

ASPECTS OF EUCALYPTUS WAFERBOARD

by

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ABSTRACT

Eucalyptus species is already well established in the pulp and paper industry. The species noted fast growth, especially in the tropical regions, provides a special resource for utilization in providing shelter in these regions, which have some of the highest growth in population rates. Waferboard industry, though well established in most developed countries, is rare in most developing countries. The fact that waferboard requires relatively low quality wood, as opposed to plywood, is an important factor and makes it more appealing for development in these regions.

Technical information on utilization of *Eucalyptus* for waferboard is lacking in most aspects, and most of the experimentation has mainly been conducted on preliminary levels only. The study was carried out to fill that gap and provide data which can lead to increased utilization of the species in the waferboard industry. This was achieved by the making of panels under standard conditions and performing standard tests on the specimens cut from the laboratory made panels.

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1. INTRODUCTION

In most parts of the world, increasing attention is being paid to the material resource required to maintain and generate the energy necessary to sustain community and other activities. In countries where the standards of living remain low, limited resources now demand greater attention. The use of a particular resource will depend on several factors. These include the resources' availability and renewability, and the disturbance to the environment entailed in their extraction and harvesting. The amount and type of energy required in production and subsequent processing, application, and disposal is also quite important.

Wood-based materials are more attractive in this respect than most alternative materials. The amount of raw material required and the cost of protecting the environment at all stages, up to the processing of products, is much less with wood than with aluminium, steel, or concrete (2). The energy required for conversion of raw material into products of comparable use such as sawn wood, reinforced concrete, cast iron and aluminium alloys is in ratio of 1:8:16:39 (2). The energy required to extract logs, to manufacture and to transport the materials to a building site and to construct some house sections, is much less for wood based materials than for common alternatives (2), in most situations. Thus, due to these advantages and the rising energy costs, it is justified to predict that the worlds' dependence on forest products will increase. Some of the data used in earlier calculations for projection of global requirements of industrial wood by year 2000, were collected during a period of rapid economic growth and thus neglected the full impact of the energy crisis (33). There is nevertheless, an

unmistakable upward trend in the consumption of all forest products. Admittedly, the rise may turn out to be more modest than some projections. A very large increase in the demand for paper and allied products is expected, followed by a considerable increase in demand for wood based panels. These are products which do not require large quantity and/or high quality logs. In the future more emphasis will be placed on growing smaller logs in shorter rotation and the utilization of wood waste for reconstituted products.

Future supply of forests is a controversial issue. Certainly, increased needs for food, water, and living space will reduce the availability of land for wood production. There are three ways in which greater efficiency can be attained:

1. By growing more wood of the required properties per unit area and time.
2. By utilizing the tree more completely.
3. By taking other more active steps to meet the essential needs of the end-user with minimum amount of raw material.

This last approach may take the form of modifying and rationalizing the patterns of use of wood through greater quality control and by using different and more efficient methods of pulping, paper making, and flaking. Further, the same goal may be achieved in the other industries by modification of construction methods, building codes, wood protection methods, etc. The investigation, of increased utilization of Eucalyptus is approached from this view.

The forest products industry, in most parts of the world, is facing a decline in both quality and quantity of available logs, to satisfy the growing domestic demand, for producing lumber and plywood. However, the total wood supply is such that the industry can be maintained at present operating levels and can, perhaps, be expanded. This will necessitate changes in using the total raw material base. Production lines will have to be modified or changed altogether to use new types of raw material or other species, particularly for panels.

Eucalyptus species are not usually considered for most structural applications (4). They are used in particleboard plants in Brazil and Australia, either partly or exclusively (18). Further, this species has been shown to be ideally suited for composition board and composite materials. Studies conducted in Zambia, using *Eucalyptus grandis*, indicated that the species forms satisfactory waferboard panels (18). Investigation using species of similar density range carried out at Washington State University showed that flakeboards made from alder (*Alnus rubra*) had excellent bending properties (24). There is an increased acceptance of Eucalyptus paper and panel products in the forest products markets today (18).

Eucalyptus has many characteristics which make it suitable for use in flakeboards, particularly those of structural panels, therefore, research should be conducted to determine the production parameters for manufacturing suitable panels. Short rotation Eucalyptus trees provide wood of lower density, which makes it possible to produce a lower density panel product than can be obtained with available conifers. Older trees, with much higher density, higher extractive content and poor bonding by conventional adhesives, present challenges which are

responsible for the limited use of Eucalyptus at the present time and therefore must be addressed, too.

Eucalyptus grows with a relatively straight bole. For this reason, it is readily converted into wafers. Boards made from Eucalyptus are expected to cost less because of lower material requirement, ease of cutting and nailing. The product is expected to have better structural properties than waferboards made of comparable species.

There are several unknowns as far as the successful use of Eucalyptus for waferboard panel production is concerned. Suitability of the material has to be studied carefully. Excessive shrinking and drying defects are common with wood of young rapidly grown trees. The performance of Eucalyptus waferboard panels will be assessed, using standard tests to determine if they are suitable for structural applications. These tests and property requirements, formulated by Canadian Standards Association, series CAN 3-0188-M are accepted in the building industry. A thorough investigation of the boards made under controlled conditions will make it possible assess the potential of this product. The development of a data base and performance information on structural waferboards of Eucalyptus, will greatly aid in the species' utilization. This panel product could supplement presently inadequate plywood supplies in Kenya. Because of the shrinking raw material base, development of such Eucalptus panels would make it possible for manufacturers to continue to operate at the present or at an increased level. The new panel product should fit in with the current panel applications in Kenya .

2. SCOPE AND OBJECTIVE OF THIS STUDY

One of the major challenges faced in wood utilization is the great variation in properties between and within species. This necessitates a proper understanding of the properties of individual species before it can be utilized for commercial purpose.

Eucalyptus spp is currently one of the most promising species for planting in sub-tropical and tropical countries. Its utilization in the pulp and paper industry is well recognised and documented. In the panel board industry however, the use of *Eucalyptus* species is quite limited. Problems indicated with its utilization for composite boards include: high shrinkage, poor gluing properties, high energy consumption for processing due to high density, and poor flaking properties (18). With the increasing importance of these species in the tropics, there is a need to provide a data base which can increase its utilization in the growing composite board industry.

This study was undertaken in an effort to contribute to the data base, which can lead to enhanced utilization of *Eucayptus* species in the relatively young flakeboard industry, and particularly in structural waferboard panel industry for tropical applications.

The following steps were carried out in this study:

SCOPE AND OBJECTIVE OF THIS STUDY / 6

1. Literature review to determine the appropriate production parameters for producing structural waferboard panels from Eucalyptus sp,
2. preparation of experimental structural panels,
3. investigation of the strength properties of these panels and,

3. LITERATURE REVIEW

3.1. EFFECT OF PH ON WOOD GLUING

Generally, most wood are acidic. This has been demonstrated for a number of known species (4). Certain woods, have been responsible for damage to other materials, for instance corrosion of metals, by western red cedar (23). Acidity in wood has also been shown to cause other utilization problems. A study by Kitahara and Mizumo (22) indicated that the strength properties of particleboard were correlated with pH of the wood chips and that in some cases, the acid in wood is sufficient to precure urea resin adhesive. Chugg and Gray (8) reported a change of joint strength with a change in wood pH.

Goto and Onishi (15) on the other hand, observed that the relationship between glue joint strength and pH were not significant. Rather specific gravity and wettability were more important factors. Sakuno and Goto (34) indicated that pH affected wettability of wood having specific gravity lower than 0.8.

A study of tropical woods (27) showed that removal of extractives improved the wettability and increased the pH of the wood in all species tested. The gelation time of urea formaldehyde to which wood extractives were added, increased with increased amount of cold or hot water extractives (27). With cold water extractives it was observed that both gelation time and pH of the wood were affected.

3.2. EFFECT OF WOOD SPECIFIC GRAVITY

Extensive work has been carried out on the effect of specific gravity on gluing of wood. A study done on gluing of fifteen species using urea formaldehyde and casein adhesives, showed that urea formaldehyde adhesive was less sensitive to specific gravity variations than casein (8).

Troop and Wangaard (38) investigated twenty-nine tropical American woods on their gluing characteristics. Resorcinol formaldehyde and phenol resorcinol formaldehyde adhesives were used for gluing. They generally, observed that with increasing specific gravity the joint strength increased but the amount of wood failure decreased. Interference of the glue curing, as evidenced by high variability of bond strength values, was noted. This was attributed to probable wood surface defects or the nature of chemical components, such as gums, resins, oils, and waxes which occurred at various levels in the wood extract. They concluded that, due to variations in specific gravity within the species, interference from extractives was partly obscured in the shear strength data.

On the effect of specific gravity, pH and wettability on the strength of glue joints, Freeman (10) found that specific gravity was of prime importance. High specific gravity woods were found to give higher bond strength.

Carstenen (5) working with both softwoods and hardwoods observed that the wide variation of density, grain configuration, moisture content and surface characteristics were well reflected in gluability.

Goto and Onishi (15) studied the effect of specific gravity, wettability, pH, and percentage of extractives on gluability of eighteen tropical woods. They found a high degree of correlation between glue joint strength and specific gravity. The glue joint strength increased as specific gravity increased. Of the four factors investigated, specific gravity was shown to have the greatest effect on glue joint strength, followed by wettability.

Yagishita and Karasawa (40), in their investigation of fourteen hardwood species, reported that the correlation between bond strength and specific gravity was such that, the higher density species showed higher values of strength with phenol formaldehyde adhesive and melamine formaldehyde. Urea-formaldehyde did not show a similar trend.

In their study, Sakuno and Goto (34) attempted to find the point at which specific gravity ceases to have significant effect on glue joint strength. They studied thirty six species using both urea formaldehyde and phenol formaldehyde glues. Their conclusion was that, up to 0.8, specific gravity had a significant effect on the joint strength. At specific gravities higher than 0.8, the effect of specific gravity was found to be insignificant. Wood failure, however, showed the opposite trend. There was no correlation between wood failure and specific gravity for values of 0.8 and lower. However, wood with specific gravities above 0.8 showed significant correlation at the 5% level. Similar results were obtained by Moriya (26), working with red lauan sawn boards.

3.3. EFFECT OF EXTRACTIVES

Numerous studies have shown that extractives significantly affect gluing properties of wood. However, little is known about the nature and a mode of action of these extractives. The problem is compounded by the fact that extractive type and quantity vary within species and individual trees therefore findings with one species may not be universally applicable to others.

Troop and Wangaard (38), in their review of the subject, cited investigations which have shed some light on this matter. Rapp† studied the gluing characteristics of Lignum Vitae (*Guaiacum officinale* L.), a species which is known to be among the most difficult to glue. He investigated the possibility of various surface treatments to improve the gluing performance by removal of, at least, part of the resinous extractives contained in the wood. The solvents used included carbon tetrachloride, benzene, acetone, and ethyl alcohol. None of these solvents seemed to improve the gluability of the specimen. However, application of 10% caustic soda (NaOH) solution wiped on the surface, allowed to react for 10 minutes and then removed by washing with water, improved the bond strength. This test showed an increase in both the shear strength and wood failure. A combination of sanding and caustic soda treatment gave still higher values of shear strength and wood failure.

A study carried out by Gamble Brother Inc, indicated that washing of the surface of teak, which contains oily extractives, with acetone improved joint shear

† original not seen, cited from Troop and Wangaard (38)

strength and wood failure substantially. Troop and Wangaard (38), on the other hand reported that Burma teak does not necessarily require preliminary treatment when glued with resorcinol adhesive, but may require pretreatment if permanence and maximum bond strength is needed, as in high quality furniture and plywood.

In his review of extractives effect on wood, Narayanamurti (27) pointed out that the distribution of extractives varies both vertically and horizontally in a tree bole. Extractives affect the hygroscopicity, swelling, and shrinkage of wood. The effect of extractives in gluing of wood is of special importance. Narayanamurti (27) reported that different researchers observed, during testing of glue joints, that sapwood which has a lower extractives content, can be glued better under some conditions and with certain adhesives than heartwood. He found that the gluability of *Diospyros melaxylon* is improved by extraction. Further, other species which in turn were treated with extractives from *Dispyros melaxylon* lost considerable glue joint strength.

Narayanamurti et al (28) studied the effect of extractives on the setting of adhesives. Wood extractives affect the bonding of wood but their effect may vary from glue to glue. Viscosity and rigidity of the glue was found to be affected by the presence of extractives. The effect of extractives on the modulus of rigidity and time of gelation in adhesion was investigated, using teak and *Acacia Catechu* with animal and urea formaldehyde glues. They found that the extractives increased the gelation time and lowered the rigidity of glues but the effect depended on the species being glued. Teak extractives were more inhibitory than

those of the Acacia.

Chugg and Gray (8) reported that extractives lower surface tension of the wood surface and reduce wettability, which is essential for a strong glue bond. Most wood species contain traces of low molecular weight fatty acids or resins which could easily migrate to the surface during drying or hot-pressing and form a refractory surface layer. Thus, if the surface tension of the wood becomes sufficiently low, the glue tends to display a definite receding angle of contact of some parts of the surface so that they remain completely free from the glue. This behavior is more likely with glues possessing a high surface tension such as cold setting phenol formaldehyde or urea formaldehydes.

Hancock (16) reported that Douglas fir veneer dried at high temperatures, had fatty acids concentrated at the surface. These fatty acids were shown to reduce the wettability of veneer and to affect the rate and depth of penetration of the glue. In a study on surface inactivation of wood at high temperatures, using microsections of white spruce (*Picea glauca* Moench Voss) that had extractives removed by varying degrees, Chow (7) found that the extractives may serve as catalysts for oxidation. Wood exposed to temperatures over 180 degrees Celcius for prolonged time periods suffered additional oxidation and pyrolytic degradation, particularly at the surfaces.

Goto and Onishi (15) in their study of tropical woods reported that the relationship between the glue joint strength and percentage of extractives either by cold or hot water was not significant. However, glue joint strength increased

with the decrease of percentage of extractives in the ether solubles when the effect of specific gravity was excluded. They further reported that the value of pH and percentage extractives were less important on the glue joint strength than wettability and specific gravity. Sakuno and Goto (34) made similar observations in their investigation of thirty six tropical species. They reported that specific glue joint strength (shear strength of glue joint/ specific gravity) was significantly correlated to the percentage of ether extracts for urea formaldehyde adhesive (for woods of specific gravity 0.8 and below). There was no significant correlation at the 5% level of significance between glue joint strength and percent ether extractables of wood species with specific gravity higher than 0.8.

Chen (6), using eight tropical woods studied the effect of extractive removal on adhesion and wettability. Solvents used for extraction were sodium hydroxide solution (10%), acetone and alcohol-benzene. The woods were glued with urea formaldehyde and resorcinol formaldehyde adhesives. Glue joint strength was improved by all treatments for all, but one species. With 10% solution of sodium hydroxide, some species were affected more by the treatment than the others, regardless of the adhesive used. Extractive removal improved wettability and increased pH of the wood in all the species examined. A positive linear correlation existed between wettability and joint strength of blocks glued with urea formaldehyde. However, no such correlation was observed for resorcinol formaldehyde; possibly due to the fact that the resorcinol condensation is more pH tolerant than that of the urea formaldehyde system.

Imamura et al (20), observed that phenol formaldehyde adhesive was inhibited in

kapur wood (*Dryobalanops* sp). These extractives were also found to inhibit the curing of paint films with unsaturated polyester resin varnish type. The same study also showed that only certain fractions of the extractives exerted an inhibitory effect while the rest of the extractives had no inhibitory effect. Onishi and Goto (29) investigated the effect of wood extractives isolated with the aid of cold water, boiling water and alcohol-benzene on the gelation time of urea formaldehyde resin and the resulting compressive strength of the glued material. The results showed that gelation time of urea formaldehyde increased with the increase of added amounts of cold and boiling water extractable wood extractives. For the cold water wood extractives, it was observed that the gelation time decreased with decreasing pH. Alcohol-benzene extractives also exhibited an effect on the gelation time of urea formadehyde though to a lesser extent than did the soluble water extractives.

In summary, previous work on the effect of extractives on the resin chemistry indicates, that extractives in general affect gelation time and the ability of the adhesive to wet the wood surface. Hence, with high extractive content woods the resin chemistry has to be adjusted in order to maintain optimum condition during the resin polycondensation process.

3.4. EFFECT OF WETTABILITY

The intended function of an adhesive cannot be fully realized unless the adhesive spreads effectively over the wood surface. Surface irregularities have to be minimized and good chemical contact with the wood substrate made, so that a

permanent, high strength bond is developed between the glue and the wood. The physical quantities which determine effectiveness of spreading and adhesion are the surface tension of the wood surface and interfacial tension between the adhesive and the wood.

It has been clearly demonstrated that glue bond strength is correlated to surface wettability (1, 2, 3, 6). The adhesion theory relating to surface energetics has been studied extensively (10). The concept of equilibrium contact angle and the methods of measuring it on wood surfaces have been developed (10). Most of the wettability measurements on wood have been made using homogeneous liquids, such as water. An investigation on wetting of wood by liquids of varying surface tension, pointed out the probability that bond strength is closely dependent upon wetting, spreading, and surface tension of the adhesive (15). Thus, it is ascertained that bond quality is significantly influenced by the wettability, resin content, and wood surface characteristics (18). Viscosity of glue was found to increase more rapidly in woods of high wettability than those showing non-wetting behavior (12).

Changes in wettability are caused by contamination of the wood surface by active chemicals which reduce surface tension (19). The chemicals may be traces of low molecular weight fatty or resin acids which migrate, from the interior, to the surface and lower the surface tension and reduce wettability. Tests based on wet-shear strength, percent of wood failure and percent of delamination have shown that a positive correlation exists between contact angle and glue bond quality (25).

In some cases, extractive removal has improved wettability and increased pH (33). At the same time, a reverse correlation has been demonstrated with specific gravity. Wettability decreased with increasing specific gravity. Further glue joint strength increased with increase in wettability when the effects of specific gravity are excluded (30).

The interaction of specific gravity, wettability and adhesive was studied by Sakuno and Goto (35). Specific glue joint strength (shear strength /specific gravity) and wettability were significantly correlated at the 5% level for all species with specific gravity of 0.8 and below for both urea formaldehyde and phenol formaldehyde resins. No correlation was observed between specific glue joint strength at the 5% level for species having specific gravity higher than 0.8.

3.5. RESIN TYPE

Although the possibility of using phenol formaldehyde resin as an adhesive was recognized at the end of nineteenth century, it was not until the 1930's that liquid phenolic resin were used commercially (24). Presently, phenolic resins are the most widely used adhesives in plywood, waferboard, glulam beams production as well as, boat construction.

Most commercial phenolic resins are prepared by the reaction of formadehyde with specific phenols. The phenolic resin is manufactured in two basic ways: an initial addition reaction between phenol and formaldehyde to form alcohols, and a subsequent condensation reaction in which a phenol alcohol reacts either with

itself or with another phenol. Then, in turn, these products react with each other by further condensation reactions.

In the initial step, if the phenolic resin is prepared with excess of formaldehyde at high pH (10-12), the product will be a phenol alcohol with a number of methylol groups. When this resin is subjected to heat or acid, it is capable of further polymerization. The process can be slowed down at any stage between the addition reaction and final cure, by cooling. The reaction can be accelerated by increasing the temperature or adding an acid catalyst. Thus, the polymerization of this resin is continuous and whereby it bears the name "one stage resin" or resole.

On the other hand, if the phenolic resin is prepared with an acidic catalyst and less than one mole of formaldehyde per mole of phenol, the resin will be a linear, structure similar to dihydroxydiphenylmethane and the chains will be phenol terminated. The limited amount of crosslinking in the structure of this resin makes it permanently fusible and soluble; it will cure only upon addition of a curing agent, consequently it is normally referred to as a "two stage resin" or novolac. The resin used in this experiment was a one stage resin, PF-IB947

4. MATERIALS AND METHODS

4.1. WOOD FURNISH

Eucalyptus globulus logs were secured for the experiment from the Richmond Forest Products Laboratory in Richmond, California. Two logs of 20 cm and 30 cm in diameter and approximately 60 cm in length were split into quarter billets. The billets measured 15 cm in length. To facilitate waferizing, the billets were soaked in warm water for 30 days, then air-dried to a moisture content of about 65%. The moisture content was determined by a cubed cutting sample of 4 cm from the billets, and determining their weight gain, which was all attributable to the water absorbed. Wafers were produced at the CAE plant, using their disc waferizer. Total weight of wafers produced was about 34 Kilograms at around 65% moisture content. The wafers had an average length of 2 cm and width of 0.5 cm. All wafers had equal thickness of 0.76 mm. All dimensional measurements of wafers were determined using a vernier calipers capable of measuring 1/100 mm, with 30% random sampling of all the wafers (based on weight). After drying to 7% moisture content in an electrically heated drum dryer; the wafers were screened to remove fines using a of 6-mesh plate screen. This removed most of the fine particles which constituted about 12% (determined by weighing) of the wood furnish, (Fig 3). About 50% of these wafers were used for the extractive procedure.

4.2. EXTRACTION

TAPPI 12 SO-75 (41) procedure for removal of extractive was used, with slight modification due to the size of the particles involved. This involved use of ethanol-benzene (50:50) to extract waxes, fats, and some resin and possibly some of the wood gums. Hot-water was used to extract tannins, gums, sugars, starches and colouring matter.

Five grams of wafers were wrapped with a nylon cloth material and placed in a paper thimble positioned in the Soxlet apparatus. Extraction with 200 cc solvent was carried out for 48 hours, with the liquid kept boiling briskly to effect siphoning from the extractor of no less than two times per hour.

After extraction with ethanol-benzene, each sample was transferred to a Buchner funnel to remove excess solvent with suction and both the thimble and the sample were washed with ethanol to remove the excess ethanol-benzene. The sample was then returned to the thimble for further extraction with 95% ethanol until the siphoning solvent turned colorless. Again, the sample was transferred to a Buchner funnel to remove the excess solvent with suction and washed with distilled water to remove the ethanol. The wafers were then transferred to 100 cc Erlenmeyer flask containing water and heated for 12 hrs in a hot-water bath. The water was kept boiling before the sample was added and the flask was surrounded by boiling distilled water. After this process, each sample was filtered and washed with 500 cc of boiling distilled water. This was followed by drying the wafer sample to 7% moisture content. Moisture content was determined by

use of a Moisture Teller.

4.3. BLENDING AND PRESSING

Powdered phenolic resin and wax were applied separately in a rotary drum, at the Wood Composites Lab of Forintek Canada Corp. in Vancouver. Wax emulsion was applied first at 1% level (2% solids) while the resin was proportioned at 3% and 6%.

Mats were formed by hands with the wafers oriented randomly. Boards were pressed in a hot-press of 38x38 cm (15x15 in), heated to 205 degrees celsius, using a pressure of 4133 Kpa (600 psi). Press closing time was 45 seconds. This time was found to produce boards of relatively uniform density profile, throughout the thickness of the board.

Pressing time was five minutes for all boards. This time was experimentally found to be adequate for insuring full resin cure and minimum heat damage on the panels. However, optimum pressing conditions were not established for this experiment.

In all, eight panels were made by this process. Four were made with extracted wafers and four with unextracted wafers. All the panels were of the same trimmed size; 1.27 cm (7/16 in) in thickness, and 34.56 cm (14 in) in width and length.

4.4. BENDING STRENGTH TESTS

Fig 1 and 2 show the test specimen cutting pattern used for each treatment. Testing included modulus of rupture (MOR), modulus of elasticity (MOE) and internal bond (IB) for both panel types. All tests were done in accordance with CSA Standards CAN3-0188.0-78, for Mat-Formed Wood Particlesboards and Waferboard. Computation of strength values was in accordance with procedure shown in the standards. Dimensions for each bending test specimen were 11.1 mm in thickness, 75 mm in width and 254mm in length (span). Only dry bending and IB tests were carried out.

Fig 1. Pattern for cutting testing specimen for panel I

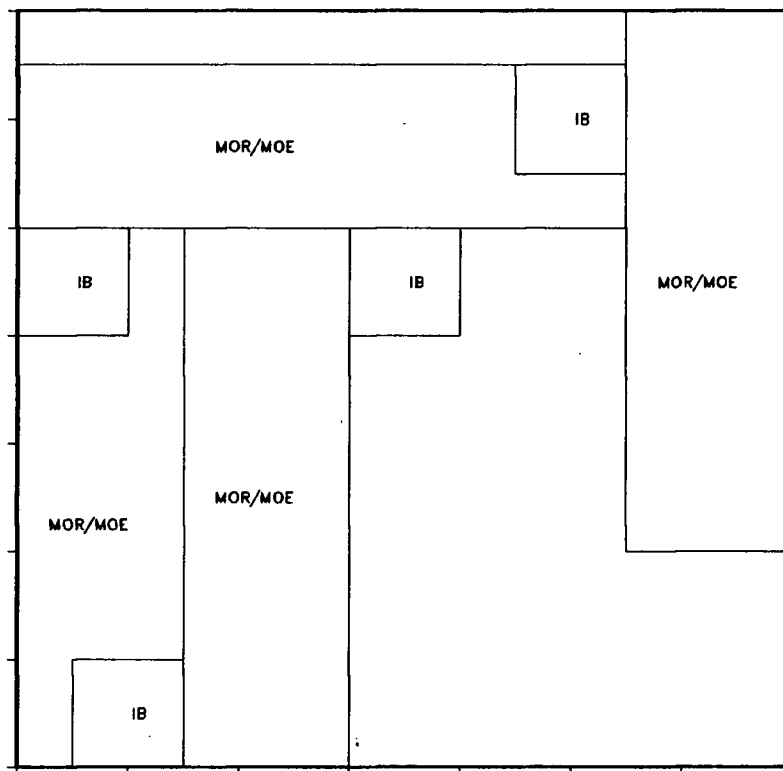
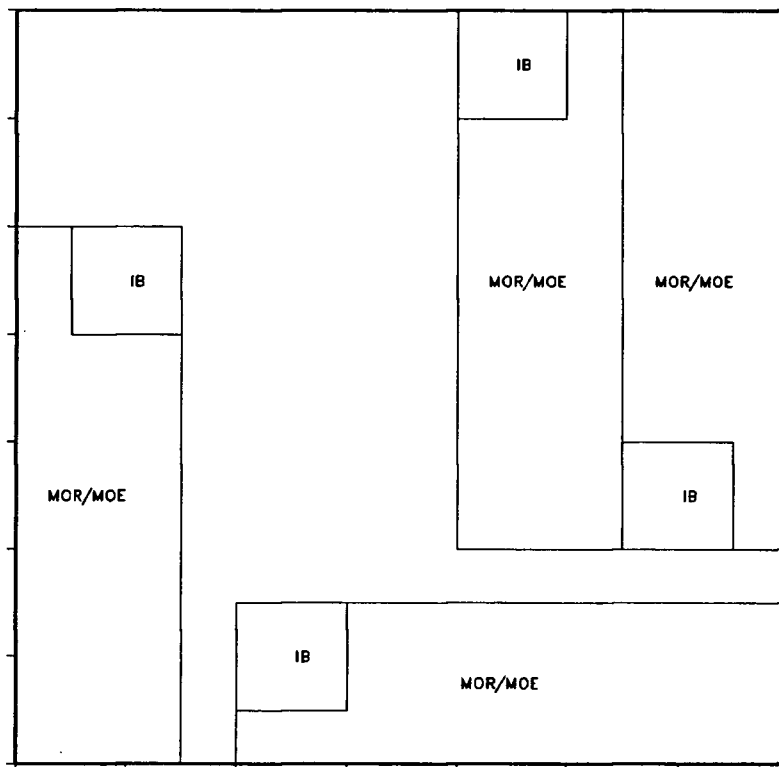


Fig 2. Pattern for cutting testing specimen for panel II



5. RESULTS AND DISCUSSION

5.1. WAFERS

Figure 2 shows an example of the wafers produced and used for board preparation. Average dimensions were about 72 mm in length, 22 mm in width and 0.76 mm in thickness. Thickness and length were kept roughly constant for all the particles produced. Width varied greatly as shown in Fig 3.

The particle dimensions conform with the recommended standards which indicates that wafer thickness may range from 0.254 mm to 1.5 mm. The width be 5 to 60 times the size of thickness, and length be 40 to 100 times the size of thickness (24). The average ideal wafer dimensions are thickness 0.64 mm, width 20 mm, and length of 68 mm (25).

Wafer length-to-thickness ratio is a better measure of the effect of wafer length and thickness on bending strength and stiffness than either of the two considered separately (26). The average wafer value, computed as a slenderness ratio for this experiment was 98.6. This value is related to an array of vital board characteristics such as contact area in the mat, mechanical properties of the finished board, and consumption of the binder per given set of board properties. Since this value is lower than values encountered with other species, eg aspen = 100, a high resin requirement was indicated.

Another parameter, known as flatness ratio, a factor of wafer width and thickness has a great influence on board separately (26). It is a better measure

of the effect of wafer width and thickness on board bending strength and stiffness than either of the two dimensions considered separately. The average flatness ratio computed for the wafers used in this experiments was 30, representing a rectangular cross section ($w/t > 1$).

Wafer surface area per unit weight is a highly important parameter, which must be considered in resin application if adequate bonding is to be achieved. The surface area per unit weight of a given wafer not only depends on the density of the wood species from which it is produced, but also on the wafer size (27). Geimer (28) identifies wafer size as having enormous influence on surface area per unit weight.

The average length to width ratio was 3.3, slightly higher than 3 required to provide orientation (27). MOE and MOR are highly dependent on the wafer size and geometry in boards with randomly arranged wafers. Water absorption (WA) in waferboard is also affected by wafer geometry (28). Its effect on water adsorption can probably be related to the change in surface area covered by the resin and its bulking effect. Geometry may also affect water absorption indirectly by causing mechanical restraint in the board from stresses induced by crushing and density variation.

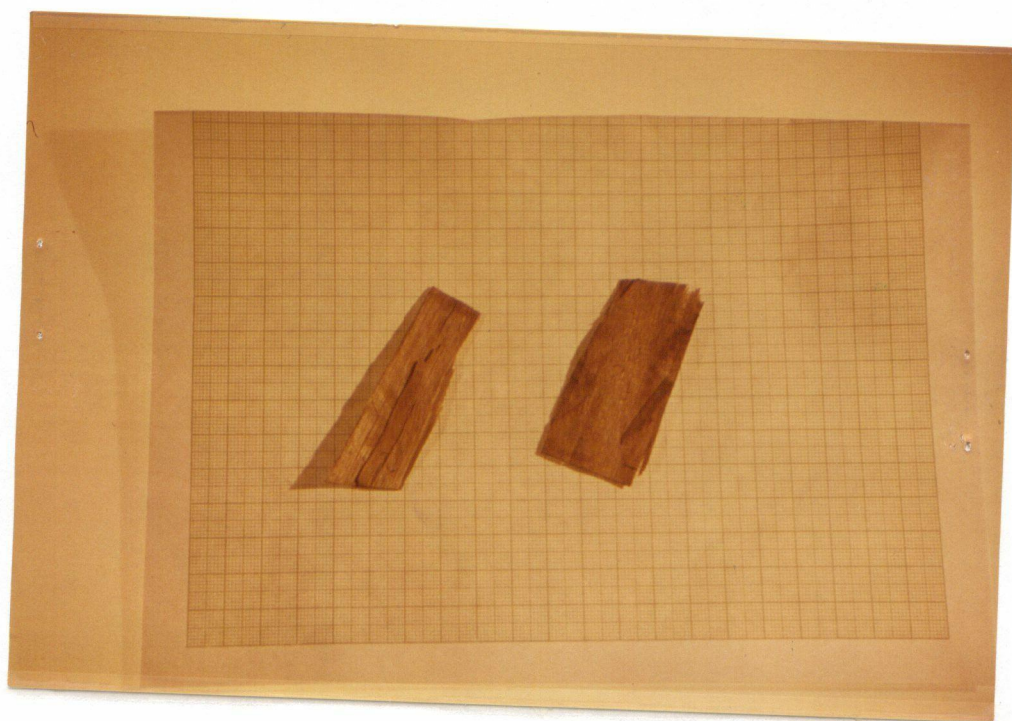
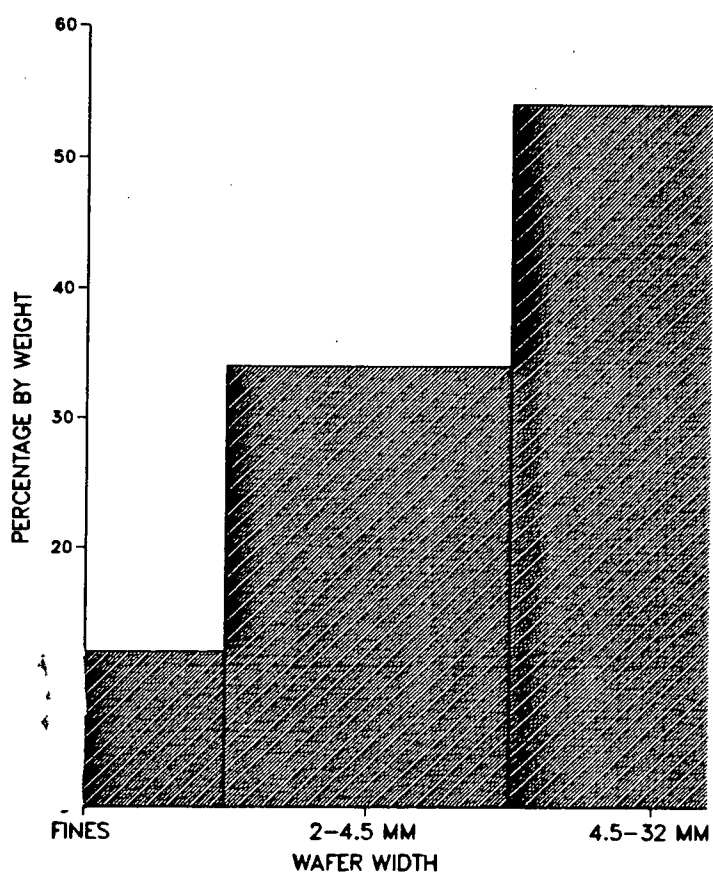


Fig. 3: Sample of Wafers produced and used for panel preparation.

FIG 3. WAFER DISTRIBUTION



5.2. BENDING STRENGTH

Two properties are usually measured: modulus of rupture (MOR), and modulus of elasticity (MOE). Technically, modulus of rupture is the computed maximum fiber stress in the extreme upper and lower surface fibers of the specimen under test. This value is regarded as the breaking strength of the product under test and is reported in pascals (Pa). Other terms used interchangeably for this parameter are bending strength and flexural strength. Modulus of elasticity (MOE) refers to stiffness of the material and it is also reported in pascals. In waferboard, both of these properties are determined perpendicular to the face of the panel. MOR and MOE, as indicated earlier, were determined by centre loading.

MOE and MOR are particularly important for boards to be used for structural application, such as sheathing, subflooring, siding and industrial parts requiring strength, and rigidity. In most applications, waferboard is used as an alternative to plywood. Canadian Standards Association recommends minimum values of dry MOE and MOR in the range of 4,000 MPa and 18.6 MPa, respectively.

5.2.1. Modulus of Rupture

Tables 1 to 4 give the statistical analyses of MOR of the panels tested. As it is evident from Table 3, the effect of changing resin content, from 3% to 6%, and removal of extractives had significant influence on MOR. Thus the design model was significant at the 5% level. The combined effect of resin change and extractive removal accounted for 60% of the total MOR increase as indicated by

the coefficient of determination of 0.600. Variation throughout the experiment was quite moderate as indicated by a coefficient of variation of 16.407. Further analysis of the data, Table 4, showed that removal of extractives had a more pronounced effect than an increase in the amount of resin. This is explained by the higher F value. There was no significant interaction between the extractive content change and resin change. It was, therefore, possible to analyze the effect of each individual treatments.

5.2.1.1. Effect of Extractive Removal

Tables 3 and 4 show the effect of extractive removal. Although the increase MOR was statistically insignificant at the 5% level, there was, nevertheless a considerable increase in MOR values namely 46% at 3% resin level, 43% at 6% resin level, the average increase being 44.5%. As it is observable from Table 6 however, the standard deviations for all the means did not differ very much.

The increase in MOR values is an indication of improved bonding strength between individual wafers. Since bonding is both a physical and a chemical phenomenon, extractive removal was expected to reduce the negative extent of the chemical effect. Tables 3 and 4 show that a reduction in inhibition did occur to some extent, though it was statistically insignificant. Similar observations were observed by Troop and Wangaard(38), using teak wood. The effect therefore must be dependent on other factors.

5.2.1.2. Effect of Resin Increase

Tables 3 and 4 show the effect of doubling the amount of resin applied on board MOR. There was some increase in MOR values: 2.3% for extracted wafers, 3.4% for unextracted wafers and an average increase of 4.3%. The increase in MOR values attributable to doubling the resin content showed no significant effect at the 5%, or 1% level.

Ideally, an increase in resin level should increase MOR values as it provides more bonding sites. There is, however, an optimal level beyond which, increased levels of resin would have a negative effect on the strength properties of board, as well as being wasteful. For most commercial operations (40), with low density hardwoods and softwoods as sole source of raw material, a resin level of 3% is common. Recommended level is at 5% (40). As can be observed from Tables 1 to 4, the optimal application level for powdered resin is lower than 6%. The expected level for liquid resin should be less, since it flows easily.

5.2.2. Modulus of elasticity

Table 8 shows the effect of both extractives removal and resin change on MOE values of the experimental board. Generally, the mean values were quite high, three to four times higher, as compared to other commonly used species like aspen (Appendix 4). This difference is explained by fact that the species used is a particularly high-density hardwood species. Tables 7 and 8 list these values. The combined effect of both treatments had a considerable effect but statistically insignificant at the 5% level. The treatment accounted for about 58% of the increased MOE values whereas the coefficient of determination was 0.575. Coefficient of variance was 16.612.

5.2.2.1. *Effect of Extractive Removal*

Absence of extractives had the same effect on both MOE and MOR. An increase of 23% was realized at 3% resin content and a 36% increase was found for MOE values for the 6% resin level application. Both changes were statistically insignificant at the 5% level. There was a higher MOE increase at the high resin level compared to the lower one. Removal of extractives had the same effect on MOE values as the change of resin content.

5.2.2.2. *Effect of Resin Change*

Doubling of resin level from 3% to 6% resulted in a notable increase of the MOE of the specimen. There was a 39% increase in MOE values for boards made of extracted wafers, and 25% increase for boards made of unextracted wafers. The average increase was 32% (see Tables 7 and 8). As is evident from Table 7, the increase in MOE values, though considerably substantial, were statistically insignificant. Increase of resin level had a more pronounced effect on the strength properties than removal of extractives (Table 8). This is an indication that the optimal level of application for this particular experiment was higher than 3%.

5.2.3. **Internal Bond**

Tensile strength perpendicular to the surface of the board has been used for a long time, and is also referred to as internal bond. It is the best single measure of the quality of manufactured boards because it indicates the strength of the bond between flakes. It is an important test for quality control because it indicates the adequacy of the three most fundamental processes for board preparation; blending, forming, and pressing. Factors which affect internal bond include:

4. board density,
5. board thickness,

6. orientation of the flakes,
7. density profile,
8. moisture content,
9. resin type, distribution and level.

Both resin increase and removal of extractives affected internal bond. Table 12 shows that both treatments had a significant effect on the internal bond of the board at the 5% level. The treatments accounted for about 57% of the strength increase ($R\text{-squared}=0.57$). Coefficient of variation was about 16.6122, a constant value found for all the data. This is an indication of consistence in the experiment. Thus, it can be concluded that the model was statistically significant and the combined effect of both treatments was significant. The total increase in IB was 49%.

Individual treatments did not seem to have a significant effect on the internal bond values. Interaction between extractive removal and resin change was not significant, thus, the effects of the individual treatments could be investigated separately. The average values of internal bond, obtained were quite high compared to those obtainable with other species as evidenced in Table appendix 8.3. Sometimes the former were 3 to 4 times as high.

5.2.3.1. *Effect of Resin Change*

The increase of resin level from 3% to 6% had the same effect on the IB as it had on MOE and MOR. There was a substantial increase on the boards IB strength values with increased resin level (Tables 11 and 12). The increase was more pronounced with boards made of extracted wafers. All the changes in strength values were not statistically significant.

5.2.3.2. *Effect of Extractive Removal*

Tables 11 and 12 show the effect of extractive removal on the internal bond. Among the three strength properties investigated here, internal bond is the most sensitive indicator of the bonding strength and hence, the adhesion between resin and wafers. As indicated in the Table 11 removal of extractives did not change the internal bond value significantly. Viewed in percentage change, the increase was considerable at both resin levels; 22% increase at 3%, and 35% at 6% resin level. It was observed that removal of extractives had a more pronounced effect at the high resin level than at the lower levels. It is probable that the removal of extractives means that less resin is used in combating the negative extractive effect, and hence the amount applied is directly available for bonding the wafers together. Troop and Wangaard (38) did observe increased strength values with extractive removal.

Table 1. Analysis of variance for MOR data.

Source	DF	Sum of Squares	Mean Square	⁺ F Value
Model	3	3552.25	1184.08	14.03
Error	28	2363.75	84.42	
Corrected	31	5916.00		
Total				

Table 2. MOR Treatments and their F Values

Source	DF	ANOVA SS	⁺ F Value
Resin	1	190.133	2.25
Wafer	1	3362.00	39.82
Resin*Wafer	1	0.125	0.00

Table 3. MOR mean (Mpa) values for all treatments.

Resin	Sample size	Mean	+ MOR
3	16	53.56	
6	16	58.44	
Wafer			
Ext	16	66.25	
Unx	16	45.75	
Resin	Wafer	Sample size	MOR +
3	Ext	8	63.75
3	Unx	8	43.38
6	Ext	8	68.75
6	Unx	8	48.13

Table 4. MOR range and standard deviation for each treatment.

Resin level (%)	Specimen NO	Mean	Std Dev	Std Error	Minimum	+ Maximum
Wafers extracted						
3	8	63.75	7.722	2.730	52.00	74.00
6	8	68.75	9.407	3.326	58.00	84.00
Wafers unextracted						
3	8	43.38	10.528	3.722	27.00	59.00
6	8	48.13	8.871	3.136	35.00	60.00

Table 5. Analysis of variance MOE data.

Source	DF	Sum of Squares	Mean Square	⁺ F Value
Model	3	277939991.60	92264666.86	10.88
Error	28	238482904.63	8517246.59	
Corrected	31	516422896.22		
Total				

Table 6. MOE Treatments and their F Values

Source	DF	ANOVA SS	⁺ F Value
Resin	1	144461752.53	16.96
Wafer	1	122415800.78	14.14
Resin*Wafer	1	13062438.28	1.53

Table 7. MOE mean (Mpa) values for all treatments.

Resin	Sample size	Mean	+ MOE
3	16	53.56	
6	16	58.44	
Wafer			
Ext	16	66.25	
Unx	16	45.75	
Resin	Wafer	Sample size	MOE +
3	Ext	8	12778.44
3	Unx	8	17027.88
6	Ext	8	16843.00
6	Unx	8	12963.31

Table 8. MOE range and standard deviation for each treatment.

Resin level (%)	Specimen NO	Mean	Std Dev	Std Error	Minimum	+ Maximum
Wafers extracted						
3	8	14079.38	2505.800	88.934	10007.00	18223.00
6	8	19606.63	3089.76	1092.400	15620.00	23250.00
Wafers unextracted						
3	8	11477.50	2160.640	763.900	9916.00	16277.00
6	8	14449.13	3684.422	1302.3.640	10849.00	22802.00

Table 9. Analysis of variance for IB data.

Source	DF	Sum of Squares	Mean Square	⁺ F Value
Model	3	279400.38	93133.46	12.45
Error	28	209490.50	74.81	
Corrected	31	488890.88		
Total				

Table 10. IB treatments and their F Values

Source	DF	ANOVA SS	⁺ F Value
Resin	1	2926.13	0.39
Wafer	1	276396.13	36.94
Resin*Wafer	1	78.1	0.01

Table 11. IB mean (Kpa) values for all treatments.

Resin	Sample size	Mean	IB
3	16	511.125	
6	16	530.25	
Wafer			
Ext	16	613.50	
Unx	16	427.75	+
Resin	Wafer	Sample size	IB
3	Ext	8	602.50
3	Unx	8	419.75
6	Ext	8	624.75
6	Unx	8	435.75

Table 12. IB range and standard deviation.

Resin level (%)	Specimen NO	Mean	Std Dev	Std Error	Minimum	+ Maximum
Extracted Wafers						
3	8	602.50	72.016	25.461	510.00	686.00
6	8	624.75	79.430	28.083	507.00	750.00
Unextracted Wafers						
3	8	419.75	109.514	38.719	200.00	509.00
6	8	435.75	80.240	28.369	295.00	553.00

6. CONCLUSIONS

This study was done on limited quantity of wood material and the results therefore do not necessarily reflect the behavior of the species as a whole. More sampling is required on all the species provenances before any definite conclusion can be made. General conclusions, however, can be made from the tests conducted under this study.

1. Eucalyptus spp can provide suitable dry bending MOR, MOE and IB to be used in the waferboard industry.
2. There is need to develop a more specific adhesive for high- extractive-content, hardwoods species in order to obtain high quality products, and not to use adhesives which were mainly developed for softwoods.
3. Treatment of the species to reduce extractives effect on gluability is a possibility. This may increase costs of productions, but the easy and fast growth of the species reduces the extent of extractive occurrence in the species .

To enhance utilization of this species, and many other tropical species, future research should be directed at studying the gluing phenomenon on these species.

7. REFERENCES

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8. APPENDICES

8.1. APPENDIX 1 : STATISTICAL ANALYSIS OF THE DATA.

SAS

14:18 TUESDAY, NOVEMBER 3, 1987 1

ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
RESIN	2	3 6
WAFER	2	EXT UNX

NUMBER OF OBSERVATIONS IN DATA SET = 32

SAS

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ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: MOR

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	3552.25000000	1184.08333333	14.03	0.0001	0.600448	16.4072
ERROR	28	2363.75000000	84.41964286		ROOT MSE		MOR MEAN
CORRECTED TOTAL	31	5916.00000000			9.18801626		56.00000000

SOURCE	DF	ANOVA SS	F VALUE	PR > F
RESIN	1	190.12500000	2.25	0.1446
WAFER	1	3362.00000000	39.82	0.0001
RESIN*WAFER	1	0.12500000	0.00	0.9696

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ANALYSIS OF VARIANCE PROCEDURE

MEANS

RESIN	N	MOR
3	16	53.5625000
6	16	58.4375000

WAFER	N	MOR
EXT	16	66.2500000
UNX	16	45.7500000

RESIN	WAFER	N	MOR
3	EXT	8	63.7500000
3	UNX	8	43.3750000
6	EXT	8	68.7500000
6	UNX	8	48.1250000

SAS

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ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
RESIN	2	3 6
WAFER	2	EXT UNX

NUMBER OF OBSERVATIONS IN DATA SET = 32

SAS

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ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: MOE

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	277939991.59375000	92646663.86458330	10.88	0.0001	0.538202	19.5826
ERROR	28	238482904.62500000	8517246.59375000		ROOT MSE		MOE MEAN
CORRECTED TOTAL	31	516422896.21875000			2918.43221503		14903.15625000

SOURCE	DF	ANOVA SS	F VALUE	PR > F
RESIN	1	144461752.53125000	16.96	0.0003
WAFER	1	120415800.78125000	14.14	0.0008
RESIN*WAFER	1	13062438.28125000	1.53	0.2258

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ANALYSIS OF VARIANCE PROCEDURE

MEANS

RESIN	N	MOE
3	16	12778.4375
6	16	17027.8750

WAFER	N	MOE
EXT	16	16843.0000
UNX	16	12963.3125

RESIN	WAFER	N	MOE
3	EXT	8	14079.3750
3	UNX	8	11477.5000
6	EXT	8	19606.6250
6	UNX	8	14449.1250

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ANALYSIS OF VARIANCE PROCEDURE

CLASS LEVEL INFORMATION

CLASS	LEVELS	VALUES
-------	--------	--------

RESIN	2	3 6
-------	---	-----

WAFER	2	EXT UNX
-------	---	---------

NUMBER OF OBSERVATIONS IN DATA SET = 32

SAS

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ANALYSIS OF VARIANCE PROCEDURE

DEPENDENT VARIABLE: IB

SOURCE	DF	SUM OF SQUARES	MEAN SQUARE	F VALUE	PR > F	R-SQUARE	C.V.
MODEL	3	279400.37500000	93133.45833333	12.45	0.0001	0.571498	16.6122
ERROR	28	209490.50000000	7481.80357143		ROOT MSE		IB MEAN
CORRECTED TOTAL	31	488890.87500000			86.49741945		520.68750000

SOURCE	DF	ANOVA SS	F VALUE	PR > F
RESIN	1	2926.12500000	0.39	0.5368
WAFER	1	276396.12500000	36.94	0.0001
RESIN*WAFER	1	78.12500000	0.01	0.9193

SAS

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ANALYSIS OF VARIANCE PROCEDURE

MEANS

RESIN	N	IB
3	16	511.125000
6	16	530.250000

WAFER	N	IB
EXT	16	613.625000
UNX	16	427.750000

RESIN	WAFER	N	IB
3	EXT	8	602.500000
3	UNX	8	419.750000
6	EXT	8	624.750000
6	UNX	8	435.750000

SAS

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RESIN=3

TTEST PROCEDURE

VARIABLE: MOR

WAFER	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
EXT	8	63.75000000	7.72287881	2.73044999	52.00000000	74.00000000	UNEQUAL	4.4137	12.8	0.0007
UNX	8	43.37500000	10.52802383	3.72221852	27.00000000	59.00000000	EQUAL	4.4137	14.0	0.0006

FOR HO: VARIANCES ARE EQUAL, F'= 1.86 WITH 7 AND 7 DF PROB > F' = 0.4324

----- RESIN=6 -----

VARIABLE: MOR

WAFER	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
EXT	8	68.75000000	9.40744386	3.32603367	58.00000000	84.00000000	UNEQUAL	4.5115	14.0	0.0005
UNX	8	48.12500000	8.87110075	3.13640775	35.00000000	60.00000000	EQUAL	4.5115	14.0	0.0005

FOR HO: VARIANCES ARE EQUAL, F'= 1.12 WITH 7 AND 7 DF PROB > F' = 0.8809

SAS

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RESIN=3

TTEST PROCEDURE

VARIABLE: MOE

WAFER	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
EXT	8	14079.3750000	2505.79995425	885.93406997	10007.0000000	18223.0000000	UNEQUAL	2.2242	13.7	0.0435
UNX	8	11477.5000000	2160.63819937	763.90096123	9916.0000000	16277.0000000	EQUAL	2.2242	14.0	0.0431

FOR HO: VARIANCES ARE EQUAL, F'= 1.35 WITH 7 AND 7 DF PROB > F'= 0.7056

----- RESIN=6 -----

VARIABLE: MOE

WAFER	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
EXT	8	19606.6250000	3089.76230882	1092.39594041	15620.0000000	23250.0000000	UNEQUAL	3.0337	13.6	0.0092
UNX	8	14449.1250000	3684.42185569	1302.63983946	10849.0000000	22802.0000000	EQUAL	3.0337	14.0	0.0089

FOR HO: VARIANCES ARE EQUAL, F'= 1.42 WITH 7 AND 7 DF PROB > F'= 0.6539

SAS

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RESIN=3

TTEST PROCEDURE

VARIABLE: IB

WAFER	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
EXT	8	602.5000000	72.01587127	25.46145546	510.0000000	686.0000000	UNEQUAL	3.9436	12.1	0.0019
UNX	8	419.7500000	109.51418695	38.71911211	200.0000000	502.0000000	EQUAL	3.9436	14.0	0.0015

FOR HO: VARIANCES ARE EQUAL, F'= 2.31 WITH 7 AND 7 DF PROB > F'= 0.2911

----- RESIN=6 -----

VARIABLE: IB

WAFER	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
EXT	8	624.7500000	79.42966340	28.08262681	507.0000000	750.0000000	UNEQUAL	4.7347	14.0	0.0003
UNX	8	435.7500000	80.24026421	28.36921747	295.0000000	553.0000000	EQUAL	4.7347	14.0	0.0003

FOR HO: VARIANCES ARE EQUAL, F'= 1.02 WITH 7 AND 7 DF PROB > F'= 0.9793

SAS

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WAFER=EXT

TTEST PROCEDURE

VARIABLE: MOR

RESIN	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
3	8	63.75000000	7.72287881	2.73044999	52.00000000	74.00000000	UNEQUAL	-1.1619	13.5	0.2654
6	8	68.75000000	9.40744386	3.32603367	58.00000000	84.00000000	EQUAL	-1.1619	14.0	0.2647

FOR HO: VARIANCES ARE EQUAL, F'= 1.48 WITH 7 AND 7 DF PROB > F'= 0.6155

----- WAFER=UNX -----

VARIABLE: MOR

RESIN	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
3	8	43.37500000	10.52802383	3.72221852	27.00000000	59.00000000	UNEQUAL	-0.9759	13.6	0.3462
6	8	48.12500000	8.87110075	3.13640775	35.00000000	60.00000000	EQUAL	-0.9759	14.0	0.3457

FOR HO: VARIANCES ARE EQUAL, F'= 1.41 WITH 7 AND 7 DF PROB > F'= 0.6627

SAS

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WAFER=EXT

TTEST PROCEDURE

VARIABLE: MOE

RESIN	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
3	8	14079.3750000	2505.79995425	885.93406997	10007.0000000	18223.0000000	UNEQUAL	-3.9298	13.4	0.0016
6	8	19606.6250000	3089.76230882	1092.39594041	15620.0000000	23250.0000000	EQUAL	-3.9298	14.0	0.0015

FOR HO: VARIANCES ARE EQUAL, F'= 1.52 WITH 7 AND 7 DF PROB > F' = 0.5940

----- WAFER=UNX -----

VARIABLE: MOE

RESIN	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
3	8	11477.5000000	2160.63819937	763.90096123	9916.0000000	16277.0000000	UNEQUAL	-1.9678	11.3	0.0741
6	8	14449.1250000	3684.42185569	1302.63983946	10849.0000000	22802.0000000	EQUAL	-1.9678	14.0	0.0692

FOR HO: VARIANCES ARE EQUAL, F'= 2.91 WITH 7 AND 7 DF PROB > F' = 0.1824

SAS

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WAFER=EXT

TTEST PROCEDURE

VARIABLE: IB

RESIN	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
3	8	602.5000000	72.01587127	25.46145546	510.0000000	686.0000000	UNEQUAL	-0.5870	13.9	0.5667
6	8	624.7500000	79.42966340	28.08262681	507.0000000	750.0000000	EQUAL	-0.5870	14.0	0.5666

FOR HO: VARIANCES ARE EQUAL, F'= 1.22 WITH 7 AND 7 DF PROB > F'= 0.8026

----- WAFER=UNX -----

VARIABLE: IB

RESIN	N	MEAN	STD DEV	STD ERROR	MINIMUM	MAXIMUM	VARIANCES	T	DF	PROB > T
3	8	419.7500000	109.51418695	38.71911211	200.0000000	502.0000000	UNEQUAL	-0.3333	12.8	0.7443
6	8	435.7500000	80.24026421	28.36921747	295.0000000	553.0000000	EQUAL	-0.3333	14.0	0.7438

FOR HO: VARIANCES ARE EQUAL, F'= 1.86 WITH 7 AND 7 DF PROB > F'= 0.4306

SAS

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VARIABLE	N	MEAN	STANDARD DEVIATION
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----- RESIN=3 WAFER=EXT -----

MOE	8	14079.38	2505.80
MOR	8	63.75	7.72
IB	8	602.50	72.02

----- RESIN=3 WAFER=UNX -----

MOE	8	11477.50	2160.64
MOR	8	43.38	10.53
IB	8	419.75	109.51

----- RESIN=6 WAFER=EXT -----

MOE	8	19606.63	3089.76
MOR	8	68.75	9.41
IB	8	624.75	79.43

----- RESIN=6 WAFER=UNX -----

MOE	8	14449.13	3684.42
MOR	8	48.13	8.87
IB	8	435.75	80.24

SAS

OBS RESIN WAFER STDEV

1	3	EXT	2505.80
2	3	UNX	2160.64
3	6	EXT	3089.76
4	6	UNX	3684.42

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8.2. APPENDIX 2 : COMPARATIVE DATA FROM ANOTHER SPECIES

Appendix 8.3: STRENGTH PROPERTIES OF ASPEN WAFERBOARD PANELS(JESSOME 1979)
THICKNESS 1.27 CM (7/16 INCHES).

PROPERTY	NO. OF SAMPLES	MEAN VALUE	STANDARD DEVIATION	COEFFICIENT VARIATION
DENSITY (g per cu cm)	40	0.68	0.034	5
THICKNESS SWELLING(%)	39	8	2.8	35
MOR(MPA)	44	24	3.4	14
MOE(MPA)	44	3778	414	11
IB(KPA)	44	586	117	20

8.3. APPENDIX 3 : PHYSICAL AND CHEMICAL PROPERTIES OF THE WOOD USED

1. pH 4.2: determined by mixing four of air-dried groundwood with 400cc of distilled water. After two hours the water and ground wood was filtered and the filtrate used for pH determination using a standard Beckman pH meter. The pH was recorded after the meter had indicated a constant value. The pH average value of three samples was taken as the pH of the wood.
2. Specific gravity of the wood .71
3. Specific gravity of the panels .83