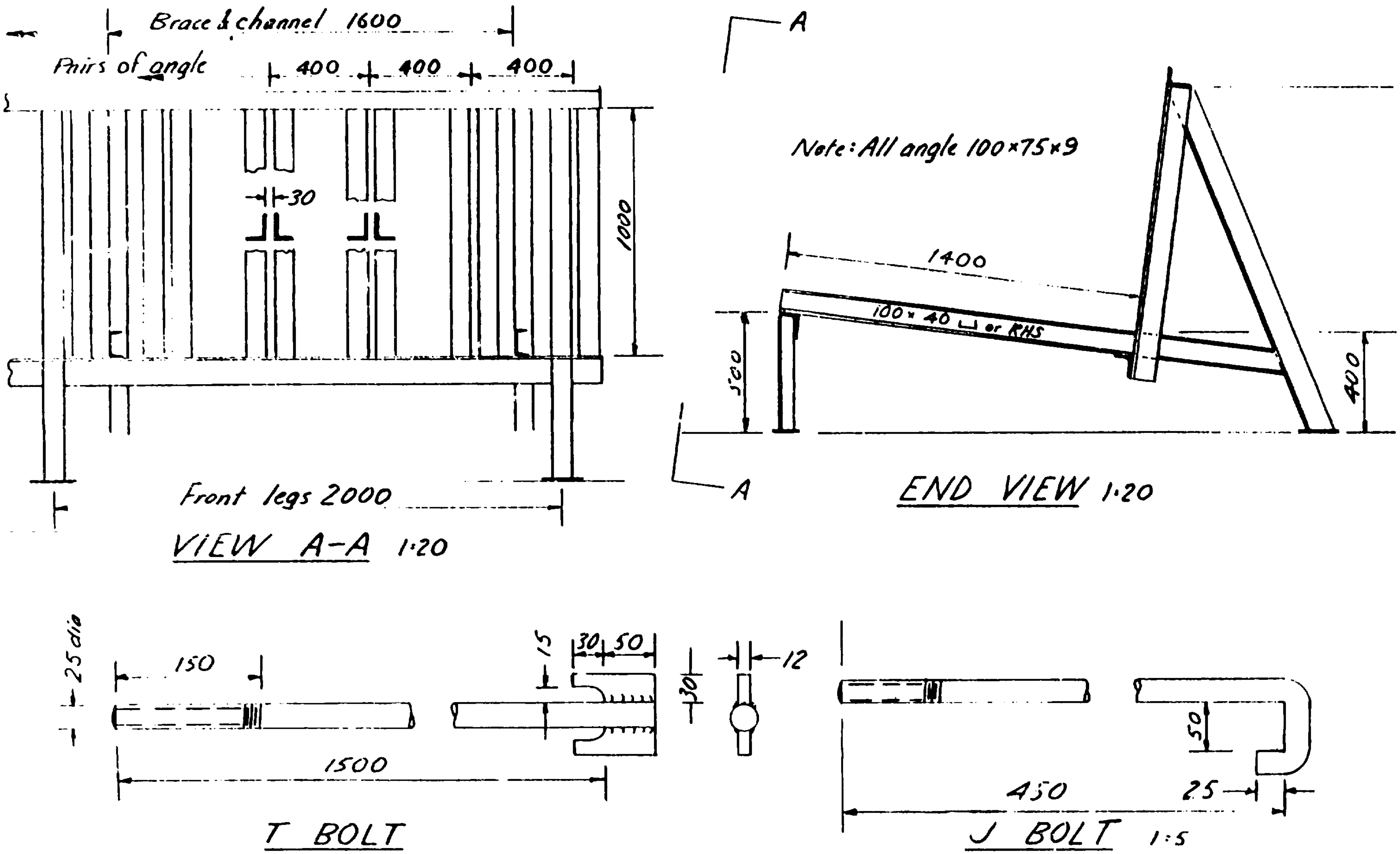
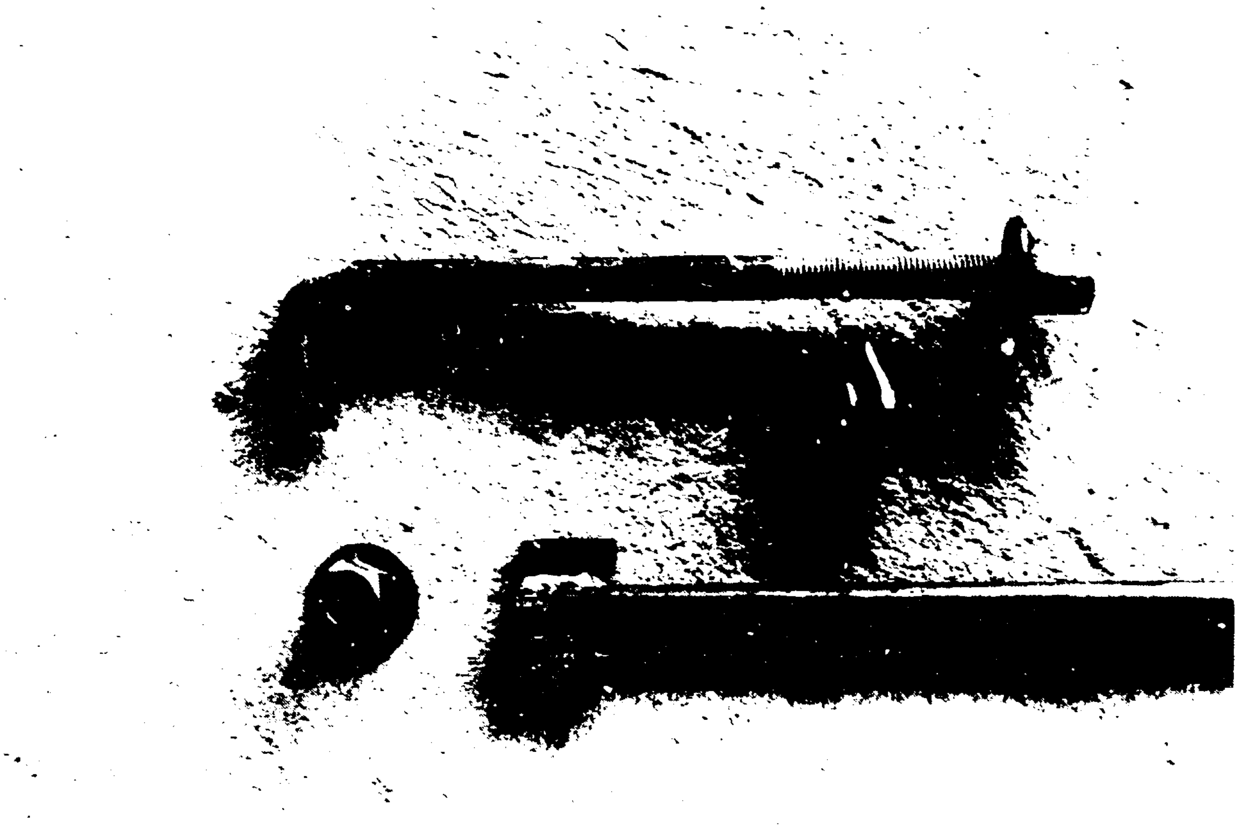


Figure 3. Glulam jig and bolts



(a) Clamping bolts and nuts with integral faced washers

(b) Pneumatic impact wrench with adapted deep socket in use

Figure 4. Clamping and tightening equipment

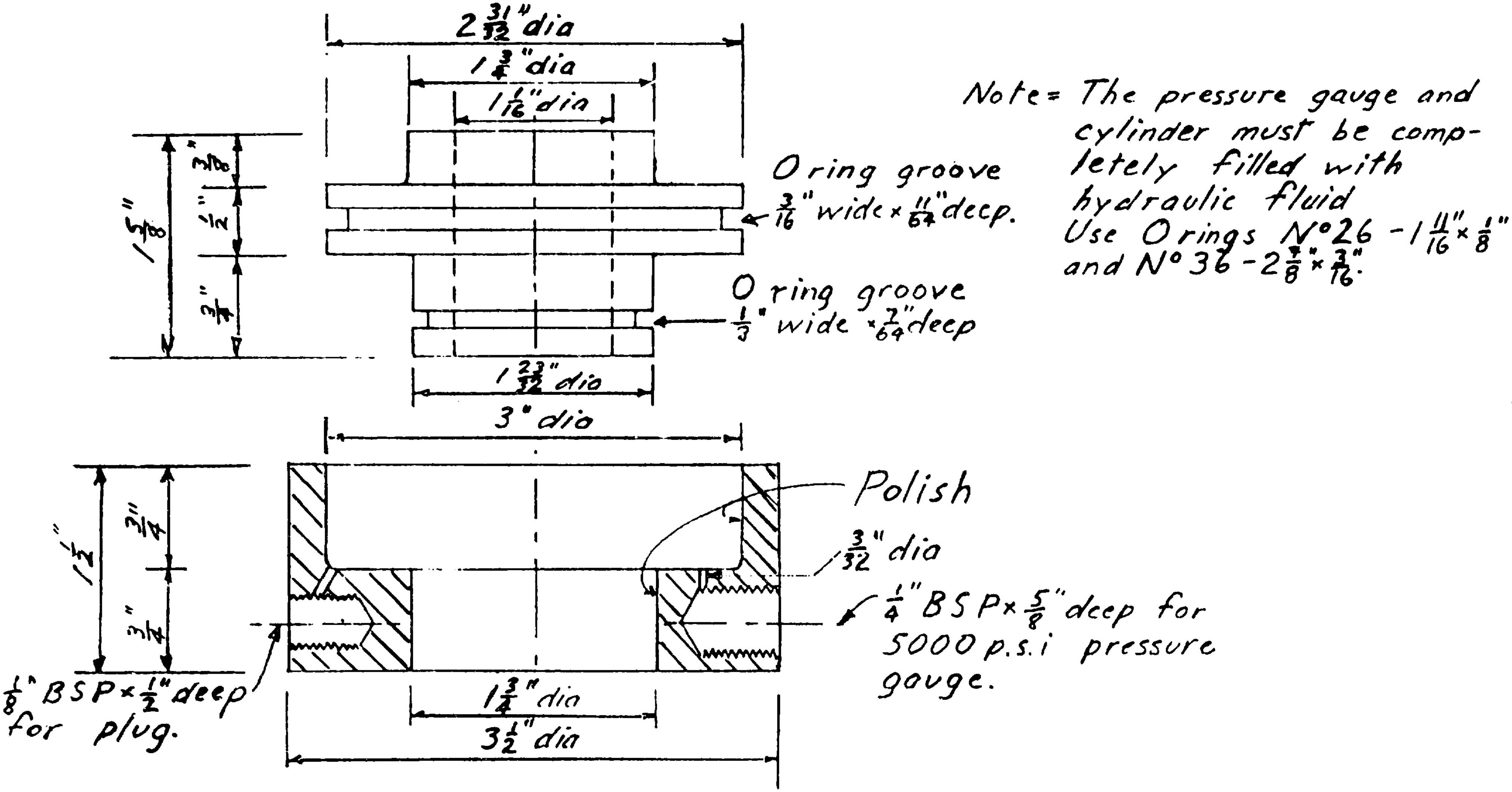


Figure 5. Compressometer

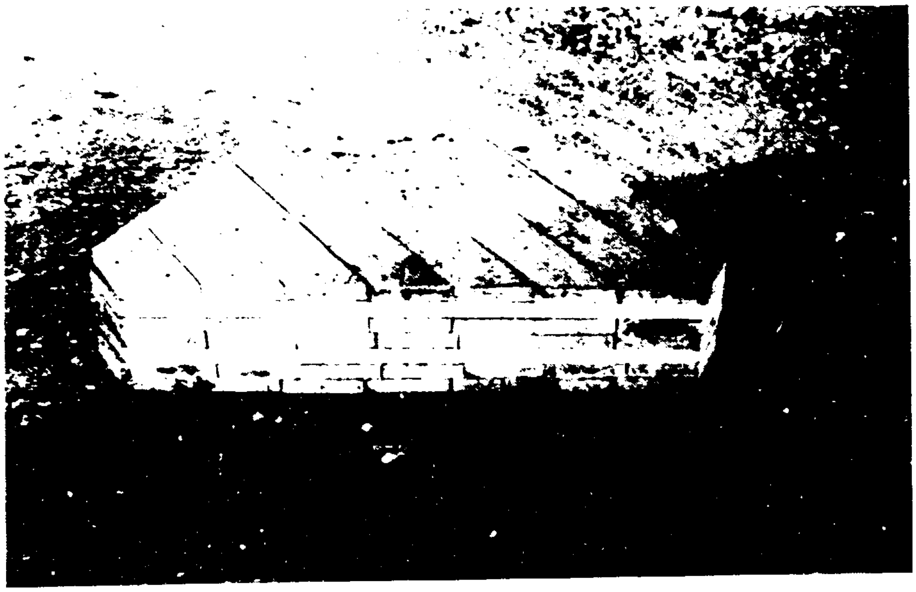


Figure 6. Heavy duty dolly

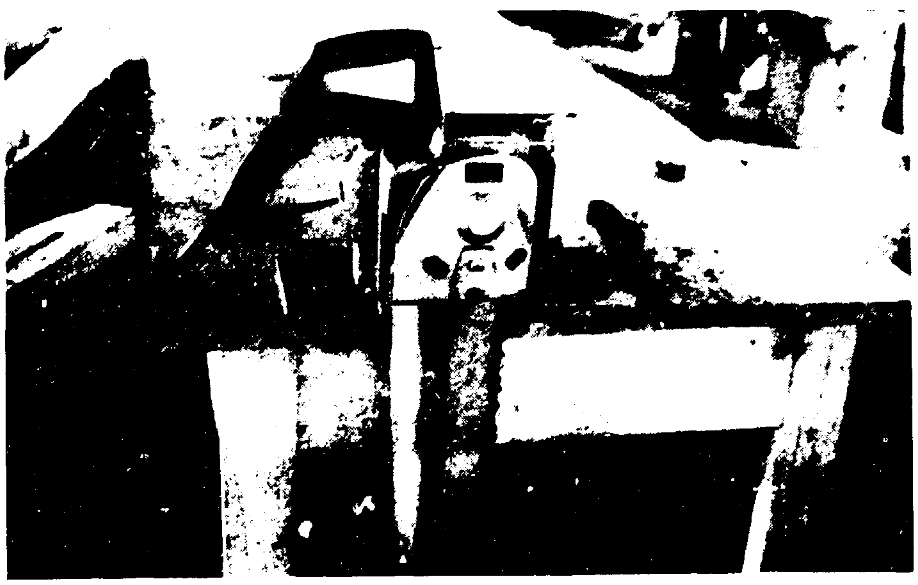


Figure 7. Electric, vertical chain saw

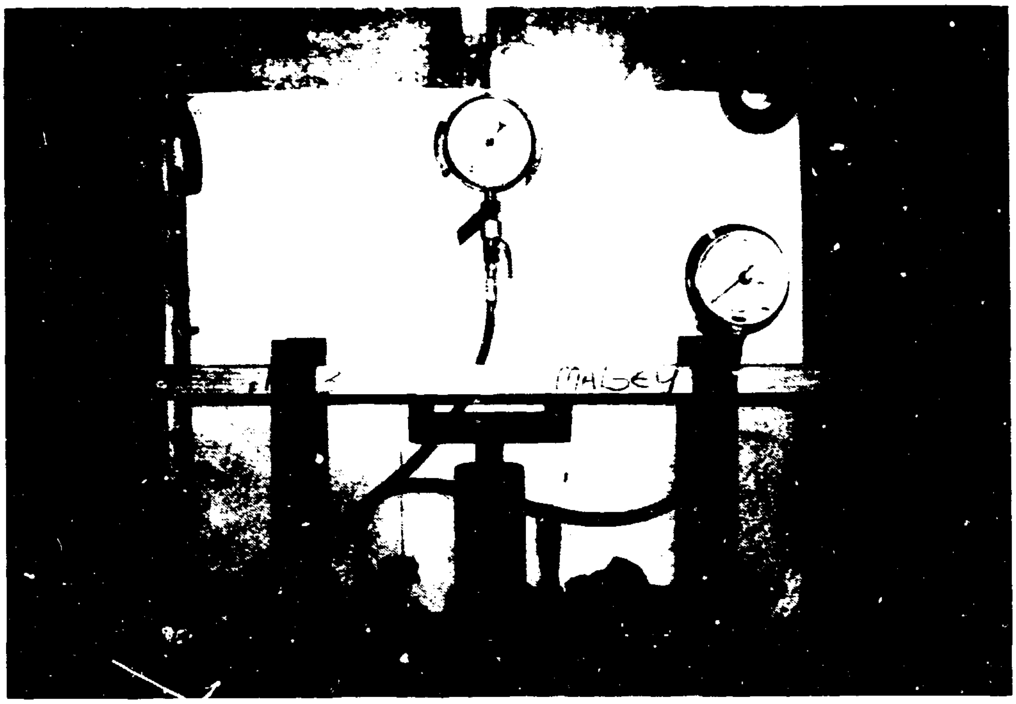


Figure 8. Apparatus for testing fingerjoints

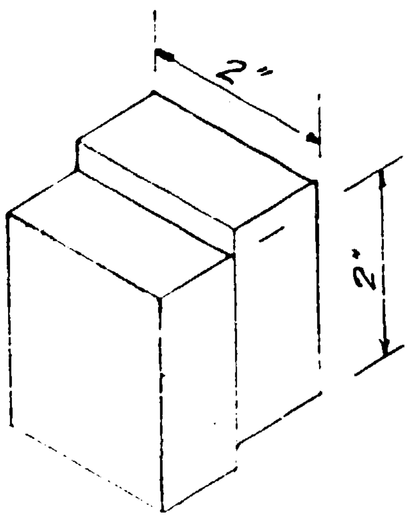
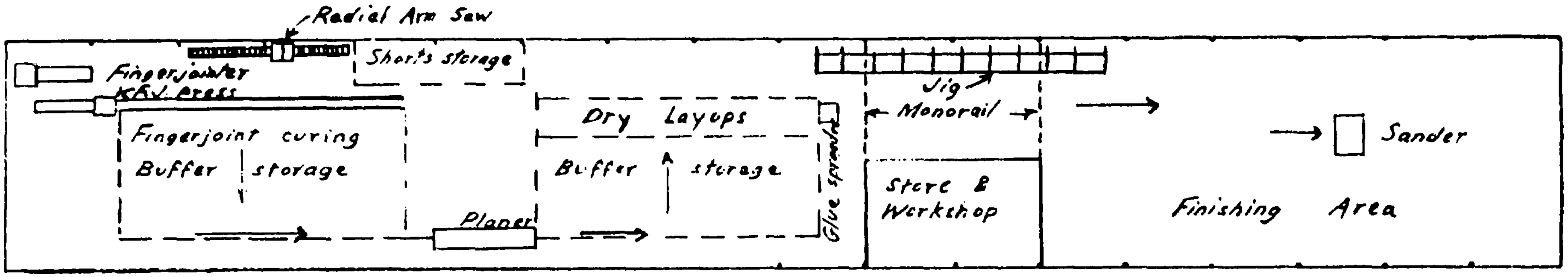
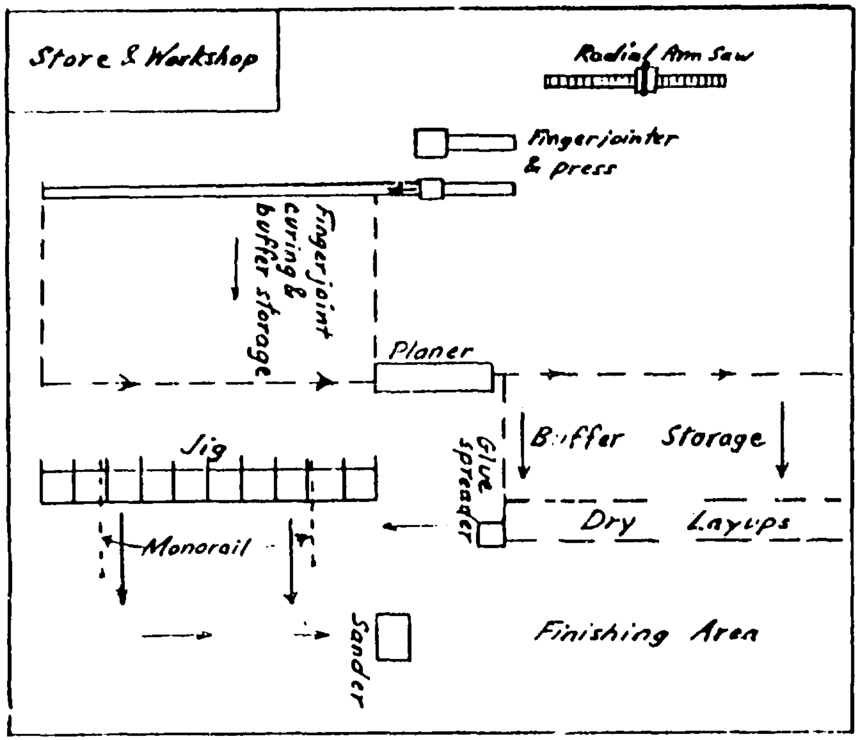


Figure 9. Shear test specimen



(a) Lineal factory



(b) Square factory

Figure 10. Glulam factory layouts

ANNEX

"Madison formula" for a water repellent wood finish

The following text is from the United States Department of Agriculture, Forest Service, Research Note FPL-0124, revised 1978: "Wood finishing" Water repellents and water-repellent perservatives" by William C. Feist and Edward A. Mraz, and is reproduced with kind permission:

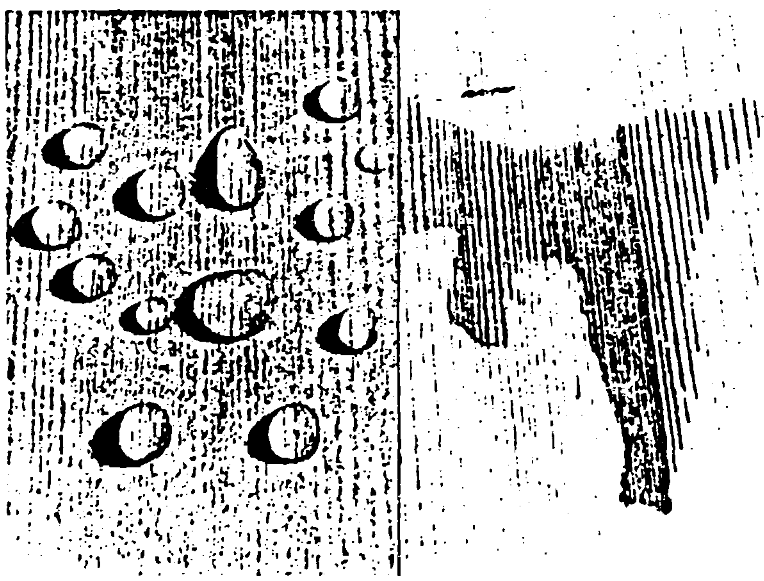


Figure 1.—Closeup view of wood surfaces. Left - Surface brush treated with water repellent resists penetration by liquid water. Right - Untreated wood surface absorbs water quickly. M 145 933-16

In many ways, water is one of wood's worst enemies. Water plays a key role in the rapid weathering of wood exposed outdoors, in the performance of exterior finished wood, and in the decay or rotting of wood. Properly seasoned wood that stays dry is not subject to decay, to premature failure of paints and finishes, or to many of the other serious problems associated with weathering.

Fortunately, there are some relatively simple wood treatments that can be used to slow down the pickup of water and help keep wood dry. These treatments are called water repellents (WR). When a preservative is added to a WR, it is called a water-repellent preservative (WRP). The composition of these two treating materials is very similar; both contain a substance that repels water (usually paraffin wax or related material), a resin or drying oil, and a solvent such as turpentine or mineral spirits. Addition of a preservative such as pentachlorophenol or copper naphthenate to a water repellent helps to protect wood surfaces against decay and mildew organisms.

Homeowners can avoid many exterior wood-finishing problems by first treating with a WR or WRP solution to guard against damage to the wood and paint caused by water and by decay and stain fungi (mildew). WR or WRP treatment of wood is recommended both before painting and also as a natural finish for wood. Use of the WRP is recommended in areas where mildew growth is a problem or where decay may occur.

(The WR and WRP treatments are very effective when used on wood exposed outdoors above ground. In areas where decay is a serious problem, or where wood will be in contact with the ground (wood foundations or fence posts, for example), wood will need far more protection than that afforded by a surface treatment with a WR or WRP. In such cases, wood properly protected by treatment with a commercial preservative is recommended. Such treated wood is normally available at a lumberyard and should conform to recognized standards for maximum service life.)

A WR or WRP should be applied to all exterior wood that is normally painted. In a new house, lumber treated by the manufacturer (particularly for millwork items such as window frames) should be used, if possible, and all cut ends should be treated on the job by brushing or, preferably, dipping. If untreated lumber is used, all exterior surfaces should be treated.

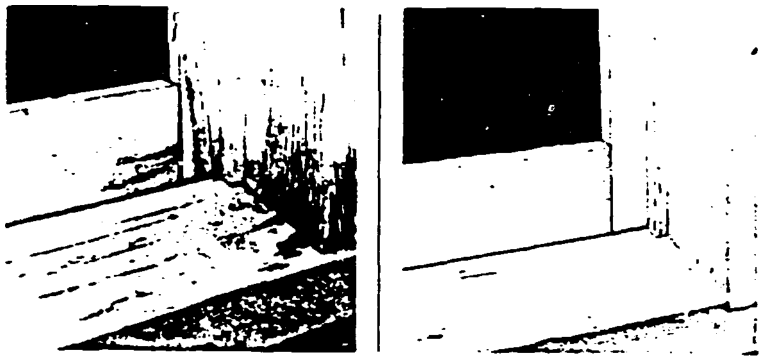


Figure 2.—Experimental window sash and frames after 5 years' rain and weathering. Left - The sash and frame were not treated before painting. Rain that entered the joints caused extensive paint peeling and excessive swelling of the wood. It has also caused cracking of the putty and serious decay in the sash, which must now be replaced. Right - Before painting, the sash was dipped for 3 minutes in WRP. The solution was brushed on the frame. The wood is in good condition, and the paint has weathered normally to the point where repainting is needed.
ZM 119 771 ZM 119 770

Most WRP's are intended for exterior use because the preservatives in them, particularly pentachlorophenol, are toxic. Users must read the label on the original container carefully to determine if the material is allowed and recommended for indoor use. When in doubt, only a WR should be used, even outdoors, in case toxic chemicals should cause any problems such as contact with people, animals, or plants. The WR's, too, should be allowed and recommended for indoor use. The warning at the end of this publication has further information.

How Does a WR or WRP Work?

A WR or WRP is a solution that gives wood the ability to repel liquid water, such as rain and dew (fig. 1). They do this because they contain a waxlike substance. By repelling water, they resist decay and stain by denying fungi that cause these conditions the moisture they need to live. A WR or WRP also reduces water damage to the wood, such as the excessive swelling and shrinking that leads to cracking and warping. They protect paint from the blistering, cracking, and peeling that often occur when excessive water penetrates the wood. As mentioned earlier, a WRP also contains a fungicide—often pentachloro-

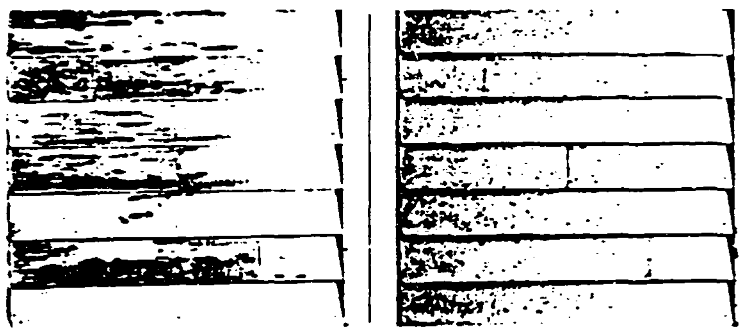


Figure 3.—Experimental panels of bevel siding after 5 years' rain and weathering. Left - The siding was not treated before painting. Rain that entered the butt and lap joints has caused serious paint peeling. Right - Before painting, the siding was dipped for 10 seconds in WRP. The paint has weathered normally to the point where repainting is needed.

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phenol—that kills any surface mildew living on the wood.

There is a further benefit from a WR or WRP treatment of exterior wood species that contain colored water-soluble extractives, such as redwood and western redcedar. When water soaks into these woods through the paint and then dries out again, the colored substances are sometimes left on the paint surface. WR or WRP treatment will help reduce this type of paint discoloration by preventing waterscaking.

The effectiveness of a surface treatment with WR or WRP has been confirmed in outdoor exposure studies conducted at the Forest Products Laboratory and at the USDA Forest Service Southern Forest Experiment Station in New Orleans, La. The differences between WRP-treated and untreated window sash and frames (fig. 2) and bevel siding (fig.3) are significant after exposure to severe weather conditions. The treated siding was dipped for 10 seconds, and the treated window sash for 3 minutes in a WRP solution similar to that described at the end of this report. This is the degree of treatment usually given by manufacturers. The treated window frame and sill (fig. 2) were brushed with the WRP solution, an easy treatment for any homeowner or painter. Treating by dipping, however, can be expected to be more thorough and effective than brush application. The units shown in figure 2 are still being tested after 20 years of exposure. Window units treated with a WR (prepared as described at the end of this report) are also in good condition after 20 years' exposure (fig. 4) even though all the original paint has weathered away. Untreated painted window units decayed severely and actually fell off the test fence after only 6 years' exposure (fig. 5).

Applying WR or WRP to Wood

Applying WR or WRP solution to the surface of unfinished wood by brushing or by dipping is an effective treatment for siding and exterior millwork (doors, window sash, door and window frames, sills, moldings, fascia), for wood fencing, and for lawn furniture.

The following steps are suggested for application to new wood:

(1) If treated siding or millwork is purchased, only freshly cut surfaces need to be brush or dip treated.

(2) Wood that has not been factory treated can be treated by either brushing or dipping. Dipping is more effective. Care should be taken to treat ends of boards and joints between boards. Open joints should be caulked after treating and priming.

(3) Freshly treated wood must be allowed to dry. If the treatment is applied with a brush, 2 days of warm favorable drying weather must be allowed before painting. If dipped for 10 seconds or more, 1 week of favorable drying weather is necessary before painting. If enough time is not allowed for most of the solvent to dry from the wood, the paint applied over it may be slow to dry, or may discolor or dry with a rough surface that looks like alligator leather.

When applying WR or WRP to previously painted wood, loose paint must be removed, the WR or

Figure 4.—Closeup view of water-repellent-protected window unit and frame after 20 years' exposure. Firm wood resists penetration by the knife blade.
M 145 288-16

WRP should be brushed into the joints only, and excess solution wiped from the paint surfaces with a rag. Two days of favorable warm drying weather must be allowed before repainting.

Whether treatment is to new wood or previously painted wood, particular care should be taken to apply the solution well at the ends of boards, at joints between boards, and to all newly exposed wood such as drill holes. Some homeowners do not realize that water will climb by capillary flow up the back of bevel siding from the lap joints. WR or WRP applied to lap joints of the siding does a good job of preventing capillary flow. Accordingly, places that should be treated well include the butt and lap joints of horizontal siding, edges and top and bottom ends of vertical siding, and the edges and corner joints in window sash, sills, window frames, doors, and door frames. Often bottoms of doors and window sash are overlooked. These are areas where water can penetrate deeply and cause extensive damage if not treated. Treatment with WR or WRP will eliminate many such problems later.

Using WRP As An Exterior Natural Finish

The color and appearance of weathered wood can be affected, to a marked degree, by mildew. In most parts of the country, mildew grows on the wood surface and gives it a dark gray, blotchy, and unsightly appearance. In contrast, in very dry climates or in coastal regions where salt atmospheres may inhibit the growth of mildew, weathered wood often has a clean, silvery appearance.

The color of weathered wood is influenced to a lesser degree by highly colored wood extractives in such woods as western redcedar and redwood. These extractives gradually diffuse to the surface and produce a dark-brown color. This color may persist in protected areas not exposed to direct sun and rain. The extractives can be removed by scrubbing with detergent and rinsing.

A clean golden-tan color can be achieved in the weathering of wood by treating the surface to retard the accumulation of wood extractives and mildew. The treatment, originally recommended by the California Redwood Association,[3/] consists of applying a WRP to the wood surface. This method of finishing also is recommended for other siding species and for natural finishing of exterior plywood, brushed plywood, and low grades of lumber that do not hold paint well. The treatment also reduces warping and cracking and prevents water staining at edges and ends of wood siding. The WR can be used for this purpose, but will not protect against mildew growth and subsequent graying.

3/ CRA, San Francisco, Calif.

The first application of the WRP is usually short-lived. When the wood surface starts to show blotchy discoloration caused by extractives and mildew, it should be cleaned by mild scrubbing with a detergent, followed by rinsing with water. Then another liberal brush application of water-repellent preservative solution should be applied.

Frequently, it is necessary to clean and re-treat smoothly planed wood surfaces after the first year of exposure. After cleaning and re-treating, the treatment should last much longer and need be refinished only when the surface starts to show an uneven discoloration pattern or small black spots indicating the start of mildew. The treatment will be more durable on weathered or rough-sawn surfaces because they absorb a greater quantity of solution than does a smooth surface.

Pigments in the form of colors in oil and tinting colors can also be added to the WRP solution to give a desired color effect and improve durability. A quantity of 4 to 6 fluid ounces of color per gallon of solution is usually adequate. Pigmented WRP should be applied to the full length of a course of siding without stopping, to avoid the formation of lap marks. Lap marks would also be minimized by applying two coats, the second coat applied before the first dries. Penetrating pigmented stains such as described in USDA Forest Service Research Note FPL-046 "Forest Products Laboratory Natural Finish," are considered much more durable than the WRP-type finish and can always be applied to wood previously finished with the WRP after the WRP-treated wood has had 1 year or more of weathering.

Figure 5.—Closeup view of decayed untreated window unit frame. Window unit fell apart after 6 years' exposure.
M 145 288-8

When wood weathers naturally, it is important to use nails that are highly resistant to rusting. Iron nails rust rapidly and produce a severe brown or black discoloration around the nail. Stainless steel and aluminum nails are corrosion-resistant and prevent such difficulties.

It is recommended that, for use in climates where mildew growth may be a problem—such as the southeastern part of the United States— WRP's should be prepared using exterior-grade varnish. Better performance of a WRP for these areas can be achieved by increasing the amount of pentachlorophenol to 2-3/4 cups per gallon.

Typical WR and WRP Solutions

Ingredients

WR and WRP solutions are widely made and distributed commercially and are available in most paint and lumber stores. Formulas for preparing these wood treatments are:

Ingredient	Approximate quantity for 1 gallon of Water repellent (WR)	Approximate quantity for 1 gallon of Water-repellent preservative (WRP)
Pentachlorophenol concentrate 10:1 (40%) a/	None	1-3/4 cups
Boiled linseed oil b/	1-1/2 cups	1-1/2 cups
Paraffin wax	1 oz	1 oz
Solvent (turpentine, mineral spirits, or paint thinner)	Add to make 1 gal	Add to make 1 gal

a/ Other preservatives used commercially include copper naphthenate, copper-8-quinolinolate, and bis (tri-n-butyltin) oxide. Recent Forest Products Laboratory exposure studies show that pentachlorophenol is a more effective mildewcide than copper naphthenate, which in turn is better than copper-8-quinolinolate or bis (tri-n-butyltin) oxide. In some states, PCP concentrate may be a restricted pesticide and unavailable.

b/ Exterior-grade varnish can be used in place of boiled linseed oil. If so, use twice the volume shown for linseed oil.

Mixing

Melt the paraffin wax in the top unit of a double boiler or some other container heated by hot water.

DON'T USE A DIRECT FLAME OR HEAT NEAR A FLAME SUCH AS THE PILOT LIGHT ON A STOVE—THE PARAFFIN WAX WILL IGNITE.

The solvent should be at room temperature (60° to 80°F) before mixing. While vigorously stirring the solvent, slowly pour in the melted paraffin. After the paraffin wax and solvent are mixed, add—in order—linseed oil or varnish (and penta concentrate if WRP). Stir until the mixture is uniform.

The ingredients may separate if the solution is stored at low or freezing temperatures. If this happens, warm the solution to room temperature and stir to redissolve the ingredients.

Safety First

In mixing and applying WR or WRP, care should always be exercised. The safest place to do the mixing is outdoors. The solutions are volatile, flammable mixtures. Don't breathe their vapors or expose them to flame or sparks. It is wise to wear protective clothing on the hands and arms and to take care that the solution is not splashed in the eyes or on the face. Be especially careful using WRP, as these solutions contain toxic materials.

CAUTION: Wood preservatives (a type of pesticide) can be injurious to man, animals, and plants. Therefore, for safe and effective usage, it is essential to follow the directions and heed all precautions on the labels. Some wood preservatives are toxic to humans and animals and may be root poisons and defoliants for plants. It is, therefore, advisable to wear rubber gloves and protective masks (approved for use with pesticides) and to cover nearby plant life when using any material, such as the FPL Natural Finish or a water-repellent preservative, containing preservative chemicals. The application of preservatives using any spray method can be especially hazardous and extra precautions must be taken. Avoid spraying whenever possible.

DO NOT USE ANY PRESERVATIVES INDOORS UNLESS THEY HAVE BEEN SPECIFICALLY APPROVED AND RECOMMENDED FOR SUCH USE.

Store preservatives in original containers under lock and key—out of reach of children and pets—and away from foodstuff. Use all preservatives selectively and carefully. Follow recommended practices for the disposal of surplus preservatives and preservative containers.

NOTE: Registrations of preservatives are under constant review by the Environmental Protection Agency and the Department of Agriculture. Use only preservatives that bear a Federal registration number and carry directions for home and garden use. Because the registration of preservatives is under constant review by State and Federal authorities, a responsible State agency should be consulted as to the current status of this preservative.

For Further Information

Several Forest Service Research Notes touch on various phases of wood finishing. Single copies of these are available from the Forest Products Laboratory, Forest Service, U.S. Department of Agriculture, Box 5130, Madison, Wis. 53705.

USDA Forest Service Research Notes:

FPL-046 Forest Products Laboratory Natural Finish
FPL-0123 Wood Finishing: Painting Outside Wood Surfaces
FPL-0126 Wood Finishing: Temperature Blistering of House Paints
FPL-0127 Wood Finishing: Intercoat Peeling of House Paints
FPL-0128 Wood Finishing: Mildew on House Paints
FPL-0129 Wood Finishing: Cross-Grain Cracking of Oil-Base House Paints
FPL-0131 Wood Finishing: Discoloration of House Paint by Blue Stain
FPL-0132 Wood Finishing: Discoloration of House Paints by Water-Soluble Extractives in Western Redcedar and Redwood
FPL-0133 Wood Finishing: Finishing Exterior Plywood
FPL-0135 Wood Finishing: Weathering of Wood
FPL-0232 How to Refinish Wood Siding with Latex Paints