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LABORATORY EVALUATION OF EUCALYPTUS GRANDIS
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LABORATORY EVALUATION OF EUCALYPTUS GRANDIS AND EUCALYPTUS ROBUSTA FOR THE MANUFACTURE OF COMPOSITION BOARD

By

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ABSTRACT

LABORATORY EVALUATION OF EUCALYPTUS GRANDIS AND EUCALYPTUS ROBUSTA FOR THE MANUFACTURE OF COMPOSITION BOARD

By

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Samples of plantation grown trees were obtained representing two species of the genus Eucalyptus, Eucalyptus robusta and Eucalyptus grandis. The differences between the species could be established in terms of physical and mechanical wood properties. E. robusta had the higher specific gravity and correspondingly higher mechanical properties.

Various types of resin bonded composition boards were manufactured in the laboratory from the same materials. These boards exhibited properties which compared favorably with specifications spelled out in the commercial standard for mat formed particleboard.

Species characteristics were reflected in board properties only in the case of modulus of elasticity. Here the lower specific gravity species resulted in higher moduli at constant board density, confirming similar relationships reported in the literature.

In most other cases, the relationships between raw material characteristics and board properties were obscured by the dominating effect of board density, a variable that is difficult to control in the laboratory. Linear expansion in particular is very difficult to relate to species characteristics and to any other single variable.

To my parents Sidon Keinert and Astrid Keinert
who are the light of my being.

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I wish to express my sincere appreciation and admiration to my major professor, Dr. Otto M. Suchsland, whose experience, guidance, assistance and emotional support helped me get through the hardship of this investigation. I appreciate the keen interest and cooperation of the other committee members, Dr. Alan Sliker and Dr. Eldon A. Behr, both from the Forestry Department, Wood Science Section and Dr. Frank Mossmann from the Marketing and Transportation Administration Department. My thanks to Mr. Ivan G. Borton for his encouragement and assistance in fabricating samples and parts for composition boards manufacturing.

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CHAPTER I

INTRODUCTION

By world standards, Brazil is favored with a high rainfall and good soils. The inherited native forests were plentiful, but most of the coastal forests were heavily cut-over in the early centuries of European colonization.

During the past half century the wonderful forests of *Araucaria angustifolia* on the great basalt flows of the south have been eaten into for internal consumption and for export, and the mixed rain forests of the central and upper Amazon region remain as a potential reserve of raw material. Brazil, as a developing country, provides an economical environment ideal for the establishment of a multitude of new investments in technology directed to the utilization of wood. Industries like the pulp, paper and particle board industries demand large quantities of raw material close to the manufacturing plant and markets to be served. Large reforestation programs have been underway due to government incentives. Exotic species like Eucalyptus species and pine species are the preferred ones. Fast growing, short rotation, high rate of return on investment are some of the reasons for their widespread use.

Increased demand in Brazil for housing and furniture will encourage the adoption of efficient manufacturing techniques in these industries. In the furniture industry, these developments will parallel those that occurred in Europe and in the United States since the end of World War II, namely the introduction into furniture panel construction of the composition board core. These composition boards are made today in a variety of types and qualities depending on raw material availability and application. Whether or not the Brazilian housing industry will follow the North American example is much less certain. The preference in Brazil for masonry construction is possibly more a matter of tradition than the result of efforts to minimize construction costs. The large demand for structural wood panels as it exists in North America where it has resulted in the development of huge plywood capacity and more recently of structural composition board manufacture may not materialize in Brazil for some time to come.

This does not rule out, however, the feasibility of a structural composition board industry for specific market applications. Both the furniture core and the structural composition board industries will be based on tropical and subtropical Pines and Eucalyptus species as the most logical raw materials. In contrast to the genus Pinus which is rather homogeneous, the genus Eucalyptus includes a large number of species with widely varying properties.

Most laminated wood products reflect to a greater or lesser extent the properties of the species from which they are manufactured. These relationships between raw material properties and product properties have been the object of considerable research efforts. The development of the composition board industry in Brazil based on Eucalyptus species will greatly benefit by the investigation of these important technological relationships.

Objective

It is the objective of this study to make a contribution in this area by evaluating two Eucalyptus species as raw materials for the manufacturing of a variety of composition boards ranging from waferboard to medium density fiberboard.

The selection of the two species was limited by the availability of plantation grown Eucalyptus in the United States. The differences between the two species are relatively minor and do not represent the considerable variability of the genus as it may be found in Brazil.

CHAPTER II

CHARACTERISTICS AND IMPORTANCE OF EUCALYPTUS

1) Overview

The Eucalyptus species' original habitat are the vast lands of Australia. They occur in the states of Queensland, New South Wales, Victoria, Tasmania, South Australia, Western Australia and the Northern Territory (Figure 1). The story of the cultivation of the Eucalyptus species and the early recognition of their economic potential commenced with the establishment of small plantations in Southern Europe and North Africa over one hundred years ago. Since then the ease with which Eucalyptus species can be cultivated, their rapid growth, and their adaptability, have led to their widespread introduction into many countries, especially in those which are poorly endowed with forest resources. They have become such an important factor in the economy of some countries that millions of trees are now planted each year throughout the world. *[48]

Today, Eucalyptus species are planted in all five continents of the world confirming its importance as a raw material for manufactured products on a world wide scale.

The area on which Eucalyptus species are grown outside Australia (original habitat) rose from 0.7 million ha in 1950 to 3.7 million in 1974 [2] and it continues to increase rapidly. The annual growth increment of these new forests is estimated at 40 million m^3, compared with

*numbers in brackets indicate references.

an estimated 9 million m^3 harvested annually from some 12 million (ha) of commercial Australian forests. [15] Many Eucalyptus species grow naturally on soils of low nutrient status but they have the capacity to respond with increased growth rates to more fertile conditions and especially to higher levels of nitrogen and phosphorus. Most Eucalyptus will not thrive on soils that are alkaline and have quantities of free calcium or sulphate in the profile. The effects of climate on the growth of Eucalyptus species are as important as soils effects and as a result they are planted in large quantities in tropical and subtropical areas, like the states of Florida, California and Hawaii in the United States and almost all states in Brazil. (Carter, 1974) [10] reported yields ranging from 15.0 m^3/ha/year on low quality sites to 31.9 m^3/Ha/year on high quality sites for 10 year old E. grandis plantations in Southern Queensland. (Australia). (Rudolph et al, 1978) [59] reported growth rates in Brazil averaging 40 m^3 or more for 7 to 8 year old plantations. No data were available on growth rates for E. robusta. Some Eucalyptus species develop very high levels of growth stress within the bole which may cause severe end splitting in logs, distortion during sawing, and severe shrinkage during drying.

The causes of high stress levels are not well understood; the factors suspected include genotype, age, log size, growth rate, and lean. While it is clear that growth stresses can be high in very fast-grown trees, stress is generally less severe in larger logs than in smaller logs of the same age. Hillis and Brown [33]. Most of the

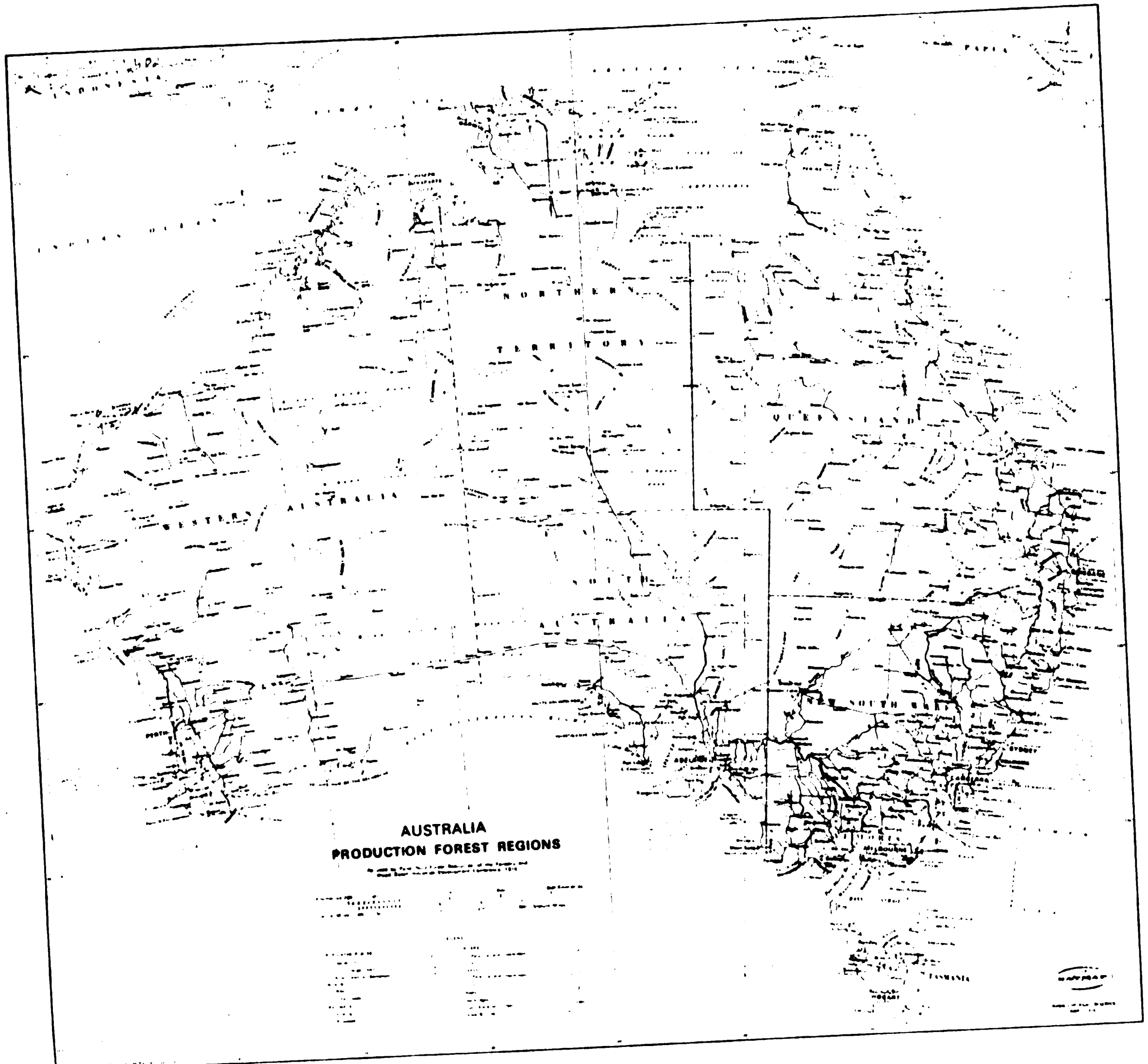


Figure 1. States and Territory of Eucalyptus Occurrence.
Source: Hillis and Brown 1978 [33].

research efforts dealing with silviculture, management, utilization and economics of Eucalyptus in Australia, Brazil, Africa and United States can be found in the Book Eucalypts for Wood Production by Hillis and Brown [33].

2) Eucalyptus Species in Brazil

Brazil is the leading Eucalyptus species planting nation totaling an area of about 1,500,000 ha [+](IBDF, 1977), thanks to the pioneering efforts of Edmundo Navarro de Andrade, who in 1910 working for the Forest Service of the Paulista Railway Company in the state of Sao Paulo, took into his hands the task of turning Eucalyptus to an important species in the economic realm. He was responsible for the planting of more than 38 million trees throughout his life. Eucalyptus are planted mainly in the states of Minas Gerais, Espirito Santo, Rio de Janeiro, Sao Paulo, in the southern Maranhao and Bahia in the northeast, Parana, Sta. Catarina and Rio Grande do Sul in the south and Mato Grosso and Goias in the center part of the country (Fig. 2).

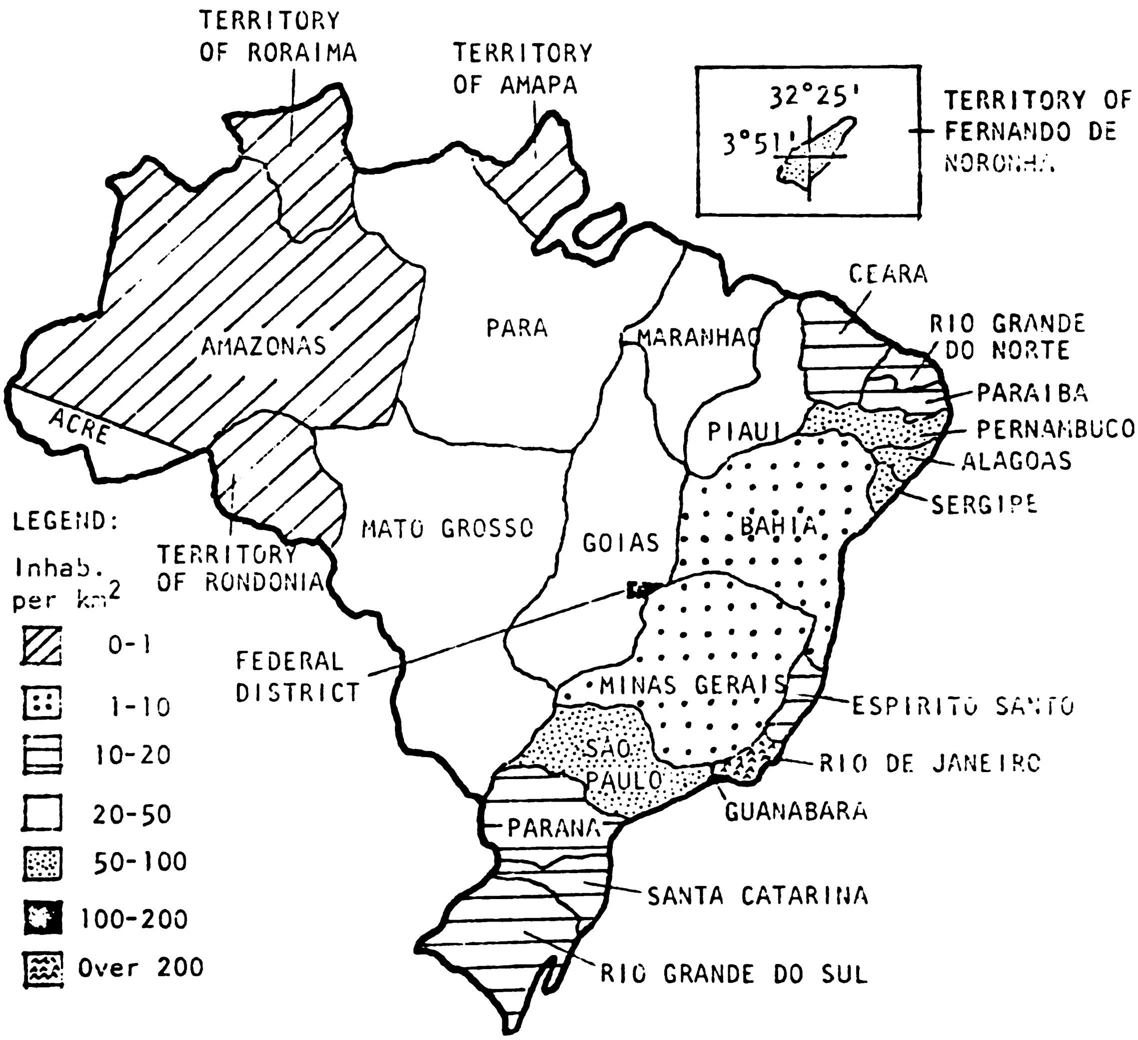
Source: [+]IBDF - Brazilian Institute for Forestry Development.

Table 1. Total Eucalyptus Planted Area (1977)

Unit: (ha)

State	Period	Total
Minas Gerais	67 - 77	663,640
Esp. Santo	67 - 77	126,573
Rio de Janeiro	67 - 77	8,986
Sao Paulo	67 - 77	318,775
Parana	67 - 77	46,812
Sta. Catarina	67 - 77	13,211
R. G. do Sul	67 - 77	16,596
Maranhao	72 - 77	16,419
Bahia	72 - 77	16,409
Mato Grosso	70 - 77	263,487
Goias	67 - 77	37,303
Total		1,511,782

Source: IBDF - Brazilian Institute for Forestry Development



Source: Instituto Brasileiro de Geografia e Estatistica, Anuario Estatistico do Brasil (Rio de Janeiro, 1977).

Figure 2.--Population density of Brazilian states.

About 80% of the Eucalyptus grown in Brazil are _Eucalyptus saligna_ and _Eucalyptus urophyla_ (known as _Eucalyptus alba_) with _Eucalyptus camaldulensis_, _Eucalyptus grandis_, _Eucalyptus globulus_, _Eucalyptus delegatensis_, _Eucalyptus tereticornis_, _Eucalyptus citriodora_, _Eucalyptus robusta_, and _Eucalyptus maideni_ making up the rest. Table 2 shows the planted area for _Eucalyptus grandis_ that is of interest for this particular study.

Table 2. Eucalyptus grandis planted area (1977)

Unit: (ha)

State	Total
Minas	95,147
Goias	5,347
Mato Grosso	28,610
R. G. do Sul	---
Parana	2,341
Bahia	---
Sao Paulo	7,492
Sta. Catarina	---
Esp. Santo	2,473
Overall	141,410

Source: IBDF - Brazilian Institute for Forestry Development.

Eucalyptus plantation management includes complete site preparation, fertilization, and weed control. Emphasis is almost exclusively on maximizing the production of wood fiber per hectare per year, for pulpwood, fiberboard, charcoal wood and similar products. Cultural practices and rotations are becoming fairly well defined. Common practice is to plant by spacing 3 by 2 or 3 by 1.5 meters, and harvest the first crop by clearcutting at age 7 or 8 years, when mean annual increment in cubic meters per hectare culminates. Stump sprouts are profuse, and at about 10 months of age are reduced manually to the best two or three per stump. The second crop is harvested at 7 or 8 years, and the process is repeated a third time, so that three crops are obtained over a 21 - 24 year period from one planting.

The site is then cleared and a new planting established to repeat the three-crop sequence. Management for combinations of products on longer rotations is just beginning; where sawlogs are desired, thinning is part of the regimen. E. citriodora is managed for a combination of essential oils such as citronella, which is extracted from the leaves, and pulpwood, poles, and some sawlogs. Two storied stand management of this species is fairly common. Rudolph [59] made a theoretical comparison of a management alternative like the one cited before (three crops) in 21 years directed to one single product, like pulpwood or charcoal against one based on one single crop in 21 years directed to multiple products, like lumber, plywood, etc., and came out with a net present worth in favor of this second one. As a result of this, depending on future market behavior, management of Eucalyptus species should be directed to multiple products production without impairing the charcoal and pulp and paper industries. Eucalyptus growth rates are nothing short of phenomenal. In well managed plantations, even without the benefit of improved seed and planting stock, yields averaging more than 40 cubic meters per hectare per year are common. On good sites and with improved seed and planting stock, yields up to 62 cubic meters have been obtained on 7 and 8 year rotations. Industrial roundwood production in 1973 (Table 3) was

Table 3. Industrial roundwood production, 1973

Product	Million cubic meters
Sawlogs	18.9
Logs for veneer and panel products	2.5
Pulpwood	4.5
Charcoal wood	20.0
Total	45.9

Source: IBDF - Brazilian Institute for Forestry Development.

Charcoal is the leading wood product in terms of raw material required. Brazil has negligible fossil fuels, and the rather large steel industry that is centered close to the iron ore sources in the southeastern state of Minas Gerais relies heavily on charcoal. In that area, natural stands of broadleaved species have been all but eliminated for conversion to charcoal. The wood volumes involved are huge. In

1973, it took 20 million cubic meters of wood to produce 11.9 million cubic meters of charcoal.

It takes 1.75 cubic meters of roundwood to produce 1 cubic meter of charcoal, and 3 cubic meters of charcoal are required to process a ton of steel. As the national forest disappears, the steel companies are recognizing the need to grow wood for charcoal by acquiring land and establishing their own plantations, and also encouraging other landowners to do so. National planning envisions tripling domestic steel output by 1985. [59] If that goal is realized, several million hectares of additional plantations will be needed to supply wood for charcoal. The lumber and panel products industries are concentrated in the southeast and south, close to the major markets. With the superb Araucaria forests disappearing, domestic softwood lumber will soon be scarce. Some lumber firms have already shifted location into the interior and to the Amazon Basin.

In these regions, scarcity of capital, limited number of species, marketability, inadequate access to the timber, and long transport to major markets (Fig. 2) are major obstacles in the establishment of lumber and panel product industries. Nevertheless, development is inevitable because the natural softwood resource in the eastern and southern regions is practically gone. The increasing exotic pine and Eucalyptus plantations, primarily in the southeast and south, will, in time, make a major contribution to the hardwood and softwood lumber and panel products supply, but the projected demand through the year 2000 will not be met without immediate large-scale expansion of pine and Eucalyptus plantations. Pulp and paper production increased from

418,000 tons in 1963 to more than 1.3 million tons in 1974. Nevertheless, consumption exceeds supply. Almost 300,000 tons of paper and paperboard were imported in 1974.

The timber in the Amazon Basin is not likely to be developed for pulp and paper products. Not only is access difficult, but the species are unsuitable using present manufacturing technology. Thus, the most logical approach to supplying adequate quantities of pulpwood for the near future is an immediate expansion of the planting program and the study of Eucalypts and pine species for an efficient utilization, primarily in the south and southeast. In these regions, there is an increasing number of fairly large pulp, paper, and other wood-fiber firms, many of them multinational companies operating entirely on plantation-grown timber, much of it produced on land which they own. Thus increasing research needs to be aimed at efficient utilization of plantation-grown Eucalyptus and pines for multiple products use.

3) Some Characteristics of the Species Studied.

Eucalyptus robusta Sm. - Swamp mahogany (syn E. multiflora poir). It is also known in Queensland as swamp messmate. "The size and strength of the tree, like that of the European Quercus robur, seem peculiarly to justify the name robusta." Thus wrote Sir J.E. Smith in his Specimen of the Botany of New Holland, published in London, 1793 [53]. The quotation concludes an ample description of the tree, and, if not the most fitting species to bear this fine title it must be remembered that it was applied when only half a dozen species of the whole genus had been encountered. Its original habitat being the coastal areas from southern New South Wales to Southern Queensland (Australia), it came early under the observation of the first white settlers. As it occurs mostly on river beds and in swampy localities, it is commonly known as swampy mahogany. It grows to a fairly large tree, clad with a reddish, soft brittle bark. The foliage is coarse, the individual leaves being broadly lanceolate and firm, with many lateral veins. Von Mueller [21] states that they are "lighter colour above and more shining beneath," but this is clearly an error; the reverse being the fact. The buds have a distinct rostrate opercula, and seven are frequently arranged in stellate on a long, flattened peduncle.

The fruits are elongate - ovoid, truncated, and when viewed from above, show a maltese-cross design that is a helpful guide to the preliminary identification of the species.

<u>Eucalyptus grandis Hill</u>. Rose gum, is also known in New South Wales as flodded gum toolur (syn. <u>E. saligna var. pallidivalvis</u>). This is a magnificent and useful tree whose claim to specific rank has suffered some reverse. First described by W. Hill, director of the Brisbane Botanic Gardens in 1862,[52] it was not formally recognized as distinct from <u>Eucalyptus saligna</u> until Baker and Smith in 1902 described it under the title <u>E. saligna var. pallidivalvis</u>. In 1918 Maiden lifted it from it's similars under the fitting name quoted before. The evolutionary changes that are operating on the whole genus present, in the era of today, no types more confused with one another, than <u>Eucalyptus grandis</u>, <u>Eucalyptus saligna</u>, <u>Eucalyptus botryoides</u>. Examples of each may be found so opposed in their obvious characteristics that

any suggestions of kinship is unreasonable, on the other hand, the merging of one type to the other may be so gradual that two individuals close together in the scale may present no discoverable difference.

The distinction between Eucalyptus saligna and Eucalyptus grandis is subtle and morphologically ill-defined. The oil of the former contains less Eucalyptol than that of the latter, and the timber of Eucalyptus saligna is darker in color and denser than the timber of Eucalyptus grandis, it is also less tough yet more durable. The young foliage and buds of Eucalyptus grandis are less often glaucous than its similars whilst its fruits are larger and generally coarser.

The original habitat of the tree extends from about Goulburn, New South Wales in the south to northern Queensland. Its greatest concentration is in the northern rivers district of New South Wales, where on the coastal belt and in the gullies of the foothills magnificent specimens stand straight and clean of limb in the glory of a clear blue grey bark, towering over the surrounding trees and undergrowth. The fruit is urceolate, either sessile or shortly pedicellate on an aneled peduncle, glaucous, with the valves prominently exserted. The valves are whitish from which feature the varietal name of the synonym suggested. [21]

4) Plantation Background.

The Eucalyptus species used in this study came from a small experimental plot planted October 15, 1971 near Palmdale, State of Florida.

According to the U.S. Forest Service Experimental Station in Lehigh Acres, Florida, the seeds of Eucalyptus robusta were from Immokalee Seed Orchard, Florida, and Eucalyptus grandis from Biggar Site, Lee County, Florida. Some of the trees were machine planted, others hand planted on an area of 25 x 30 meters with a 5 x 5 feet spacing. At the time of cutting, the trees were approximately 7 years old.

Average height was about 40 feet, average D.B.H. about 9.5 inches, and specimen trees were chosen according to uniformity of size (Figures 3, 4, 5).

Figure 3. Eucalyptus Plantation Experimental Plot.

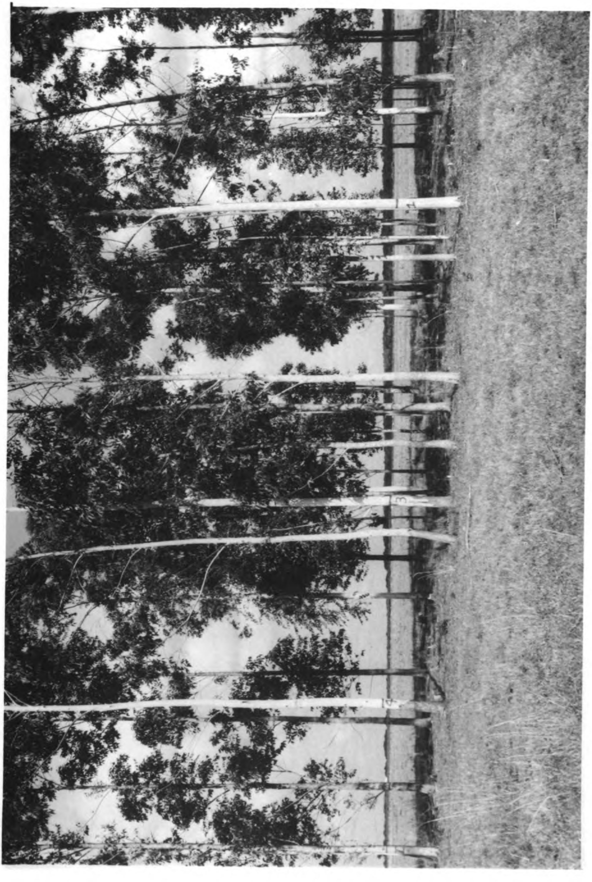


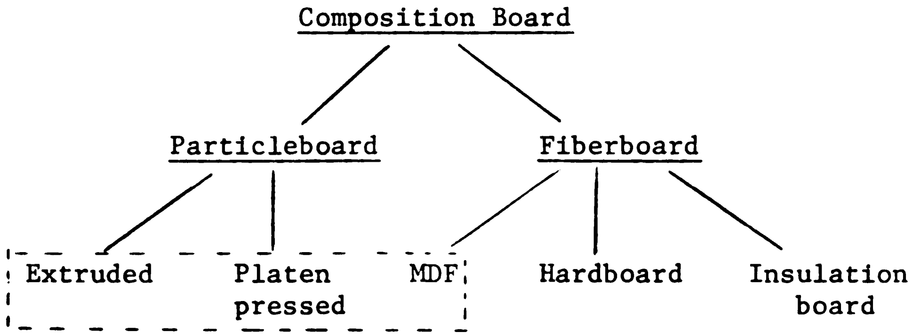
Figure 4. Eucalyptus robusta - stem and leaves.

Figure 5. Eucalyptus grandis - stem and leaves.

CHAPTER III

WOOD COMPOSITION BOARD

Composition boards are a combination of the solid wood converted into a variety of comminuted forms and a binder that can be added or generated during the manufacturing process. The quality of these products is determined largely by the quality of the glue bond (its completeness and permanence), by the geometry of the particles, and the species of wood used. Composition boards can be grouped into these categories:



Particleboard is made from wooden elements generally larger than the wooden cell. Fiberboard is made from fibers and fiber bundles having dimensions of the same order of magnitude as those of the wooden cell. Particleboard was invented 75 years ago by Henry Watson of Valparaiso, Indiana. A basic patent was issued by the U.S. Patent Office in 1905. This patent (Figure 6) shows clearly a flakeboard very similar to some types of board made today. Its industrial development which started in Europe is a result of economic wood (raw material) scarcity and the necessity of utilizing large quantities of wood residues. In the

No. 796,545. PATENTED AUG. 8, 1905.

H. F. WATSON.

COMPOSITE BOARD.

APPLICATION FILED OCT. 11, 1901. RENEWED JAN. 5, 1905.

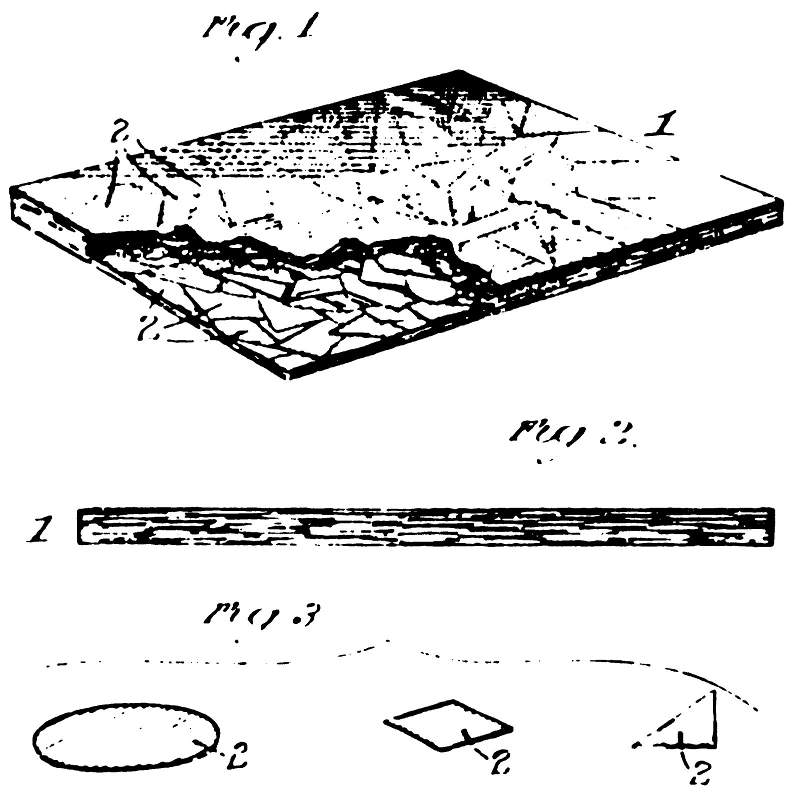


Figure 6. The Watson Patent - U.S. Patent No. 796, 545, August 8, 1905.

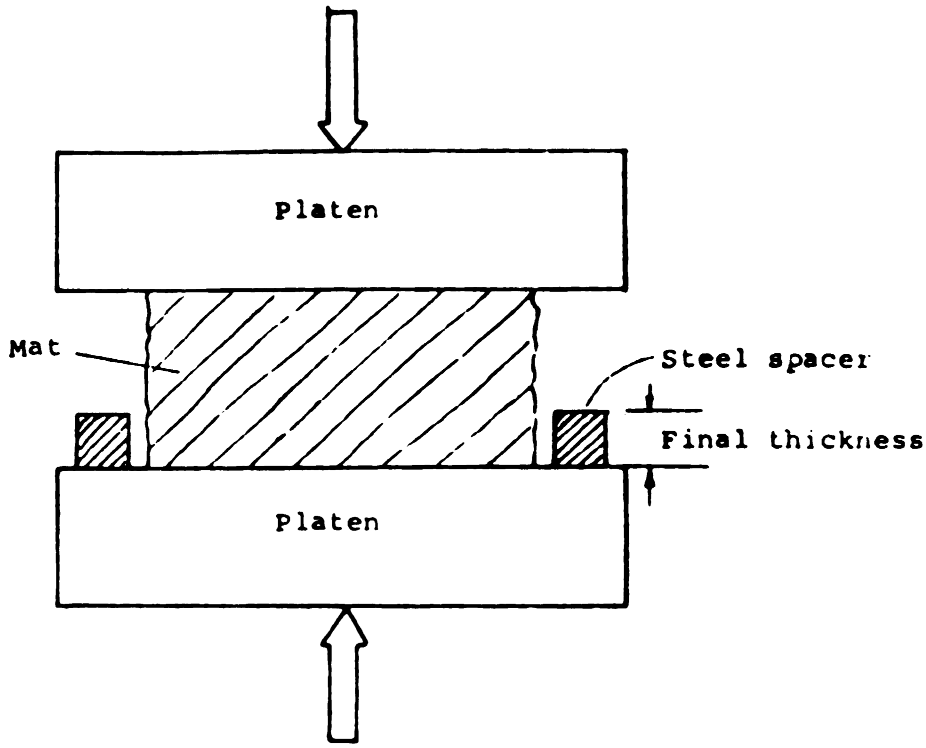
beginning, technology was simply transferred from Europe to the United States, but as demand patterns and the raw material basis changed from roundwood to cheaper residues, different process modifications occurred. Fiberboard and the recent medium density fiberboard are U.S. developments.

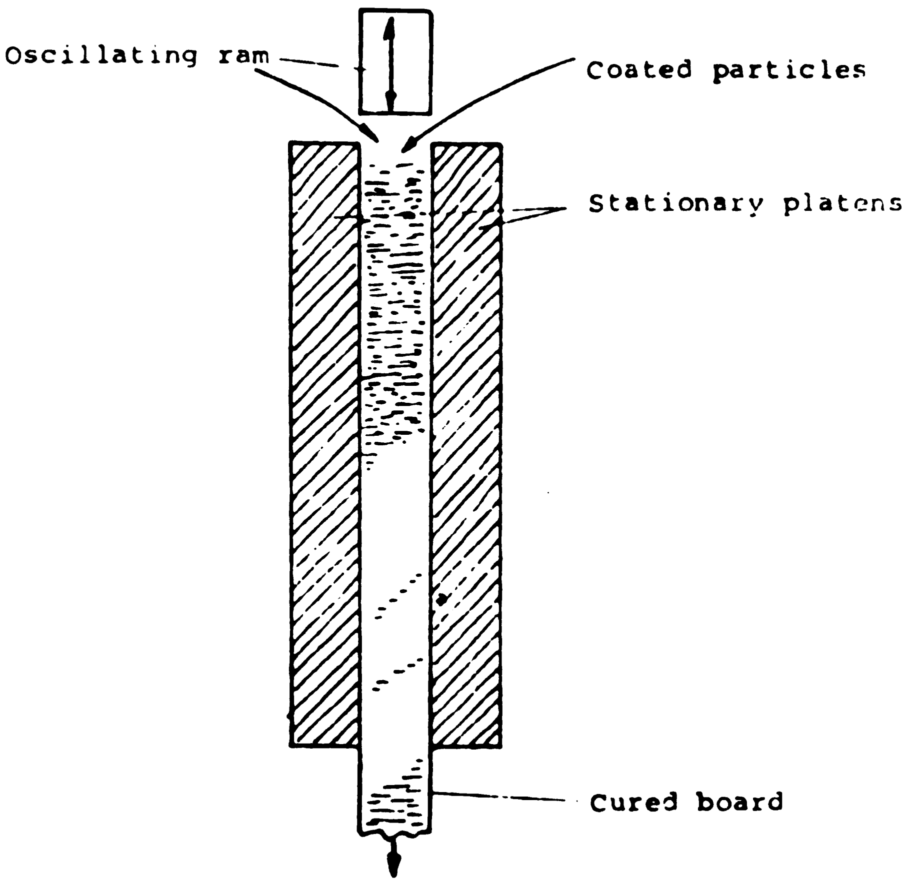
Production of particleboard in 1977 was 3,593 million square feet. Medium density fiberboard was 441 million square feet. This is based on 48 companies with 76 plants. (National Particleboard Association).

1) Basic Processes

The particleboard process is a laminating process and can be distinguished from other laminating processes by the discontinuity of laminas and the extremely low glue spread. The laminas are small particles which are formed to a mat by gravity or other method of desposition. This loose mat of adhesive coated particles is then compressed in a hot press to a considerable degree of densification. Urea formaldehyde resin is most commonly used. A small part of the total particleboard production is manufactured with phenol-formaldehyde adhesive, a waterproof adhesive. Most particleboard today is manufactured by the so-called "platen" or "mat formed" process. Only a very small part of the total production is extruded. In the extrusion process adhesive coated particles are fed continuously through a vertical die (Figure 7). The major steps in the manufacture of "mat formed" composition board are:

Figure 7. Particleboard Processes.


Platen
Mat
Steel spacer
Final thickness
Platen


Oscillating ram
Coated particles
Stationary platens
Cured board

1) Particle preparation

2) Particle classification

3) Particle drying

4) Blending (application of adhesive)

5) Mat formation

6) Pressing of mat between heated platens

A general flow diagram is shown in Figure 8 (Suchsland, O.) 1968 [77]. Board properties of extruded particleboards are quite different from those manufactured by the platen system. In general, particleboard properties can be predetermined, controlled, and modified to suit certain applications.

Medium density fiberboard (MDF) bridges the gap between fiberboard and particleboard technologies. MDF is based on a pulping process which reduces the wood raw material to fibers or fiber bundles. Yet, board formation and pressing are dry, and the final product competes with particleboard in the market place. Its properties are very similar to those of conventional particleboard. While conventional fiberboard products have densities of around 1.0 g/cm^3 (wet or dry formed hardboard) or around 0.1 to 0.5 g/cm^3 (insulation board) medium density fiberboard is manufactured at an average density of .75 g/cm^3 (Suchsland, O.) 1978 [73].

The major steps in the manufacture of medium density fiberboards are:

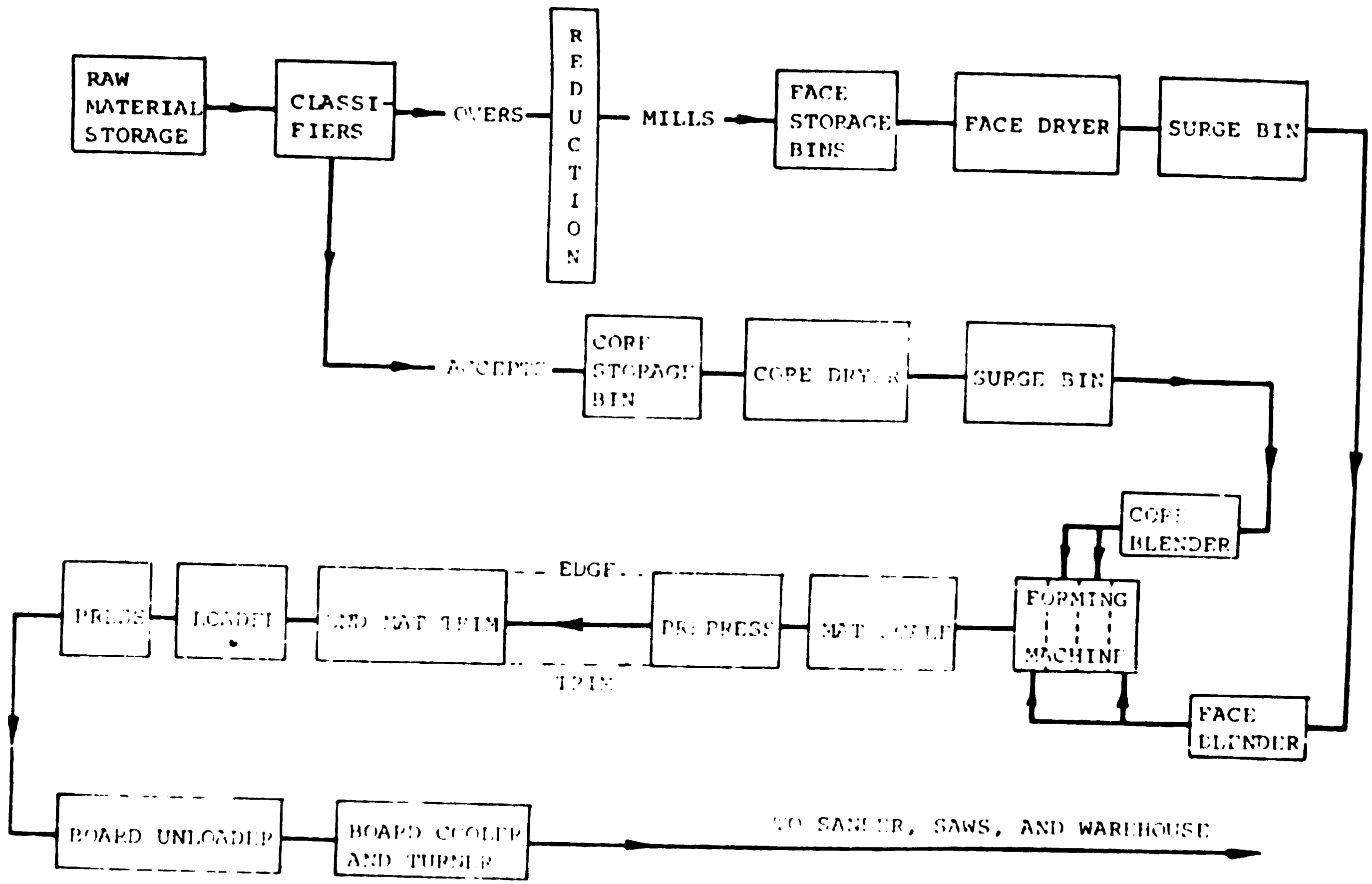


Figure 8. Typical flow chart of particle board process.

1) Fiber generation

2) Fiber drying

3) Fiber blending

4) Mat formation

5) Pre-pressing

6) Hot-pressing

Figures 9 to 13 describe a MDF manufacturing process Johnson 1973 [36].

2) Wood Composition Board Applications.

Major advantages of particleboard over other wood products are the relative ease with which it can be made into larger panels in the production plant, and the economics of manufacture.

The highest percentage of particleboard production goes into the industrial market for use in furniture. Lumber core has largely been replaced by particleboard because it is considerably cheaper than the edge-glued lumber core, and can be made in 3 ply or 5 ply construction. If edges are straight and not profiled, veneer edging is used. Due to the random structure of the particleboard core, cross bands are not required for restraint and stability in contrast to lumber core boards where cross banding must provide strength and stability across the grain of the lumber core. Therefore, it has to be made in 5 ply construction. Where edges are profiled, particleboard requires lumber edge banding because particleboard edges are too porous to be shaped and finished directly. The difference in thickness swelling between lumber bands and particleboard core would cause telegraphing of the

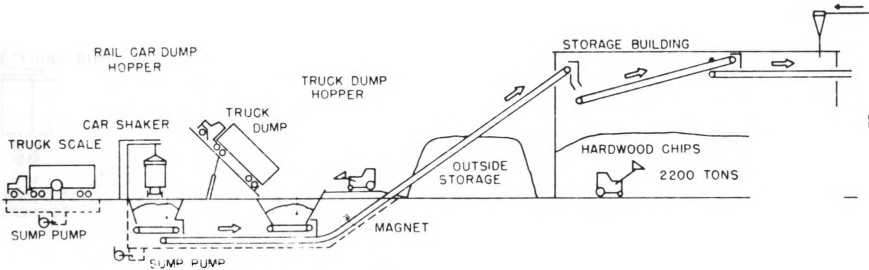


Figure 9. Medium Density Fiberboard Plant - raw material area.

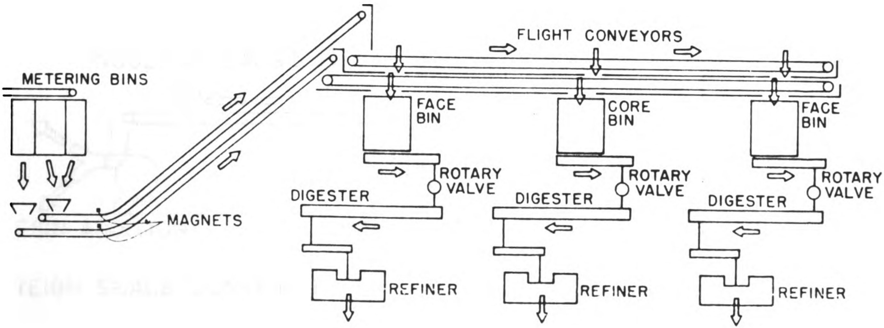


Figure 10. Medium Density Fiberboard Plant - metering bins, digesters, and refiners.

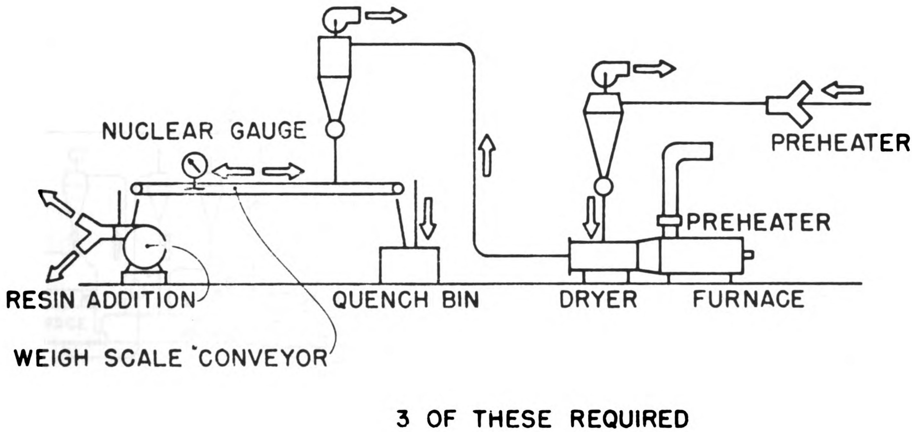


Figure 11. Medium Density Fiberboard Plant - dryer and blender.

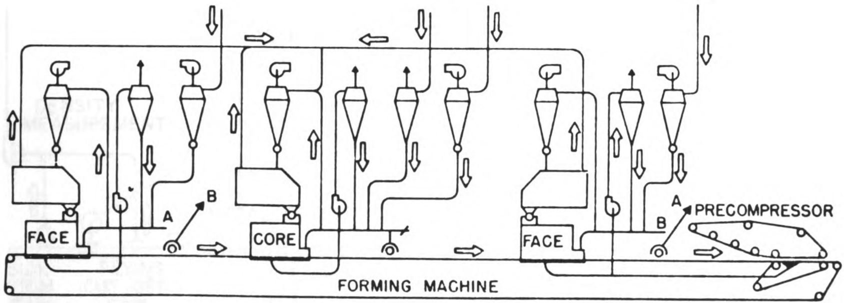


Figure 12. Medium Density Fiberboard Plant - former

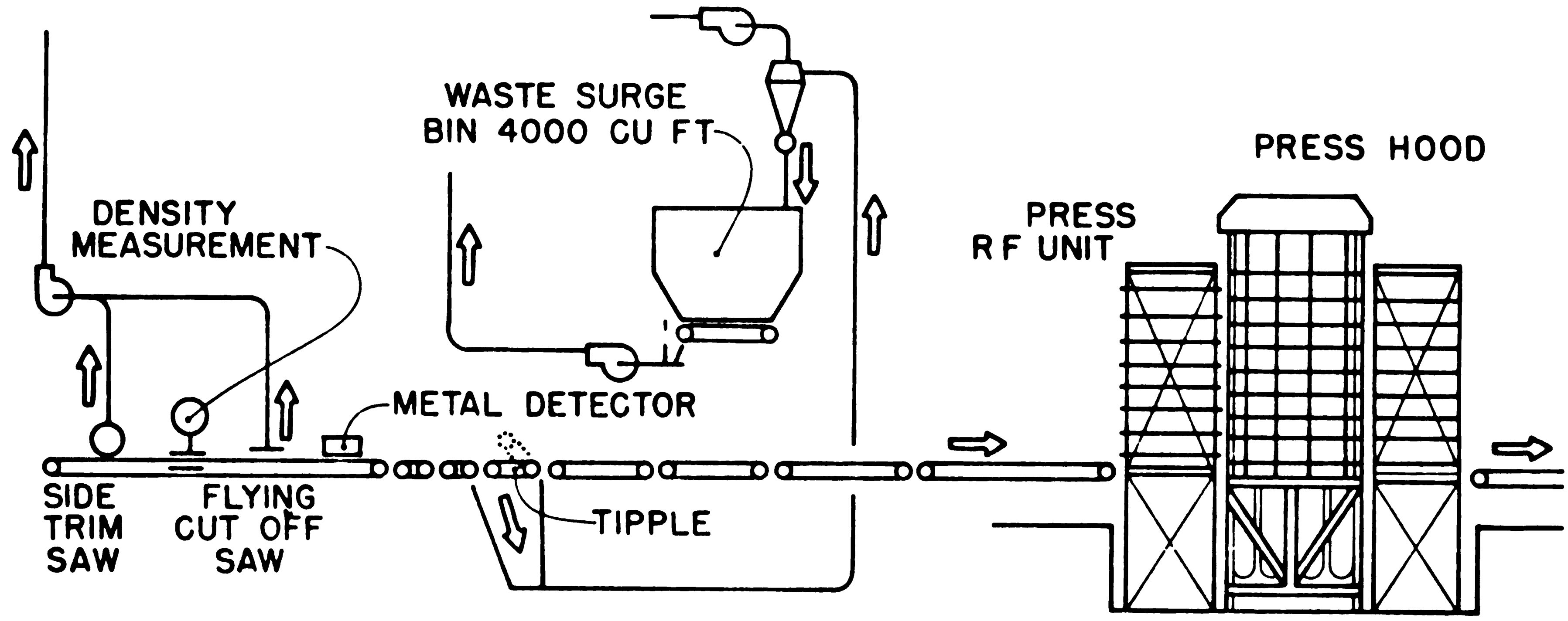


Figure 13. Medium Density Fiberboard Plant - press feed line and press.

glue joint through the thin face veneers. Five-ply construction is then needed in these cases (Figures 14, 15).

Particleboard has moved into different markets like the interior wall paneling business, store fixtures, kitchen cabinets, and other products, due to the development of techniques like direct printing methods, low and high pressure laminating, etc.

In the mid-1960's particleboard entered the structural market in the mobile home field, where it supplanted plywood for floor underlayment and mobile home decking. It entered this market because of its lower cost, its smooth surface, and because it could be obtained in 10-12 and 14-foot lengths which eliminated the need for end joints when laying the panels on the mobile home floor joint system (Maloney, T.M.,)1977 [47]. There are strong indications that particleboard will make additional strong advances in the structural market. The development of the so-called "waferboard" is a good example. How successful structural particleboard will be, will depend on research efforts, economic advantages of the new products over plywood and lumber, availability of peeler logs, demand for housing, etc.

MDF is a newcomer on the field, but has scored significant successes which are based on some of its distinct and unique properties. The most significant property of MDF as far as its use in the furniture industry is concerned, is its uniformity of structure which is reflected in a smooth and tight edge that can be machined almost like wood (Figure 16). However, it is considerably more expensive than particleboard. In a panel with straight and plane edges the

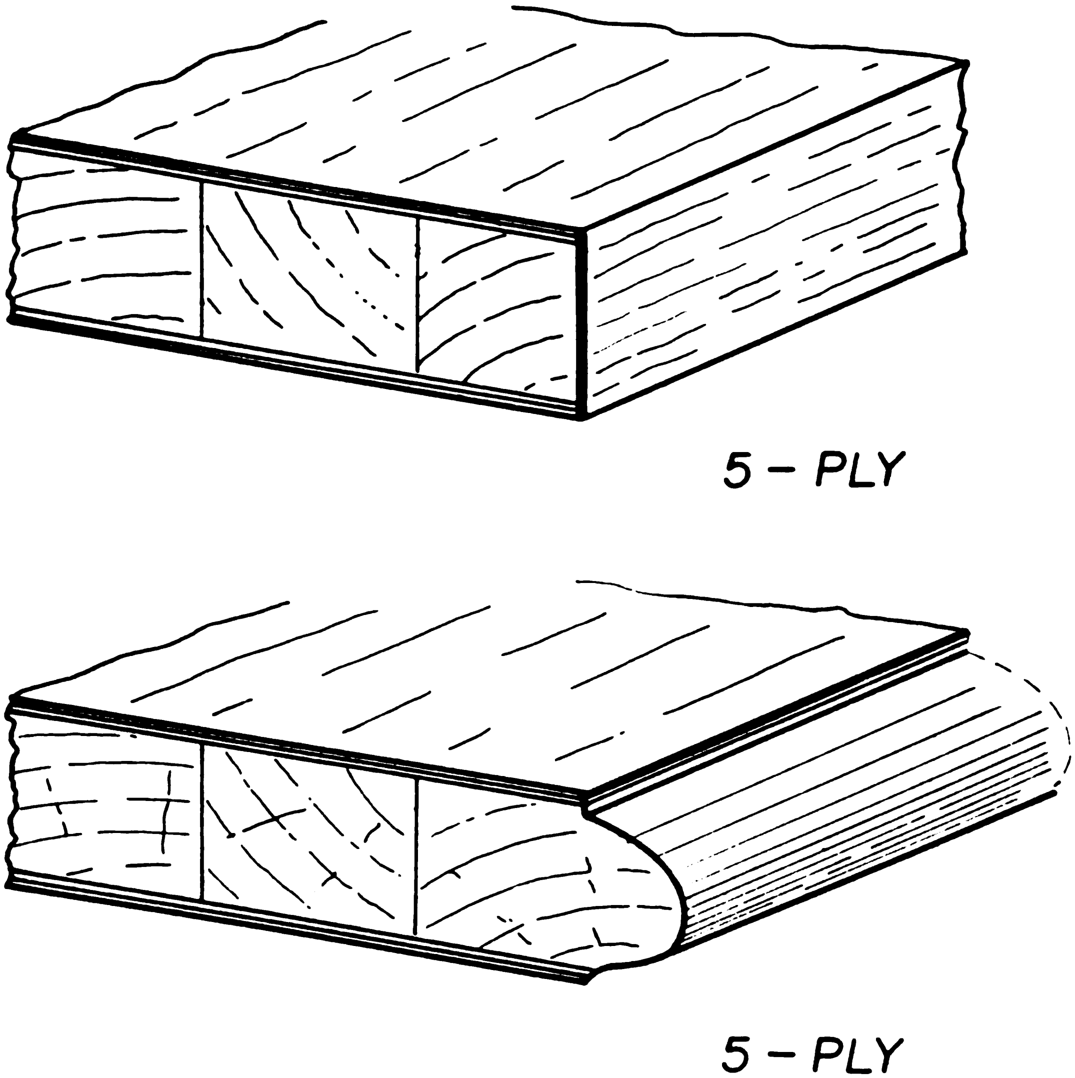
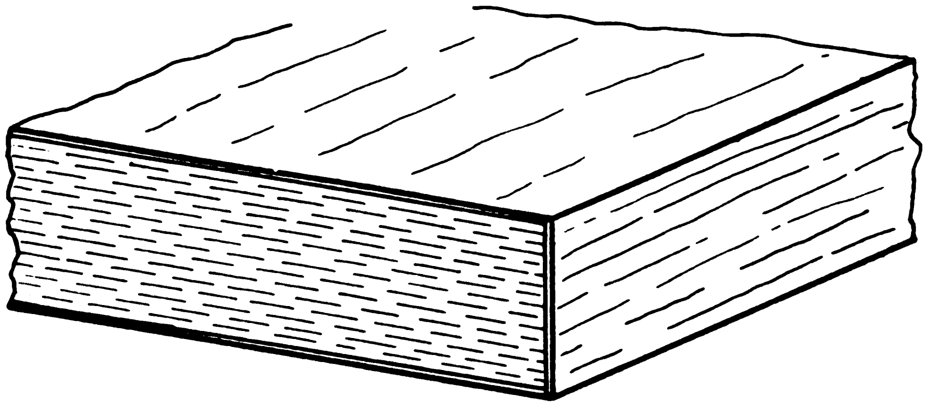
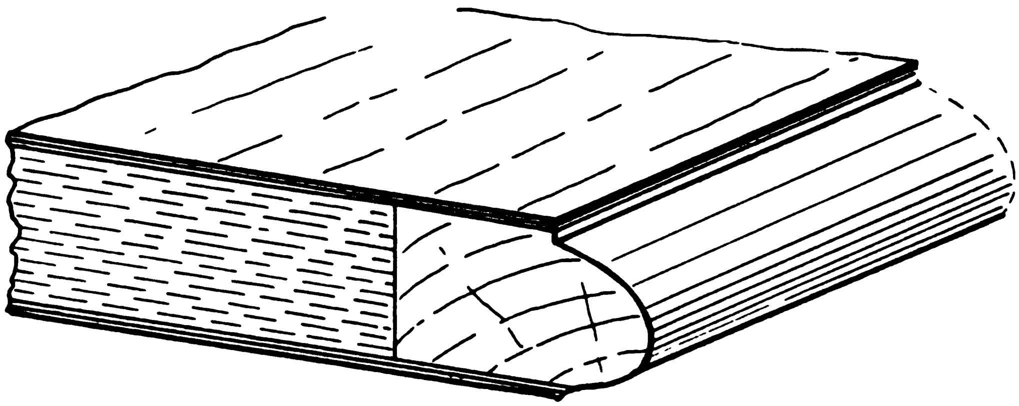


Figure 14. LUMBER CORE FURNITURE PANEL



3 - PLY

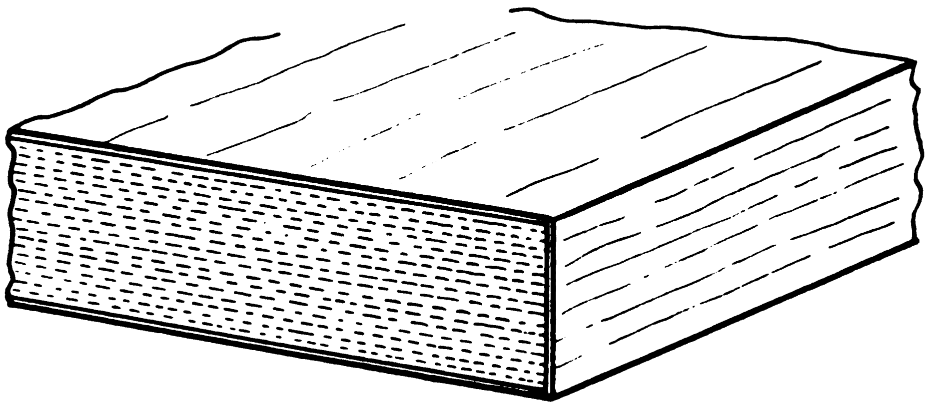


5 - PLY

Figure 15.

PARTICLEBOARD CORE

FURNITURE PANEL



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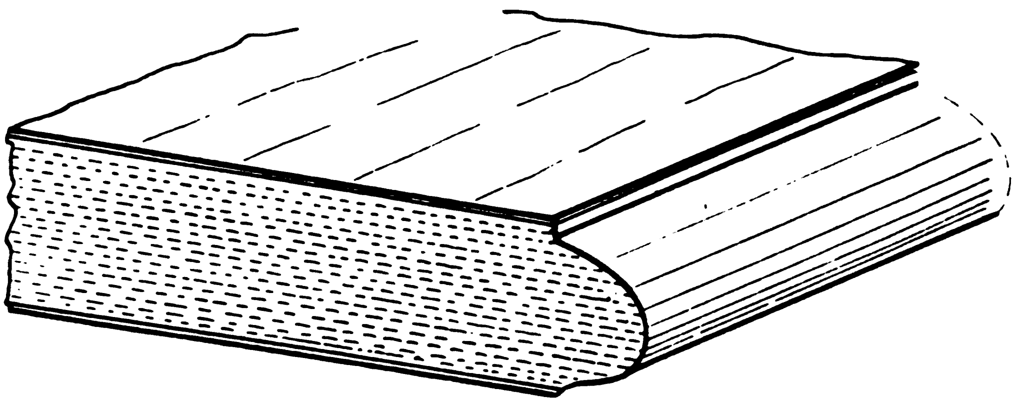


3 - PLY

Figure 16.

MEDIUM DENSITY FIBERBOARD CORE

FURNITURE PANEL

additional cost would not be justified. Where edges are profiled, lumber edge bands and, therefore, cross band veneers can be eliminated.

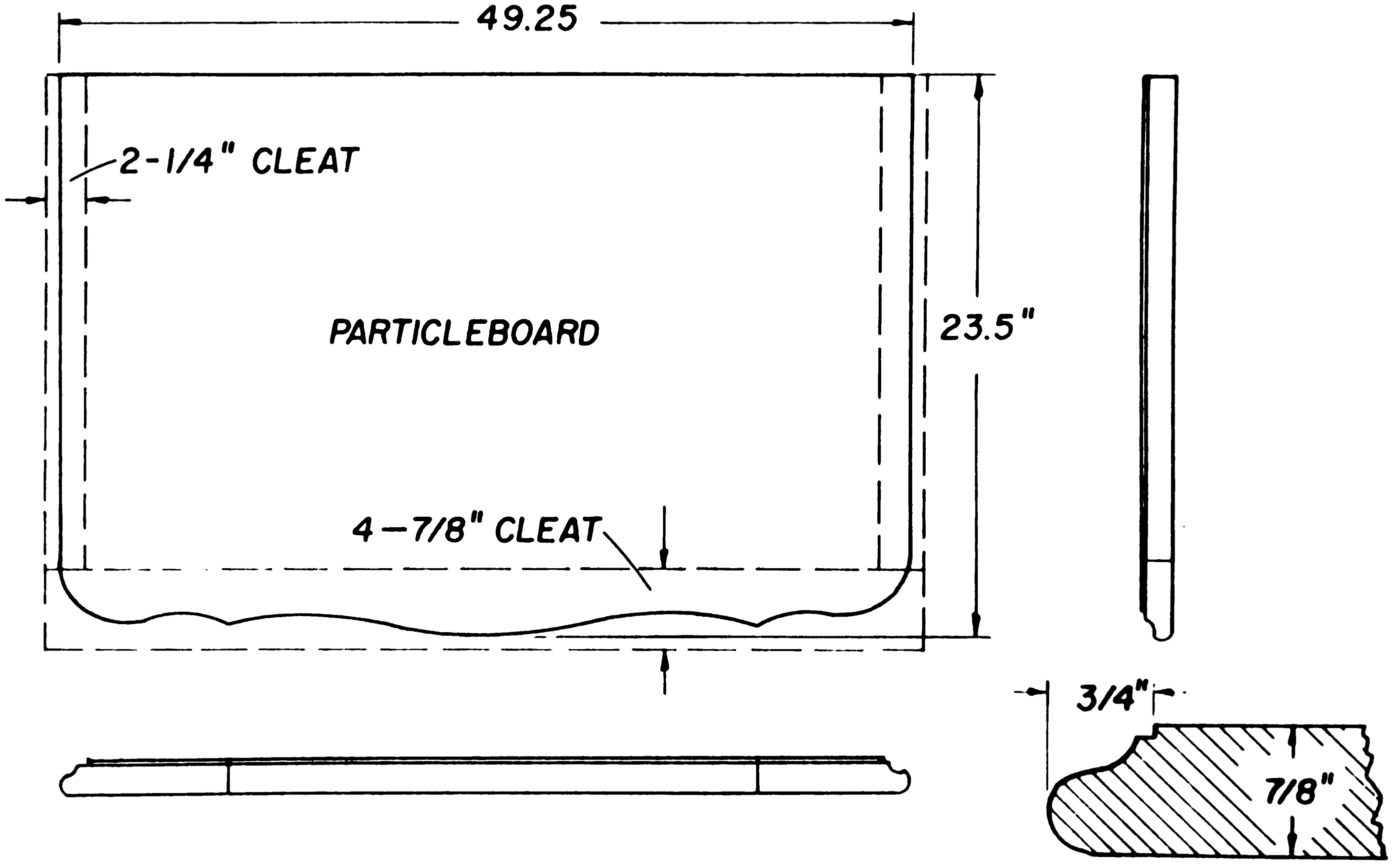
The panel edge can be machined and finished directly. The savings more than offset the higher board costs. This is demonstrated in Figure 17 and Table 4, showing a comparison of the cost of manufacturing a bureau top with particleboard and MDF (Suchsland, O. 1978) [76].

Structural applications of medium density fiberboard are still undefined. Most of the research efforts in the structural board field are concentrated on achieving maximal mechanical and elastic board properties by using large, thin flakes in both random and oriented configuration. MDF, on the other hand, by virtue of its much more homogeneous structure may offer greater resistance to deterioration by swelling stresses.

The medium density fiberboard segment of the industry is expected to have a strong impact on the board industry and markets. A number of plants have been built and others are in the process of being constructed.

3) Wood Composition Board - Property and Standards

The standards for particleboard are formulated by the National Particleboard Association. A standard was first produced for mat formed wood particleboard in 1961. With more experience in the field and far more production developing in the 1960's this standard was rewritten in 1966 and is the present one in force, a new revised edition is expected to be published in 1980. It is designated Commercial Standard



BUREAU TOP

Figure 17. Design and construction of lumber banded bureau top. (Courtesy John Widdicomb Furniture Company, Grand Rapids, Michigan).

Table 4. Cost breakdown for manufacture of bureau top with particleboard core and MDF core.

	PARTICLEBOARD solid banding	MED. DENS. FIBERBD. no banding
MATERIAL		
LUMBER	1.97	—
BOARD	1.66	2.49
VENEER FACE	.87	.87
VENEER BACK AND EDGE	.55	.53
CROSS BANDS	1.22	—
GLUE	.35	.18
TOTAL MATERIAL	6.62	4.07
LABOR & BURDEN		
YARD AND KILN	.50	—
VENEER	5.75	2.55
ROUGH MILL	1.42	—
INTERMED. MACHINING	1.54	.26
TOTAL LABOR & BURDEN	9.21	2.81
TOTAL FACTORY COST	15.83	6.88

CS 236-66 "Mat-formed Wood Particleboard." Table 5 presents the property requirements for particleboard specified in this standard.

The standard distinguishes two types of particleboard: Type 1 generally made with urea formaldehyde resin binders for interior applications and Type 2 generally made with phenolic type binders suitable for interior and certain exterior type applications when so labelled. Within each type products are further differentiated by density grade with an A, B, and C level for the interior applications and A and B density grade for exterior applications. As a further differentiation there are two quality classes in each of the density grades with each class having a separate set of physical properties established for modulus of rupture, modulus of elasticity, internal bond, linear expansion and face and edge screw holding. The main innovation in the new standard now undergoing revision is the establishment of minimum property requirements for the so-called waferboards.

In August 1973, the National Particleboard Association published NPA 4-73 "Standard for Medium Density Fiberboard," Table 6 presents the property requirements of this board, which are quite similar to particleboard. Properties of the different experimental particleboards in this study were compared to use classification Type 1 and density grade B, and class 2 which is the standard specification for industrial core stock.

Table 5. Property requirements for particleboard.

TYPE	DENSITY (GRADE) (min. avg.)	CLASS	MODULUS OF RUPTURE (min. avg.)	MODULUS OF ELASTICITY (min. avg.)	INTERNAL BOND (min. avg.)	LINEAR EXPANSION (max. avg.)	SCREW HOLDING Face (min. avg.)	SCREW HOLDING Edge (min. avg.)	TYPICAL APPLICATIONS
			psi	psi	psi	per cent	lbs	lbs	
1.[1]	A (High Density, 50 lbs/cu ft and over)	1	2,400	350,000	200	0.55	450	---	------------------------------
		2	1,400	350,000	140	0.55	---	---	------------------------------
	B (Medium Density, between 37 and 50 lbs/cu ft)	1	1,600	250,000	70	0.35	225	160	Floor underlayment
		2	2,400	400,000	60	0.35	225	200	Core stock (medium density)
	C (Low Density, 37 lbs/cu ft and under)	1	800	150,000	20	0.30	125	---	Flush door core
		2	1,400	250,000	30	0.30	175	---	------------------------------
2.[2]	A (High Density, 50 lbs/cu ft and over)	1	2,400	350,000	125	0.55	450	---	------------------------------
		2	3,400	500,000	400	0.55	500	350	Core stock for high pressure laminate overlay
	B (Medium Density, Less than 50 lbs/cu ft)	1	1,800	250,000	65	0.35	225	160	Exterior siding
		2	2,500	450,000	60	0.25	250	200	------------------------------

[1]Type 1. Mat-formed particleboard (generally made with urea-formaldehyde resin binders) suitable for interior applications.

[2]Type 2. Mat-formed particleboard made with durable and highly moisture and heat resistant binders (generally phenolic resins) suitable for interior and certain exterior applications.

Source: CS 236-66 (9)

Table 6. Property Requirements for Medium-Density Fiberboard

Density (lbs/ft^3)	Modulus of rupture (psi)	Modulus of elasticity	Internal bond (psi)	Linear expansion (%)	Screw holding face (lbs)	Screw holding edge (lbs)
31-50	3,500	300,000	100	0.30	350	300
(sp gr)	(MPa)	(MPa)	(MPa)		(kg)	(kg)
0.48-0.80	24.1	2,068	0.69		159	136

Source: NPA 4-73.

CHAPTER IV

EXPERIMENTAL DESIGN AND PROCEDURE

The experiment conducted for this study consists of two parts:

1) The determination of the solid wood properties of sample trees of Eucalyptus robusta and Eucalyptus grandis.

2) The manufacture and evaluation in the laboratory of different composition boards using material from the sample trees.

The determination of the solid wood properties was desirable for two reasons:

1) To establish a detailed description of these two species in terms of physical and mechanical properties.

2) To provide the basis for an attempt to correlate composition board properties to properties of the solid raw material.

1) Solid Wood Sampling and Testing Procedure.

Due to limitations in diameter of the trees, small testing specimens had to be used. The choice of using the Pan American Standards Commission (copant) standards was related in part to the fact that they are directed toward small specimens and secondly that these standards are an official means of comparison of results in Latin America. According to the Pan American Standards Commission,(copant) a minimum of five trees per species is necessary for the measurement of mechanical and non-mechanical properties of the solid wood. So, from the experimental plot a number of five trees of Eucalyptus grandis and five trees of Eucalyptus robusta were felled and bucked to a number of 5 to 6 bolts each. Trees were numbered from 1 to 5, bolts coded from "A" to "F" where case applied, and species differentiated by "G" or "R" for grandis or robusta. The coding would be interpreted as follows:

Code	Tree No.	Bolt	Species
1AG	1	A	E. grandis
5BR	5	B	E. robusta

The selection of bolts in order to determine the physical properties of the solid wood could not be randomized due to the limitations in diameter.

Bolts "A" and "B" with lengths approximately 2 meters and diameters varying from 15-28 cm were chosen systematically from each tree for the manufacture in the sawmill of ten boards per species with dimensions 2.5 in. x 10 in x 6 feet. This is in accordance with the copant standards.

The following standard properties were selected for evaluation:

a) Fiber dimensions

b) Static bending

c) Tension perpendicular to grain

d) Shear parallel to grain

e) Swelling and shrinkage (all directions)

f) Specific gravity and moisture content

Specimens were taken from center board after bolt conversion

(Figs. 18, 19), all mechanical tests were performed on a standard Instron testing machine.

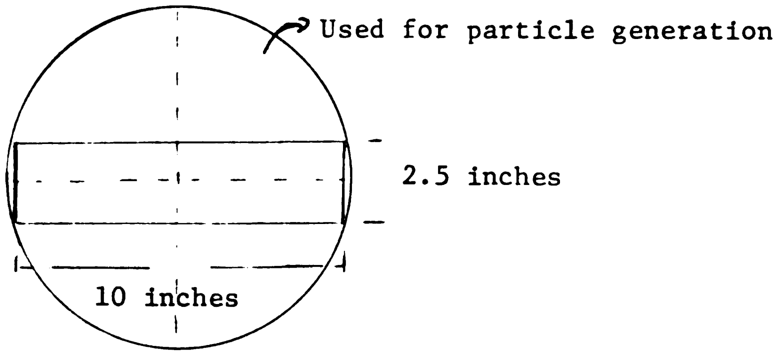


Figure 18. Bolt Conversion

From every center board of every tree, specimens were taken looking for best grain orientation possible. Boards were air dried for about a month, and after conversion, specimens were conditioned to equilibrium at 70°fahrenheit and 60 percent relative humidity.

1.1 - Fiber Dimensions

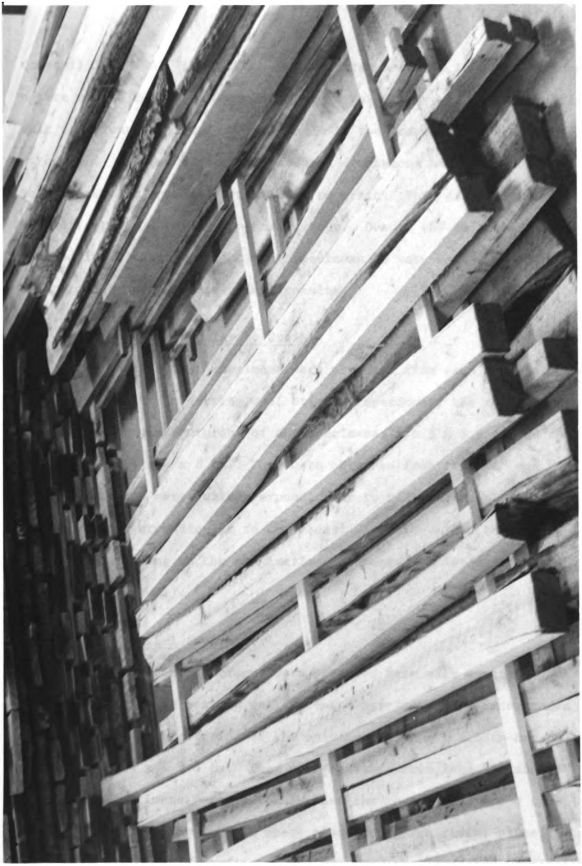
From bolts 1AG, 4BG of Eucalyptus grandis and 1AR, 4BR of Eucalyptus robusta tiny pieces were taken and macerated by the Jeffrey process.

After that a number of 150 fibers were measured in length and diameter by means of a graduated and calibrated microscope.

1.2 - Static Bending.

Fifty bending test specimens were prepared for each species with dimensions 2 x 2 x 30 cm. They were obtained from logs "A" and "B". Twenty-five specimens were loaded perpendicular to the tangential direction and 25 loaded perpendicular to the radial direction. Tests were performed according to the Pan American Standards Commission

Figure 19. Boards from which specimens were taken.



(copant) 30:1-006 (Figure 20). Due to irregularities in the structural nature of the Eucalyptus species used in this study, it was very difficult to orient specimens on a 0° angle to the longitudinal grain direction. In some cases the specimens dimensions had to be reduced to conform to a parallel orientation to grain. This difficulty may have affected the results to some extent. Due to the anisotropy of wood it is very important that specimens be very well oriented, in order to have very accurate test results.

1.3 - Tension Perpenducular to Grain.

Forty tension test specimens were prepared from each species. Due to the difficulty in getting well oriented specimens, the recommended dimensions for manufacturing of the specimens, 5 x 5 x 6.0 cm had to be changed to 4 x 4 x 6 cm. They were obtained from logs "A" and "B". Twenty specimens were pulled perpendicular to the tangential direction and 20 pulled perpendicular to the radial direction. The tests were performed according to the Pan American Standard Commission (copant) 30:1-016 (Figure 21).

1.4 - Shear Parallel to Grain.

Fifty shear test specimens were prepared from each species. Due to the difficulty in getting well oriented specimens, the recommended dimensions for manufacturing of the specimens, 5 x 5 x 6.5 cm had to be changed to 4 x 4 x 6 cm. They were obtained from logs "A" and "B". Twenty-five specimens were tested so that the shear plane was a tangential plane, and 25 with the shear plane being the radial plane. Tests were performed according to the Pan American Standards Commission

Figure 20. Solid wood static bending test.

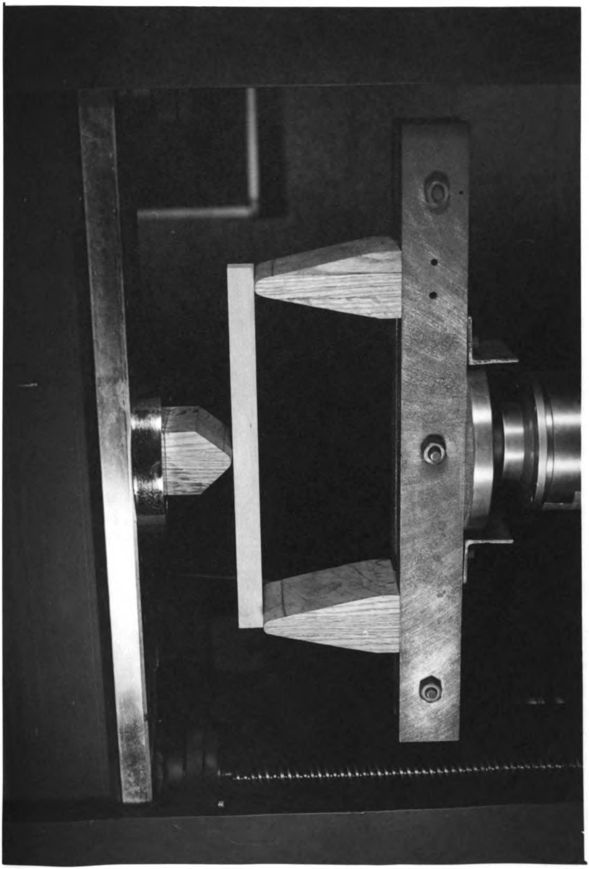
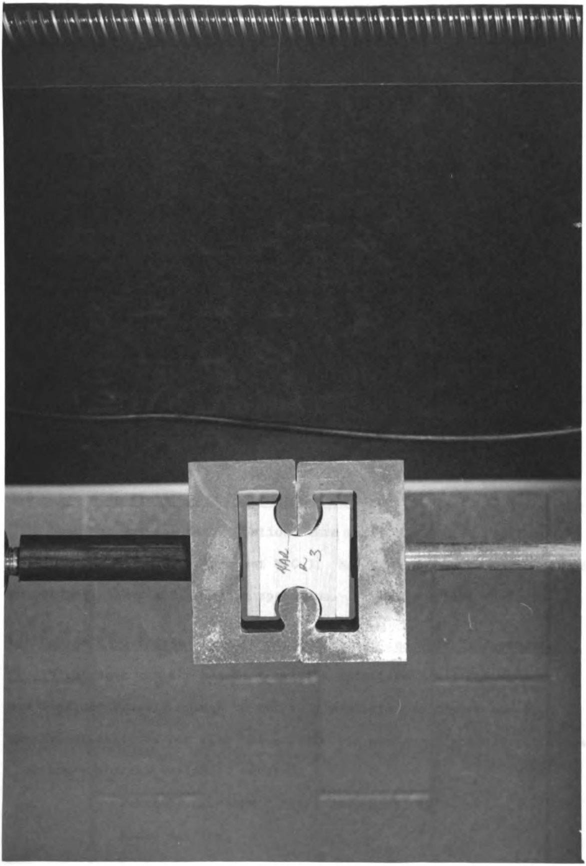


Figure 21. Solid wood tension perpendicular to grain test.



(copant) 30: 1-007 (Figure 22).

1.5 - Swelling and Shrinkage.

Due to the importance of orientation of grain in determining swelling and shrinkage in the tangential and radial directions, a number of 10 specimens with dimensions 4 x 4 x 6 cm were used per species.

Along with these specimens 10 more of the standard recommended dimensions 2.5 x 2.5 x 10 cm not perfectly oriented per species were included for a total of 20 specimens per species. For longitudinal swelling and shrinkage, 40 specimens of the standard recommended dimensions, 2.5 x 2.5 x 10 cm per species were used. Tests were performed according to the Pan American Standards Commission (copant) 30: 1-005 (Figure 23).

1.6 - Specific Gravity and Moisture Content.

Specific gravity determinations were made on all test specimens. (Weight and volume at 12 percent M.C.). Moisture content was determined on bending, shear and swelling specimens. (Ovendry weight basis).

2) Composition Boards Manufacturing, Sampling and Testing Procedure.

With regard to the manufacture of composition board the experiment was designed broadly enough to not only evaluate the importance of species differences but also the effect of a number of process variables.

These process variables were:

1) Particle geometry (Figs. 31a, b, c, d)

2) Board density

3) Resin content

Figure 22. Solid wood shear parallel to grain test.

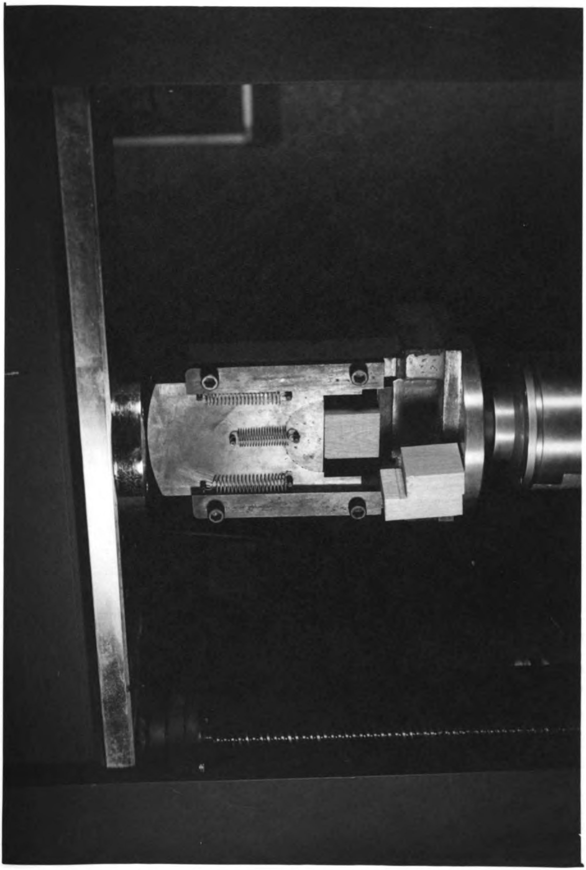
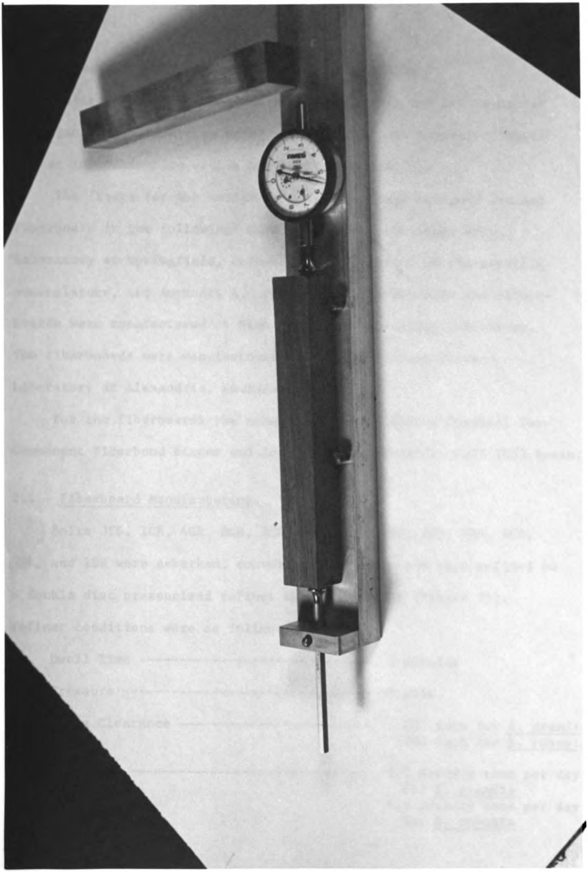


Figure 23. Solid wood swelling and shrinkage-measuring apparatus.



The complete experimental design is shown in Table 7.

Wafers, flakes and slivers were produced in the laboratory at Michigan State University using a Forest Products Laboratory flake cutter in combination with a hammermill (Figure 24).

The fibers for the medium density fiberboard category (called fiberboard in the following) were produced at the Bauer Bros. Laboratory at Springfield, Ohio. For a definition of the particle nomenclature, see Appendix A. Waferboards, flakeboards and sliverboards were manufactured at Michigan State University Laboratory. The fiberboards were manufactured at the U.S. Forest Service Laboratory at Alexandria, Louisiana.

For the fiberboards the adhesive used was Allied Chemical Two-Component Fiberbond Binder and for the Particleboards, Gulf 1653 Resin.

2.1 - Fiberboard Manufacturing.

Bolts 3CG, 1CR, 4CR, 2CR, 2CG, 5CR, 5DG, 4DG, 1DG, 4DR, 4CR, 3DR, and 1DR were debarked, converted into chips and then refined on a double disc pressurized refiner model Bauer 418 (Figure 25). Refiner conditions were as follows:

Dwell Time ---------------------------- 3 minutes

P Pressure ------------------------------ 90 psig

Plate Clearance ------------------------ .007 inch for *E. grandis*
.008 inch for *E. robusta*

Feed Rate ------------------------------ 5.2 ovendry tons per day for *E. grandis*
6.8 ovendry tons per day for *E. robusta*

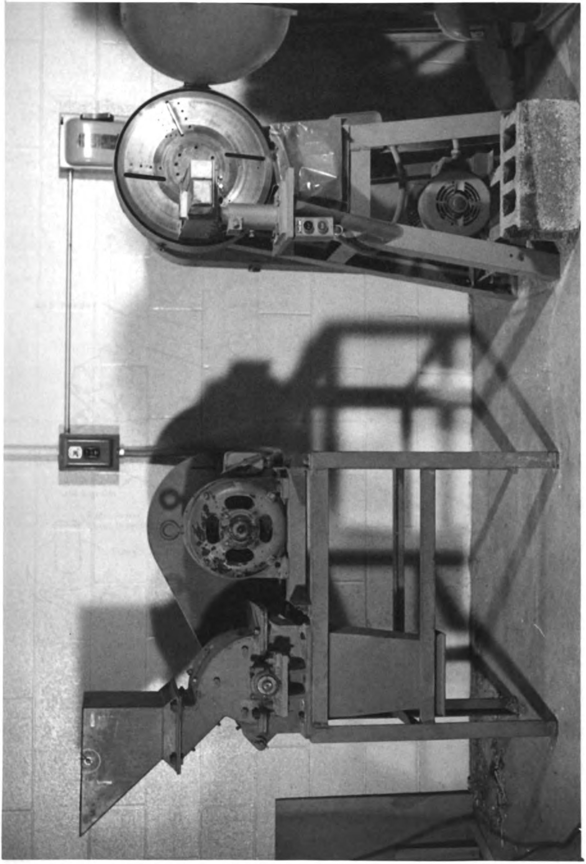
Table 7. Experimental Design and Manufacturing Data.

Species	E. robusta															
Particle Geometry	Fibers				Slivers				Flakes				Wafers			
Average moisture content prior to mat formation %	3.5				3.5				5				3			
Nominal board (g/cm^3) densities	.60		.75		.60		.75		.60		.75		.60		.75	
Resin content (%)	8	12	8	12	8	12	8	12	8	12	8	12	8	12	8	12
Press platen temperature (°F)	330				330				330				330			
Average mat moisture content prior to pressing (%)	9				8				8				8			
Pressure (psi)	450				450				450				450			
Average closing time (seconds)	30		90		30		105		45		120		45		115	
Pressing time (min)	9				9				9				9			
Board thickness (in)	5/8				5/8				5/8				5/8			
Replications	5	5	5	5	3	3	3	3	3	3	3	3	3	3	3	3

Species	E. grandis															
Particle Geometry	Fibers				Slivers				Flakes				Wafers			
Average moisture content prior to mat formation %	3.5				3				4				3.5			
Nominal board (g/cm^3) densities	.60		.75		.60		.75		.60		.75		.60		.75	
Resin content (%)	8	12	8	12	8	12	8	12	8	12	8	12	8	12	8	12
Press platen temperature (°F)	330				330				330				330			
Average mat moisture content prior to pressing (%)	9.5				8				8				8			
Pressure (psi)	450				450				450				450			
Average closing time (seconds)	30		90		30		105		45		120		40		115	
Pressing time (min)	9				9				9				9			
Board thickness (in)	5/8				5/8				5/8				5/8			
Replications	5	5	5	5	3	3	3	3	3	3	3	3	3	3	3	3

* Resin used (UF) Urea Formaldehyde.
** Fiberboards pre-pressed at 330 psi.

Figure 24. Forest Products Laboratory Standard Flakecutter and Hammermill.



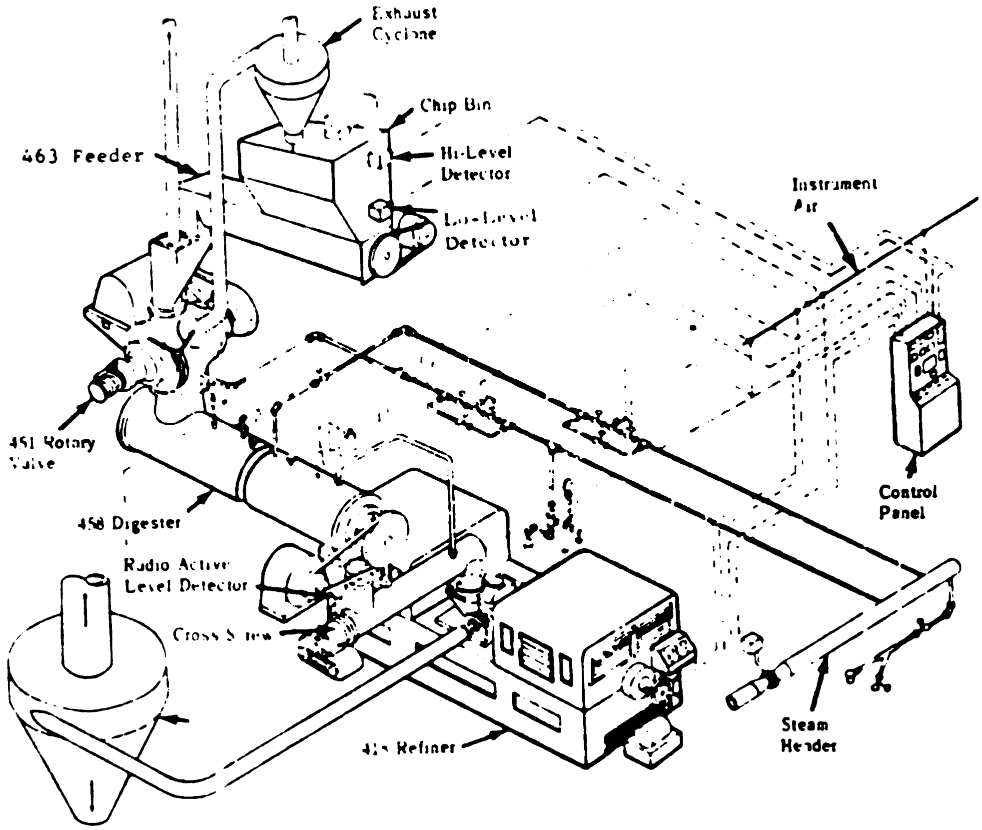


Figure 25 . Double Disc Pressurized Refiner Model Bauer 418.

Green chips of E. grandis and E. robusta entered the refiner at a bulk density of 12 and 16 lbs/ft^3 and moisture contents of 62.6 and 65.4 percent (O.D. basis). Wet fibers emerged at a bulk density of 1.5 lbs/ft^3 for both species with moisture contents of 52.3 and 60.6 percent respectively. Fibers were dried in a small rotating drum dryer capable of drying 100 pounds of wet fibers per load. Hot air (about 240°F) was introduced through the tumbling fibers from the center; wet fibers were dried to less than 5 percent moisture content. Table 8 shows the distribution of particle sizes from the dry furnish used to make the fiberboards for the study. Data were collected from a Bauer-McNett Model 203-A Classifier.

Table 8. Bauer-McNett fractions obtained from E. grandis and E. robusta (without bark) refined from green chips in a Bauer 418.

	Mesh designation[1]				
	-8/+14	-14/+28	-28/+48	-48/+100	-100
	Percent				
E. grandis	37	16.9	15.8	10.9	19.4
E. robusta	33.6	15.8	16.7	13.3	20.6

[1]Tyler Standard Sieves. All material passing a given mesh is indicated by a minus sign (-). Material retained on the mesh is indicated by a (+) plus sign.

Looking at the two distributions it can be seen that the two species are very similar, and that a high percentage of fine material was present, approximately 20 percent in both cases.

2.1.1 - Fiber Blending.

A treatment of 8 percent and 12 percent Urea Formaldehyde resin solids (Allied Chemical Two-Component Fiberbond Binder) was accomplished in a rotating wooden drum (see Figure 26). Fibers were tumbled through spray from a center mounted spray gun. Treated fibers were removed with a vacuum system mounted on a barrel.

2.1.2 - Mat Formation

Appropriate quantities of treated fibers were run through a pilot forming machine and formed into a forming box 18 x 20 inches (Figures 27 and 28).

2.1.3 - Pre-Pressing.

Mats were pre-pressed in a Riehle Testing Machine equipped with a floating load head parallel to the base of the machine (Figure 29). All mats were pre-pressed at a pressure of 330 psi.

2.1.4 - Hot Pressing.

All boards were hot pressed by the "platen" or "mat formed" process (Figure 30). Press cycle was as follows:

Platen temperature ºF	330
Pressure (psi)	450
Pressing Time (min)	9
Board Thickness (in)	5/8

For average closing times of different fiberboards refer to Table 7: experimental design and manufacturing data. Closing time was recorded for each board as the time period between reaching full pressure and reaching the stops. Thickness stops were used to control the thickness

Figure 26. Blending operation - medium density fiberboard.

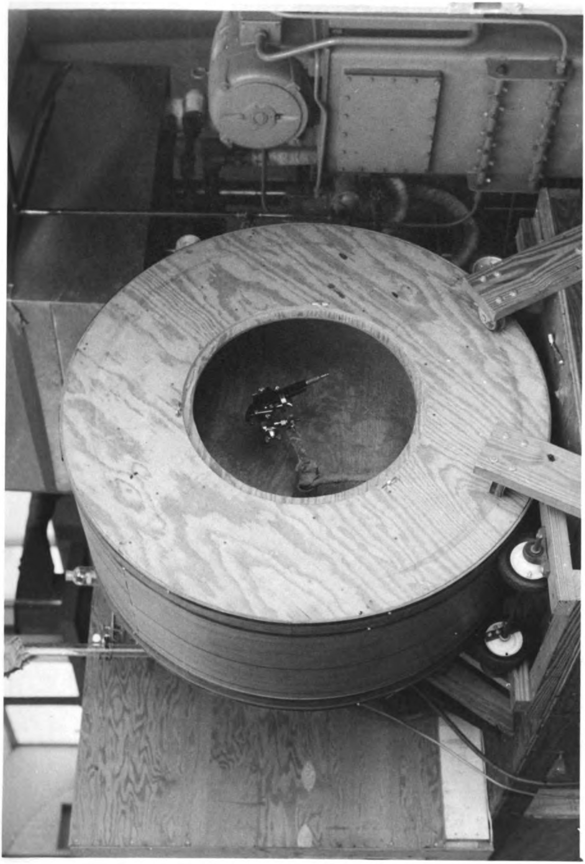


Figure 27. Medium density fiberboard - mat formation.

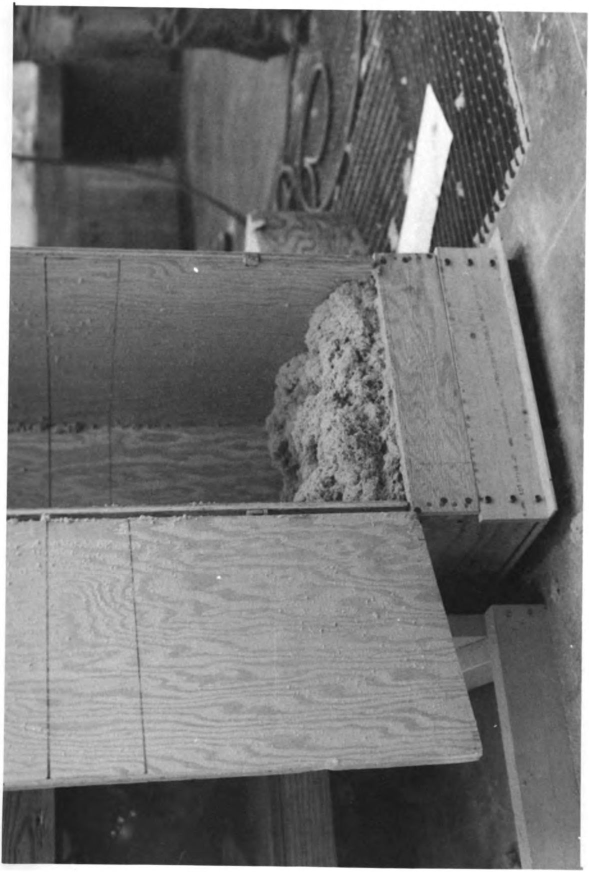


Figure 28. Mat formation equipment - medium density fiberboard.

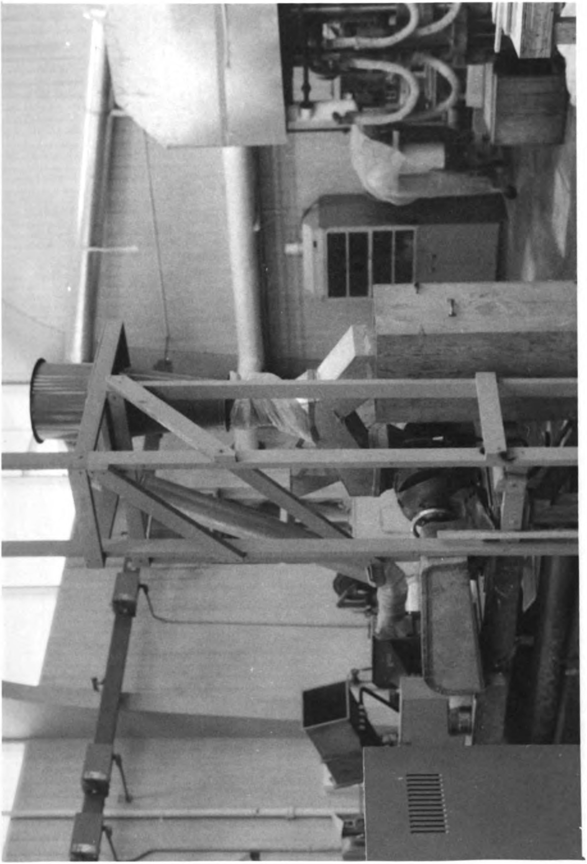


Figure 29. Medium density fiberboard - pre-pressing operation.

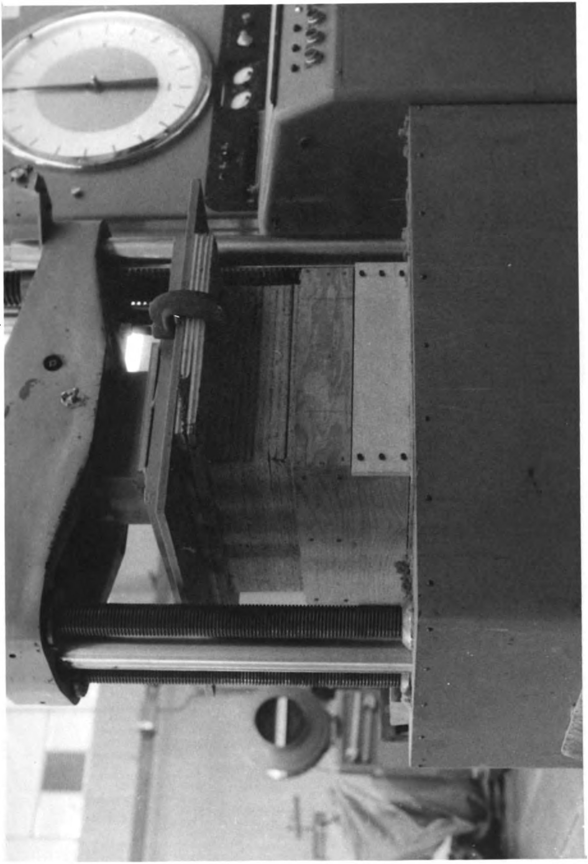


Figure 30. Medium density fiberboard - pressing operation.

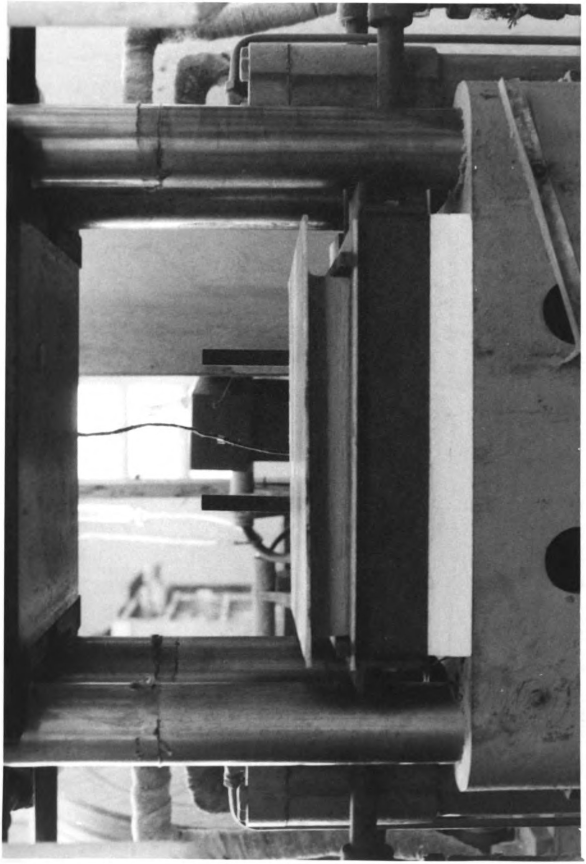
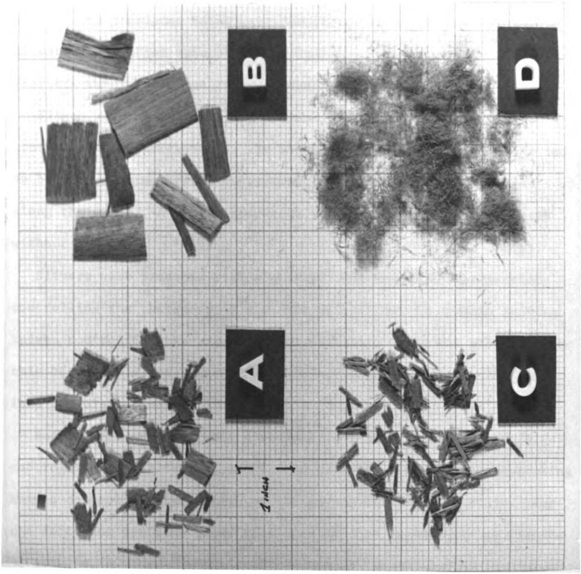


Figure 31 a, b, c, d. Illustration of particle geometry range.
a. Flakes
b. Wafers
c. Slivers
d. Fibers


B
D
A
C
1 INCH

variation between boards.

2.2 - Flakeboards, Sliverboards and Waferboards Manufacturing.

The raw material left over from the air dried solid wood and most of the remaining bolts were converted into small blocks, soaked in water, and after saturation fed radially into a standard Forest Products Laboratory disc flaking machine.

Flakes were produced with a nominal .020 inch knife projection controlling the thickness of the particles, and a distance of 1/4 inch in between scoring knives controlling the length of the particles along the grain. After this operation the flakes were hammermilled without screen.

Slivers were produced with a nominal .040 inch knife projection controlling the thickness, a distance of 1/4 inch in between scoring knives controlling the length of the particles along the grain. After this operation slivers were hammermilled through a screen with 1/2 inch circular openings.

Wafers were produced with a nominal .030 inch knife projection controlling the thickness, a distance of 1 1/4 inch in between scoring knives controlling the length of the particles along the grain. For the different particle geometries used in this study refer to Figures 31 a, b, c, d.

Particles were air dried to a moisture content below 5 percent (Figure 32). Average values of flake dimensions, sliver dimensions and wafer dimensions measured on a random sample of about 70 particles per species are shown in Table 9.

Figure 32. Particles - air drying operation.

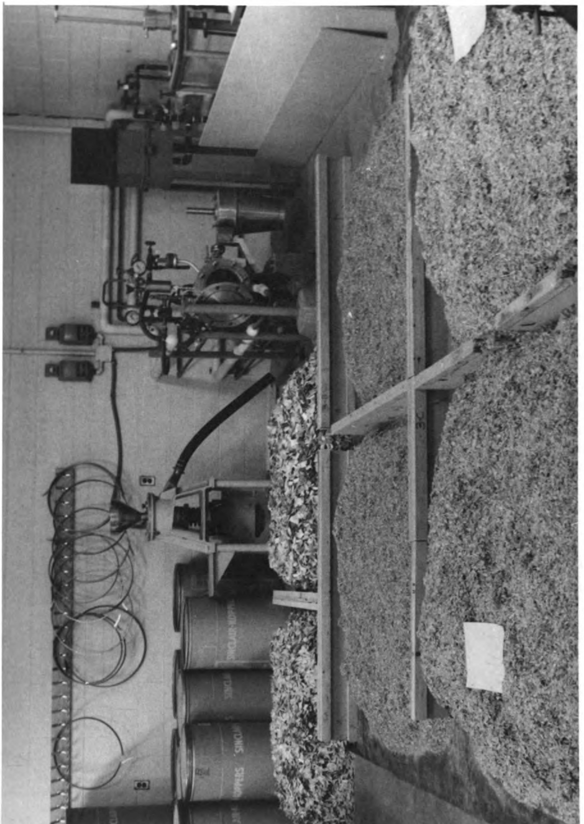


Table 9. Furnish Properties
(Average Values)

Eucalyptus robusta

Particle geometry	Flakes	Slivers	Wafers
Length (in.)	.46	.46	1.26
Width (in.)	.13	.08	.49
Thickness (in.)	.014	.031	.035
Slenderness Ratio (L/T)	38.7	15.8	37.8
Flatness Ratio (L/W)	4.4	6.8	3.65

Eucalyptus grandis

Particle geometry	Flakes	Slivers	Wafers
Length (in.)	.46	.48	1.28
Width (in.)	.17	.08	.58
Thickness (in.)	.015	.032	.033
Slenderness Ratio (L/T)	38	15.7	39
Flatness Ratio (L/W)	3.7	7.2	1.69

Small random samples of particles were classified through a sieve shaker, with meshes numbers 10, 16 and 30. Fines were defined as any particles passing through a number 30 mesh.

Wafers had the smallest amount of fines; .34 percent for E. robusta and .91 percent for E. grandis, and flakes the highest; 2.17 percent for E. robusta and 3.59 percent for E. grandis. In the actual process of board manufacturing, fines were removed through a vibrating screen.

2.2.1 - Particle Blending.

A treatment of 8 percent and 12 percent Urea Formaldehyde resin solids (Gulf 1653 resin) was accomplished in a rotating wooden drum. Particles were tumbled through spray from a center mounted spray gun. Treated particles were removed by hand.

2.2.2 - Mat Formation.

Appropriate quantities of treated particles were deposited by hand into a forming box 16 x 16 inches.

2.2.3 - Hot Pressing.

All boards were hot-pressed by the "platen" or "mat formed" process. Details of press cycle were given in section 2.1.4. For more details refer to Table 7 (experimental design and manufacturing data).

2.3. Composition Boards Sampling and Testing.

According to the commercial standard CS 236-66 (Standard for Mat-formed Wood Particleboard) boards for interior uses (Type 1) are evaluated by testing the following properties:

1) Modulus of rupture and modulus of elasticity

2) Internal bond

3) Linear expansion

4) Face screw holding capacity

5) Edge screw holding capacity

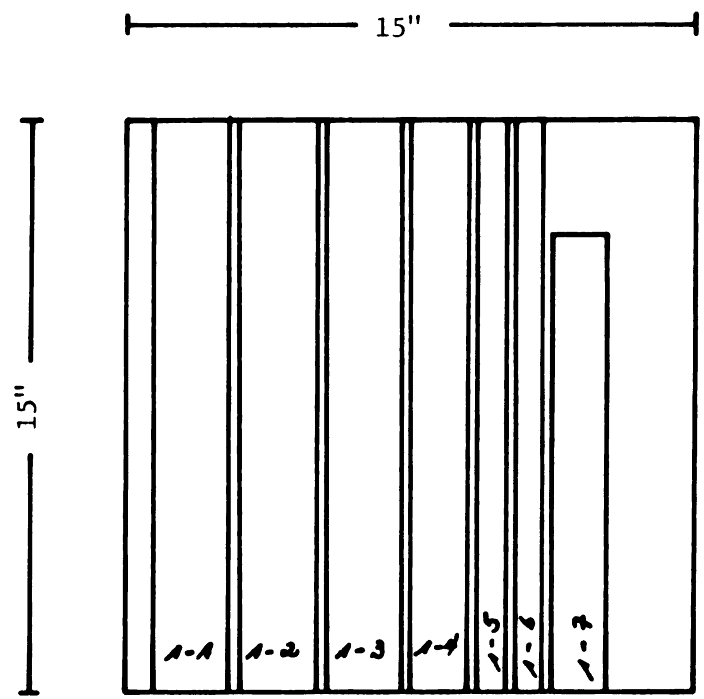
Modulus of rupture and modulus of elasticity are determined in accordance with section 11, sections 13 through 18 and paragraphs (a) and (c) of section 19 of Standard Specification ASTM D 1034-64. Internal bond is determined in accordance with sections 27 through 31 of ASTM D 1037-64; linear expansion in accordance with sections 76 through 79 of ASTM D 1037-64. Of the above standard tests, only the first three were performed in this study. However, thickness swelling and density profiles over board cross section were added as important indicators of board quality. Board density and moisture content were determined for all test specimens.

2.3.1 - Modulus of Rupture and Modulus of Elasticity.

Two specimens were taken from each composition board for a total of 240 specimens. Strips 2 x 15 inches were ripped from pre-determined locations of each composition board (Figure 33) and tested according to the American Society for Testing and Materials (ASTM) Standard D 1037.

2.3.2 - Internal Bond.

Two specimens were taken from each composition board for a total of 240 specimens. Strips 3/4 x 15 inches were cut from a pre-determined location of each composition board and then assembled to a specimen



1-1 Bending specimens (2 x 15 x 5/8 in)
1-2 Bending specimens (2 x 15 x 5/8 in)
1-3 Bending specimens (2 x 15 x 5/8 in)
1-4 Linear expansion (1½ x 12 x 5/8 in)
1-5 Internal bond (3/4 x 15 x 5/8 in)
1-6 Thickness swelling (3/4 x 15 x 5/8 in)
1-7 Density profile (2.0 x 12 x 5/8 in)

Figure 33. Composition Boards - Sampling Procedure.

developed by Suchsland 1977 [73] that is tested by means of a compressive test. In it, the center plane of the composition board specimen is oriented at 45° to the direction of an applied compressive force (Figure 34).

Planes parallel to the center plane of the specimen will thus become planes of maximal shear stresses. Correlation between the compression shear test and the standard IB test for most composition board is very high (r = .917) [73].

2.3.3 - Thickness Swelling.

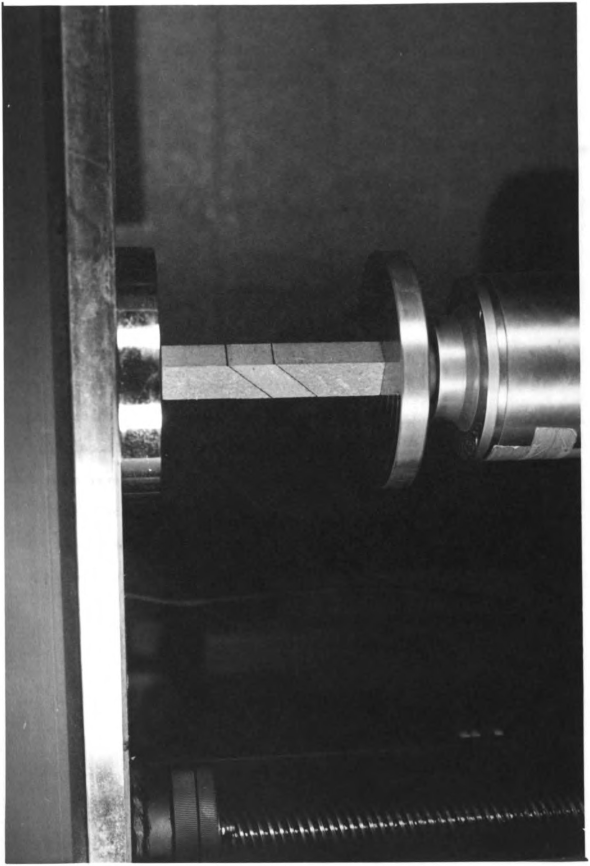
One strip 3/4 by 15 inches was taken from each composition board and converted into small specimens 3/4 x 3/4 x 5/8 inch for a total of 448 specimens. The exposure conditions were 70°F, 47 percent relative humidity, 66 percent R.H., 86 percent R.H., and 93 percent R.H. Conditions were maintained in desiccators over saturated salt solutions. One hundred twelve specimens, one from every replication, were placed in each of the four desiccators. After reaching equilibrium, specimens were weighed and measured with dial gage to the nearest .001 inch.

All were then reconditioned at 47 percent R.H. and then reweighed and remeasured. Subsequently, all specimens were ovendried for determination of moisture contents. Thickness swelling at 47 percent R.H. was used as basis for all calculations (Suchsland, O.) [70].

2.3.4 - Linear Expansion.

The linear expansion was determined on one specimen 1 1/2 inch x 12 inches in size taken from each of the 112 boards. Specimens were

Figure 34. Internal Bond - Testing Procedure.



first conditioned at 47 percent R.H. and 65°F until equilibrium was reached. They were then transferred to a condition of 90 percent R.H. and 80°F where they remained until equilibrium was reached again. The distance between markers embedded in the board surface was determined at each condition by means of an optical comparator (Suchsland, O.) [74]. The gage length was 10.0 inches. Measurements were made to the nearest .0001 inch. Specimens were ovendried after completion of test for determination of moisture content levels.

2.3.5 - Density Profile.

Since the density variation over the board cross-section significantly affects bending strength and bending stiffness, it was determined for one replication of the boards containing 8 percent resin.

Two specimens .90 inch x 12 inches were glued back to back and then thin layers were removed by planing from each surface.

After each run through the planer, the specimens were weighed and their thickness measured. The data, thus collected allowed the calculations of the density of each layer removed.

CHAPTER V

LITERATURE REVIEW

1) Properties of the Wood Species.

1.1 - Fibers.

As a general trend, fiber length, diameter and wall thickness increase with the age of Eucalyptus species. This has been shown for *E. grandis* (New South Wales and South Africa) (Bamber and Humphreys 1963) (Taylor 1972) [4, 79]. The distance from the pith usually has a greater influence on fiber length than height in the tree. In fast grown *E. grandis* (South Africa) the fiber length increased from 0.69 to 1.05 mm at 0.12 cm from the pith, and similar results were obtained at different heights (Taylor 1972) [79]. Maximum fiber length has been found at 8m with *E. grandis* (N.S.W.) (Bamber *et. al*. 1969)[3], at mid-stem position (Sri Lanka) (Ranatunga 1964), [55] and in Zambia the average increased from .87 to 1.01 mm from pith to periphery (Hans *et.al*. 1972) [28]. Fiber length in 5 year old *E. grandis* was not related significantly to seed source (Bamber and Humphreys 1963) [4]. Also the fiber length of juvenile wood of *E. grandis* (South Africa) was not strongly related to that of mature wood (Taylor 1973) [80]. The fiber diameters of *E. grandis* (South Africa) increased from pith to the periphery of 15 year old trees, with the largest ones being found at 10.7m above ground level and the smallest at the top of the tree. (Taylor 1973) [80]. Guha *et. al*. 1965, 1967) [23, 24] reported the average fiber length for *E. robusta* (India) sulphate pulp as .90 mm maximum 1.40 mm, minimum .36 mm, and average fiber diameter 0.010, maximum 0.028 mm, minimum 0.007 mm. Srivastava and Mathur (1964) [61] by the same process showed an average fiber length for E. grandis of .82, maximum 1.40 mm, minimum .56 mm and for fiber diameter, average .014 mm, maximum .028 mm, minimum .007 mm. For most of the end uses to which Eucalyptus timber is put, variation in fiber length within trees or between species has little importance, and to detect differences approximating .14 mm at least 80 fibers should be measured (Burley et. al. 1970) [8] From the literature, it can be seen, that most of the measurements related to fiber length and fiber diameter, were made on Eucalyptus grandis from different sources, and that the variation within the species and within trees is not that great, with average fiber length being close to .90 mm. The only reference made to fiber length related to Eucalyptus robusta shows that it is very close to Eucalyptus grandis in this respect as far as average values are concerned.

1.2 - Density.

Highly significant differences (at the 1 percent level) have been found in the basic density between trees of E. grandis (N.S.W.) in a number of plantations (Edwards, 1973) [14].

Density differences within single trees of E. grandis (South Africa) varied between 160 and 250 kg/m^3 (Taylor 1973) [80] and in E. robusta (Hawaii) the range of densities within a tree was between 360 and 820 kg/m^3 (Skolmen 1972) [60]. A decrease in density in the first few centimeters of growth, followed by an increase, has been found in a number of provenances of E. grandis (N.S.W.) (Bamber and Humphreys

1963) [4] at 1.5 m above ground level. The minimum density (370 kg/m^3) was found at 3.5 cm from the pith of E. grandis grown in South Africa, with the maximum of 495 kg/m^3 at the periphery (12.5 cm) (Taylor 1972) [79]. The density of wood at the 1.5 m level from 6.5 year old E. grandis (Zambia) increased from 419 in the central segment to 472 kg/m^3 in the outer segment (Hans et. al. 1972) [28]. Different conclusions have been drawn concerning the influence of sample height on wood density. A detailed survey of 14 year old E. grandis (South Africa) showed that density decreased sharply between the sampling heights of 1.5 and 4.6 m and then increased steadily as the height increased to 25.9 m. The range of densities at the 1.5 m level was between 424 and 471 kg/m^3, at 4.6 m, between 395 and 461 kg/m^3, and at 25.9 m between 476 and 533 kg/m^3 (Taylor 1973) [80]. However, the density decreased with height in two 25 year old E. grandis (N.S.W.) specimens (Bamber and Humphreys 1963, Bamber et. al. 1969) [3, 4]. A progressively increasing density has been found at each sampling level with increasing distance from the pith of E. robusta (Hawaii) (Skolmen 1972) [60]. No correlation was found between density and growth rate for E. grandis (N.S.W.) and E. robusta (Hawaii)(Bamber et. al. 1969)(Skolmen 1972) [3, 60]. Wedges from different parts of one cross section of different trees of E. grandis (South Africa) showed that growth rate had no influence on density (Taylor 1973) [80], but the slow grown wood of E. grandis (Zambia) had a density that was 18 kg/m^3 higher than that of the fast grown wood (Hans et. al. 1972) [28]. An average density of 28 lbs/ft^3 was reported for 10 year old E. grandis and E. robusta grown in southern Florida (U.S.A.) (Franklin 1977) [16]. Gueneau (1969) [22] reported a range between .775 gr/cm^3 and .889 gr/cm^3 for 45 year old E. robusta (Madagascar). In terms of density, it can be concluded that there are large variations not only between trees, within species, but even in between species of Eucalyptus grandis and Eucalyptus robusta of different sources and ages.

1.3 - Other Properties.

Among the main problems encountered in the utilization of sclid Eucalyptus wood from young rapidly grown trees are the excessive shrinkage and drying defects such as checks and splits which tend to be worse in woods of low density (Hillis and Brown 1978) [33]. E. grandis can be dried satisfactorily according to De Villiers (1973) [13]. E. robusta (Madagascar) is very suscrptible to collapse (Gueneau 1969) [22]. He also reported the following range of values for MOE:1,995,000 to 2,427,000 psi, for shear strength 1,041 to 2,214 psi, for shrinkage volumetric 16.9 to 20.7 percent, for shrinkage radial, 6.6 to 9.2 percent, for shrinkage tangential 10.6 to 12 percent. Hillis and Brown (1978) [33] reported MOE values for E. grandis between 1,617,000 and 2,015,000 psi,shear strength between 1,245 and 1,798 psi, and 12,514 and 15,950 psi. For South African E. grandis MOE of 1,828,000 psi, MOR of 11,660 psi, and shear strength of 1,190 (psi) were determined on a sample of 95 specimens (Banks 1954) [5]. From what has been found in the literature, it looks like E. grandis and E. robusta are different as far as average MOE and shear strength are concerned. Ages were not reported.

2) Composition Boards Properties.

Most composition boards consist of over 90 percent ligno-cellulosic material on dry weight basis and resin as a complement. Consequently, the properties of this raw material have a significant effect on both the manufacture and the physical properties of the final product. But the effects of interaction between processing variables on the resultant properties are normally quite large and in many instances separation of these interactions proved to be impossible (Kelly, M.W.) [38].

2.1 - Modulus of Rupture.

Modulus of Rupture (MOR) is a very important variable in determining the applicability of composition boards for structural purposes. The density of the board divided by the density of the wood equals the compaction ratio. Hse, C.-Y. [35] found a high correlation between compaction ratio and MOR for particleboards at three different densities produced from nine hardwood species from low to high specific gravity.

Vital et. al. [82] found that particleboards from four exotic hardwoods of widely varying specific gravity, made to constant board density, had higher MOR values as the compaction ratio increased from 1.2 to 1.6. Stewart, H.A. and Lehmann, W.F. [62] found the MOR to increase linearly with increasing panel density for four hardwood species ranging in specific gravity from .37 to .67 (O.D. weight volume at 8 percent moisture content). However, the modulus of rupture decreased for all board densities. So it is unanimously accepted, and adequate evidence is available, that MOR increases with board density when all other factors (particle configuration and orientation, species, adhesive content, pressing conditions)are constant. In terms of particle geometry, an important fact is that particle size for optimum MOR is not necessarily the optimum for dimensional stability or internal bond. Turner, H.S. [81] found that at constant panel density, flakes three inches long and .015 to .020 inch thick resulted in optimum MOR values. Post, P.W. [51] found a continuous increase in MOR for oak particleboard with increasing flake length over the studied range of .5 to 4 inches, but the rate of increase decreased with lengths greater than 2 inches. However, as the flake thickness increased above 0.010 inch, MOR decreased for all flake lengths. The flake length/thickness ratio was found to be closely related to MOR at all flake lengths and thicknesses. In a related study he stated that the length/thickness ratio is a better indicator of the effect of particle configuration on MOR than either dimension individually. Brumbaugh, J.I. [6] studied the effect of flake size on Douglas-fir particleboard of three densities. MOR values increased with increasing flake length within the studied range of 0.5 to 4 inches. Flake thicknesses of .009 to .018 inch resulted in no significant effect on MOR. Heebink, B.G. and R.A. Hann [31] studied the effect of particle shape on homogeneous particleboard properties of Northern Red Oak; their results also showed 1-inch flakes to result in significantly higher MOR values than .25-inch flakes at an equal thickness of .015 inch. Planer shavings, sawdust, slivers, and fines all resulted in lower MOR values than did the .25 inch long flake. Lehmann, W.F. [43] found increasing flake thicknesses always reduced MOR, when other factors were constant for phenol-formaldehyde bonded flakeboard for structural applications. Gatchell et. al. [17] found an increase in MOR as flake thickness decreased with pehnolic-bonded flakes. As a general trend found in the literature, particle thickness has more influence on MOR values than does particle length, at least at lengths greater than 1 to 2 inches.

Kusian, R. [42] found MOR increased as the flake width increased, but as the width approached particle length the MOR decreased. Suchsland, [67] stated that the ideal particle configuration for a three layer board was narrow, thick particles in the core and thin, short square particles at the surfaces. The effect of particle geometry on the resultant panel MOR values appears to be fairly well established. Particles of high length/thickness ratios, in which structural damage is minimal, normally produce particleboards with superior MOR values. Planer shavings are usually damaged and consequently produce a board with inferior MOR values (Hart, C.A. and J.T. Rice; Heebink et. al.) [29,30].

2.2 - Modulus of Elasticity.

Modulus of Elasticity (MOE) is a measure of stiffness, or resistance to bending, when a material is stressed. In general, MOE and MOR are affected similarly by various processing parameters. Suchsland,O. and Woodson, G. [72] stated that for medium density fiberboards produced in an oil heated press in a general fashion, density and density distribution directly affect the modulus of elasticity. In another study Suchsland, O., Lyon, D.E. and Short, P.E. [68] it was stated that for eight commercial MDF there was a strong correlation between MOE of the board and face density. Particleboards of constant average density posses higher MOE values as the wood density decreases or as the compaction ratio increases.

The vertical density gradient, as influenced by face weight/total board weight ratio and press closing time, has been shown by Geimer et. al. [18] to have a tremendous influence on effective MOE, even at constant density. The literature contains many studies which report a direct relationship between board density and the effective MOE; all unanimously agree that an increase in density will increase MOE.

The modulus of elasticity is strongly dependent upon flake length, longer flakes produce particleboards with substantially higher effective MOE (Heebink, B.G. and Hann, R.A.) [30], (Heebink, et. al.) [31], (Lehmann, W.F.) [43]. Stewart, H.A. and Lehmann, W.F. [62] did not find a significant effect of flake thickness on the effective MOE for particleboards produced from cross-grain flakes in the thickness range 0.006 to .018 inch. Gatchell, et. al. [17] found an increase in MOE when flake thickness decreased from .030 to .015 to .007 inch.

Lehmann, W.F. [43] also found a decrease in the effective MOE when the flake thickness increased from .030 to .045 inch, at a constant flake length of 2 inches and at all phenol-formaldehyde adhesive contents studied. Maloney, T. [45] in a study to determine the effect of short retention time blenders on large flake furnishes, found an increase in MOE as the board specific gravity increased for all resin levels studied (2, 4 and 6 percent resin solids on O.D. wood).

2.3 - Internal Bond.

The internal bond (IB) strength of a particleboard (tensile strength perpendicular to the plane of the board) is an important quality indicator. It not only reveals the quality of the glue bond, which in turn allows estimates of related properties, but it is also an important quality control tool, which, in combination with MOE, provides clues to the balance of board characteristics, which is affected, for example, by the press cycle (Suchsland, O.) [73]. Most researchers have found higher IB values with increasing board density, increasing resin content, and increasing press time and temperature.

The normal vertical density gradient in flat pressed particleboard adversely affects the IB. Highly densified surfaces increase the bending strength of particleboard, but the resultant lower density core region normally reduces the IB (Strickler, M.D.) [63] and (Plath, L. and Schnitzler, E.) [48]. However, Strickler, M.D. [63] and Geimer et. al. [18]did not find a strong correlation between core density and internal bond; Strickler attributed this to moisture and press cycle effects. Vital, et. al. [82] did not find a close relationship between IB and board density for particleboard.

The internal bond strength improves as the core particle configuration changes from a long wide flake to planer shavings or slivers (Childs, M.R., Talbott, J.W. and Maloney, T.M., Suchsland, O., Brumbaugh, J.I., Rackwits, G., Kimoto et. al., Gatchell et. al., Stewart, H.A. and Lehmann, W.F. and Lehmann, W.F.) [11, 78, 67, 6, 54, 40, 17, 62, 43]. Suchsland, O. and Woodson, G.E. [63] suggested that for commercial medium density fiberboards a low MOE and a markedly high IB could be due to a vertical alignment of the fibers. Woodson, G.E. [83] stated that IB for medium density fiberboards increased 38 percent as the resin level changed from 4 to 10 percent.

2.4 - Dimensional Stability.

The effects of moisture on particleboard have an important bearing on its properties and uses. Reduction in particleboard strength, and unreliable life span when subjected to changing moisture content, have prevented wide spread exterior and structural uses of the material (Halligan, A.F.) [25]. Kollmann et. al. [41] graphically compared the dimensional stability of particleboard to that of solid pine wood. The average linear expansion compared favorably with the longitudinal swelling of pine, but the thickness swelling is much greater than the tangential swelling and continues to increase at an increasing rate with moisture content. This reflects the large amount of springback associated with flat-pressed particleboard as a result of the compressive set during manufacture.

2.4.1 - Thickness Swelling.

There is controversy in the literature with respect to the effect of density of the board on the thickness swelling due to the so-called springback effect. Vital et. al. [82] with particleboards from exotic hardwoods of four different wood densities, studied the water absorption and thickness swelling properties. For all species combinations, the higher compaction ratio (1.6) always absorbed a lower amount of water than the lower compaction ratio (1.2).

With only a few exceptions, an increase in board density resulted in a decrease in thickness swelling for the 30, 50, 90 percent R.H. exposures. Lehmann, W.F. and Hefty, F.V. [44] found no relationship between particleboard density and thickness swelling except at the 2 percent adhesive level. At this level of urea formaldehyde resin, the lower density board, .65 gm/cm^3 (O.D. weight volume at 65 percent R.H.) had lower thickness swelling than the board with a density of .75 gm/cm^3 (O.D. weight, volume at 65 percent R.H.). Roffael, E. and Rauch, W. [57] reported on the thickness swelling of particleboards with a wide range of densities (.51 to .94 gm/cm^3) when subjected to water soaking at 20°C. They found a decrease in absorption but an increase in thickness swelling as the density increased. Halligan, A.F. and Schniewind, A.P. [26] for a series of particleboards with three resin contents at each of three densities found a higher thickness swelling as the board density increased for moisture contents above 10 percent. Below 10 percent moisture content board density appeared to have little influence on thickness swelling. Stewart, H.A. and Lehmann, W.F. [62] did not find a consistent relationship between thickness swelling and board density for particleboards produced from cross grain, knife planed flakes from four different hardwoods. Hann et. al. [27] reported increased thickness swelling in 24-hour water soaking when the density of Douglas-fir particleboard was increased from 34 to 43 lb/ft^3.

Suchsland, O. [70] determined the thickness swelling of ten commercial particleboards under cyclic relative humidity and water soak exposure and found no correlation between board density and thickness swelling. Lehmann, W.F. [43] found a relatively minor effect of density on thickness swelling with 1-30 day water soaking for Douglas-fir particleboard made at two densities (37.5 and 42.5 lb/ft^3, O.D. weight and volume at 65 percent relative humidity) with various flake configurations and three levels of phenol-formaldehyde adhesive content. Hse, C-Y [34] found increased thickness swelling with increased board density in the 5 hour boil and the VPS* test for phenol-formaldehyde bonded particleboard. Gertjejansen et. al. [19] found increased thickness swelling with increased board density for phenolic bonded waferboard. The literature doesn't show a very consistent relationship between thickness swelling and board density. Turner, H.D. [80] showed that flake length has no significant effect upon thickness swelling. Lehmann, W.F. [43] in his study of Douglas fir flakes 0.5, 1.0 and 20 inches long and .030 and .045 inch thick, found no significant effect of flake length on particleboard thickness swelling with either the VPS or relative humidity exposure tests. However, the thinner flakes resulted in slightly less thickness swelling. Brumbaugh, J.I. [6] also reported improved thickness stability with thin (.009 inch) Douglas-fir flakes and a decrease in thickness stability with a flake length of .5 inch. Stewart, H.A. and Lehmann, W.F. [62] using cross grain, knife-planed hardwood flakes of four species and three thicknesses (.006, .012, and .018 inch) found no relationship between the flake

*Vacuum pressure soak

thickness and thickness swelling in the resulting particleboard. Kimoto et. al. [40] reported a slight decrease in thickness swelling, determined by the water soak test, as the particle dimensions increased for low density Lauan particleboard. No effect of particle configuration on thickness stability was evident in the relative humidity exposure test. Heebink, B.G. and Hann, R.A. [30] found Northern Red Oak flakes 1 inch long produced a more stable particleboard than did flakes .25 inch long. Post, P.W. [51] reported that flake length had no relationship to thickness stability when the flake thickness was below .012 inch. With flakes thicker than that, stability was improved with increasing flake length. There is an agreement in the literature that better thickness stability is obtained with boards produced from thin particles than from thick particles. This is not true for particle length. Increasing the resin content improves the thickness stability of particleboard (Kimoto et. al., Gatchell et. al., Lehmann, W.F. and Hefty, F.V.) [40, 17, 44]. Lehmann, W.F. [45] found optimum thickness swelling for urea formaldehyde bonded Douglas-fir particleboard occurred below 8 percent adhesive (resin solids and O.D. weight). Lehmann, W.F. [43] also found improved thickness stability in Douglas-fir flakeboard with increasing levels of phenol-formaldehyde adhesive. The three adhesive levels studied (3, 6, and 9 percent resin solids on O.D. wood) did not indicate an optimum level, but the improvement obtained between 6 and 9 percent was lower than the improvement between 3 and 6 percent. In general, increasing the resin content up to a certain limit will result in improved interparticle bonding which should also improve the thickness stability. Wood species influence thickness swelling through density effects and resin curing. When particleboard is made, the quantity of flakes needed to form a mat is controlled to give a certain finished board density. Therefore, the degree of compression needed in pressing depends on the density of the wood species used, low density woods must be compressed more than higher density species. Most thickness swelling at high moisture contents comes from release of compression stresses arising during pressing, so the density of the wood raw material is important (Halligan, A.F.) [25].

2.4.2 - Linear Expansion.

The linear expansion of particleboard when exposed to moisture is much less than the radial swelling, but greater than the longitudinal swelling, of solid wood, excluding well oriented flakeboards where the linear expansion in the direction of orientation will decrease and approach the longitudinal swelling of wood while the linear expansion perpendicular to the alinement will increase and approach the transverse swelling of solid wood (Geimer et. al.) [18]. Studying medium density fiberboards from southern hardwoods Woodson, G.E. [85] stated that linear expansion (50 to 90 percent relative humidity) was greatest in high density boards. In another study Woodson, G.E. [84] reported no effect of refiner plate clearance on linear expansion. Suchsland, O. et. al. [68] studying the properties of selected commercial medium density fiberboards found no relationship between linear expansion and board density or density gradient. Vital, V. et. al. [82] in their study of particleboard pressed to two compaction ratios, found a slightly greater linear expansion with the higher compaction ratio. Stewart, H.A. and Lehmann, W.F. [62] in their study of particleboard made with cross grain, knife-planed flakes of four hardwood species found an increase in linear expansion with increasing board density for a 30 to 90 percent relative humidity exposure with all species except the low density basswood. This same effect was found for particleboard made with the two high-density species, red oak and hickory. After a 30 day water soak linear expansion decreased with density for the boards made with yellow poplar and basswood. Suchsland, O. [70] found no clear relationship between board density and linear expansion for ten commercial particleboards exposed to a 40 to 93 percent relative humidity increment. However, the two boards with the highest density also had the highest linear expansion; the remaining eight boards had approximately the same density but the linear expansion was widely different. Gertjejensen et. al. [19] found no effect of board density on linear expansion with phenolic bonded waferboard composed of tamarack, paper birch and aspen. Lehmann, W.F. [45], also found no effect of board density on linear expansion of phenol formaldehyde bonded particleboard made with Douglas-fir flakes of various lengths and thicknesses. No investigators have found a statistically valid relationship between linear expansion and board density. Gatchell et. al. [17] found increased linear expansion in Douglas-fir particleboard at all relative humidities when the flake thickness increased above .015 inch. Very little difference was found when the flake thickness was reduced to .007 inch. Linear expansion was also independent of flake length when the flake length was increased from 1 to 2 inches. However, with flakes .5 inch long the resulting particleboard had significantly higher linear expansion. When the particle configuration was changed from flakes to slivers to hammermilled planer shavings the linear stability also decreased.

Turner, H.D. [81] also showed the impressive improvement possible in linear stability by decreasing the flake thickness from .030 to .009 inch. Particleboard with flakes 1.5 inches long had slightly better linear stability than with flakes 3 inches long for flake thickness of .030 inch. However, when the thickness was reduced to 0.018 inch, the linear expansion of particleboard with the 1.5-inch flake was reduced to much less than for the 3 inch flake, and was comparable to that of the 3 inch flake 0.009 inch thick. Heebink, B.G. and Hann, R.A. [31] also found that red oak flakes 1 inch long produced more linearly stable particleboards than did .25 inch long flakes, shavings, sawdust or slivers. Post, P.W. [51] also found that linear stability was not greatly affected by changes in flake length or thickness below a thickness of .012 inch; above this thickness, decreasing length reduced linear stability. Brumbaugh, J.I. [6] also found increased linear expansion in particleboard from Douglas-fir flakes as the flake length decreased and the flake thickness increased.

Heebink, B.G. [32] found reduced linear stability with flakes 3 inches long by 0.030 inch thick as compared to flakes 2 inches long by .020 inch thick. This indicates flake thickness is a more important factor than either flake length or length/thickness ratio in controlling linear expansion.

Suchsland, O. [70] also concluded that particle size was the most important factor controlling linear expansion in his study of ten commercial particleboards. Gertjejensen, R. and Haygreen, J.G. [20] reported somewhat better dimensional stability with flakes (.5 inch long by .015 inch thick) than with wafers (1.5 inches long by .025 inch thick). The linear expansion of particleboard subjected to various exposure conditions is only slightly reduced by increasing the resin content (Gatchell et. al. and Lehmann, W.F.) [17, 43]. An exception to this appears to be the fact that at extremely low resin contents linear expansion is substantially increased, but above a resin content high enough to adequately bond the particles, further resin addition is of little benefit.

CHAPTER VI

RESULTS AND DISCUSSION OF RESULTS

1) Statistical Procedure.

Beyond the routine calculations of means, variances and standard deviations, it was necessary for the purpose of this study to use the t-test for comparison of two means, linear regression estimation and covariance analysis.

A brief description of the technicalities of regression estimation and covariance analysis follow [83].

1.1 - Regression Analysis.

Regression analysis is a statistical tool which utilizes the relation between two or more quantitative variables so that one variable can be predicted from the other, or others. The regression model is a formal means of expressing the two essential ingredients of a statistical relation:

a) A tendency of the dependent variable Y to vary with the independent variable or variables in a systematic fashion.

b) A scattering of observations around the curve of statistical relationship. These two characteristics are embodied in a regression model by postulating that:

c) In the population of observations associated with the sampled process, there is a probability distribution of Y for each level of X.

d) The means of these probability distributions vary in some systematic fashion with X.

In the basic regression model there is only one independent variable and the regression function is linear. The model can be stated as follows:

$$Y_i = B_o + B_1X_i + \xi_i$$

where:

Y_i is the value of the response variable in the ith trial.

B_o and B_1 are parameters.

X_i is a known constant, namely the value of the independent variable in the ith trial.

ξ_i is a random error term with mean $E(\varepsilon_i) = 0$ and variance $\sigma^2(\varepsilon_i) = \sigma^2$; ε_i and ε_j are uncorrelated, so that the covariance $\sigma(\varepsilon_i, \varepsilon_j) = 0$

for all i, j; $i \neq j$

$i = 1, \ldots., n.$

The model is said to be simple, linear in the parameters, and linear in the independent variable. It is "simple" in that there is only one independent variable, "linear in the parameters" because no parameter appears as an exponent or is multiplied or divided by another parameter, and "linear in the independent variable" because this variable appears only in the first power. A model which is linear in the parameters and the independent variable is also called a first-order model. To find "good" estimators of the regression parameters B_o and B_1 the method used is that of least squares.

1.2 - Covariance Analysis.

The analysis of covariance is concerned with two or more measured variables where no exact control has been exercised over measurable variables regarded as independent. It makes use of concepts of both analysis of variance and of regression. Analysis of covariance is used for different purposes, but it may be used primarily to adjust treatment means of the dependent variable for differences in the independent variable, that is, to adjust treatment $\bar{y}$'s by regression to be estimates of what they would have been had they had a common $\bar{x}$. The assumptions for covariance are a combination of those for the analysis of variance and linear regression. The linear additive model for any given design is that for the analysis of variance plus an additional term for the concomitant or independent variable.

The mathematical description is given by:

$$Y_{ij} = u + B(X_{ij} - \bar{x}) + \xi_{ij}$$

The variable being analyzed, the dependent variable, is generally denoted by "Y" while the variable used in adjustment of means, the independent variable or covariate, is denoted by X.

The assumptions necessary for the valid use of covariance are:

a) The X's are fixed and measured without error.

b) The regression of Y on X after removal of group differences is linear and independent of groups.

c) The residuals are normally and independently distributed with zero mean and a common variance.

Assumption 'a' states that the X's are parameters associated with the means of the sampled Y populations. As such they must be measured exactly. This assumption implies that, for the standard use of covariance, the groups will not affect the X values since we may have chosen for reasons of convenience. Assumption 'b' states that the effect of X on Y is to increase or decrease any Y, on the average, by a constant multiple of the deviation of the corresponding x from the mean of that variable for the whole experiment, that is, by $B(X_{ij} - \bar{x})$. The regression is assumed to be stable and homogeneous. Assumption 'c' is the one on which the validity of the usual tests, t and f, depends. An analysis, as determined by the model supplies a valid estimate of the common variance when there has been randomization. The assumption of normality is not necessary for estimating components of the variance of Y; randomization is necessary. (Wasserman and Neter, 1974). [82]

2) Solid Wood Physical Properties.

The very first phase of this research was directed toward the identification of the two species in terms of their important mechanical and non-mechanical properties, toward analysis of these properties to ascertain if in reality there was some statistical difference in between species properties.

2.1 - Specific Gravity.

Specific gravity is an important factor in determining the non-mechanical and mechanical properties, because it characterizes the amount of wood substance present in a given piece of wood. To a certain extent it also controls the extent of the dimensional changes that can take place in wood with changes in the moisture content below the fiber-saturation point. By thus influencing the basic properties of wood, specific gravity plays an important part in determining the utility of a given kind of wood, indeed even of a given piece, for a specific purpose. Measurements of specific gravity made on the bending specimens showed a difference of 18 percent for E. robusta over E. grandis (Table 10). The two average specific gravities compared at the 1 percent level of significance showed a statistical difference in between species (Figure 35). Specific gravities for both species were also measured on tensile, shear, and swelling specimens. The distributions are very similar to those of the bending specimens (Figures 36, 37, 38).

2.2 - Modulus of Elasticity and Rupture.

These two very important constants were measured, both, loading the specimens in the radial and tangential direction. Both MOE and MOR are higher in the radial direction, MOE 11 percent higher for E. robusta and 6 percent higher for E. grandis; MOR about 4 to 5 percent higher for both species.

Looking at the overall mean, the MOE for E. robusta is 11 percent higher than the respective MOE for E. grandis, and MOR about 14 percent higher (Table 10).

MOE overall mean of E. robusta tested against E. grandis, at the 1 percent significance level through a t-test showed a significant

Table 10. Solid Wood Properties.

[Mean Values]

Eucalyptus robusta

Modulus of Elasticity MOE (1000 psi)			Modulus of Rupture MOR (psi)			Tensile Strength ⊥ to Grain (psi)			Shear Strength (psi)			Specific Gravity (Average)			Overall M.C. (%)
Rad.	Tang.	Overall	Rad.	Tang.	Overall	Rad.	Tang.	Overall	Rad.	Tang.	Overall	Bend.	Tens.	Shear	
1499	1349	1424	12,921	12,470	12,694	398	530	465	1515	1816	1668	.59	.61	.57	11.0
(275.49)	(262.22)	(276.8)	(1896.5)	(1996.4)	(1940)	(64.5)	(103.3)	(108.4)	(193.5)	(285.6)	(286.1)	(.065)	(.071)	(.065)	--

Eucalyptus grandis.

Modulus of Elasticity MOE (1000 psi)			Modulus of Rupture MOR (psi)			Tensile Strength ⊥ to Grain (psi)			Shear Strength (psi)			Specific Gravity (Average)			Overall M.C. (%)
Rad.	Tang.	Overall	Rad.	Tang.	Overall	Rad.	Tang.	Overall	Rad.	Tang.	Overall	Bend.	Tens.	Shear	
1317	1240	1279	11,404	10,876	11,140	321	450	386	1390	1704	1547	.50	.53	.49	11.0
(194.35)	(201.12)	(199.65)	(2139.5)	(1772.8)	(1962.7)	(57.5)	(96.2)	(101.8)	(200.5)	(257.7)	(277.9)	(.055)	(.055)	(.062)	--

* Numbers in parentheses are standard deviations.

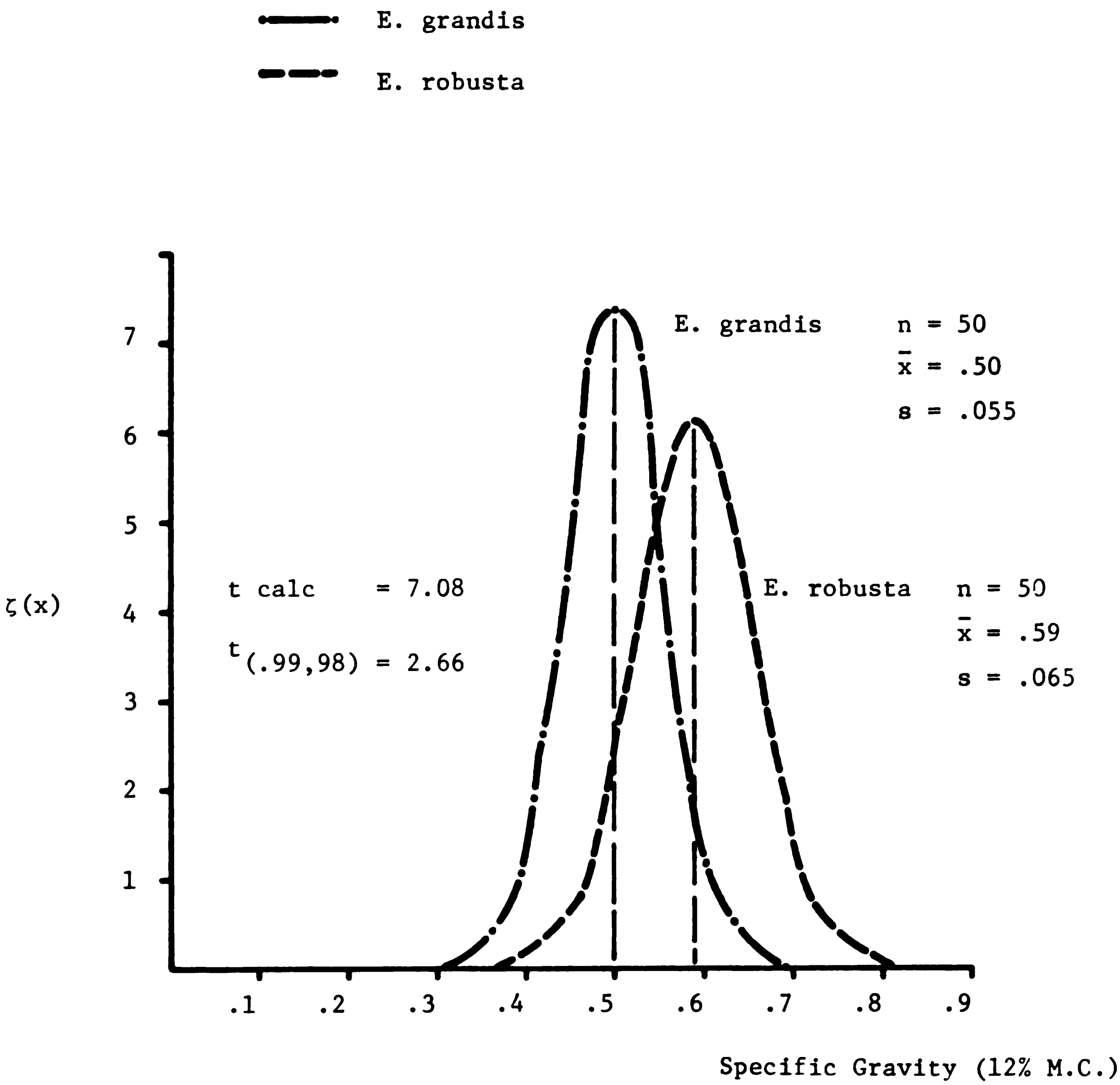


Figure 35. Bending Specimens - Specific Gravity Distribution

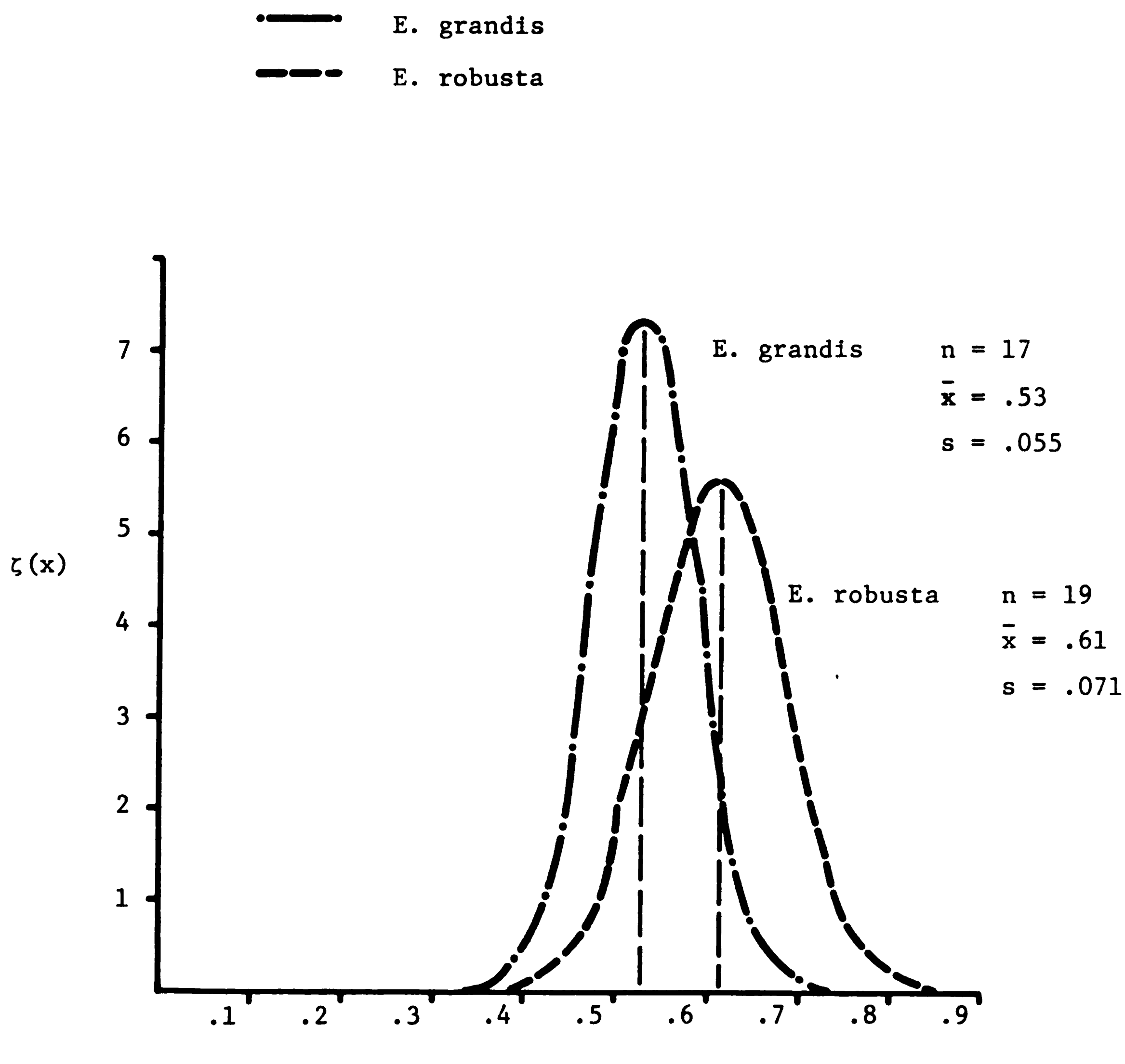


Figure 36. Tensile Specimens - Specific Gravity Distribution

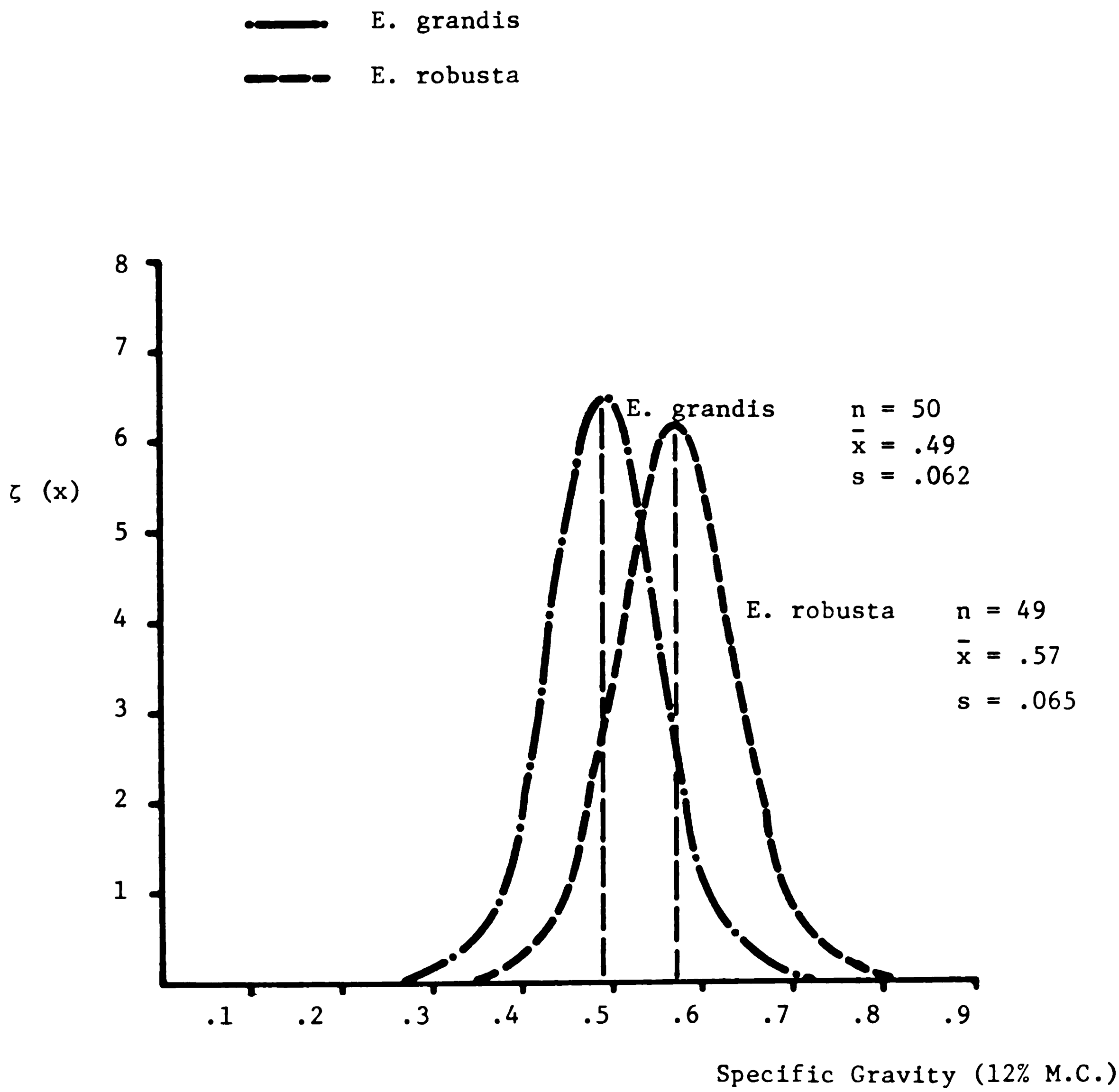


Figure 37. Shear Specimens - Specific Gravity Distribution

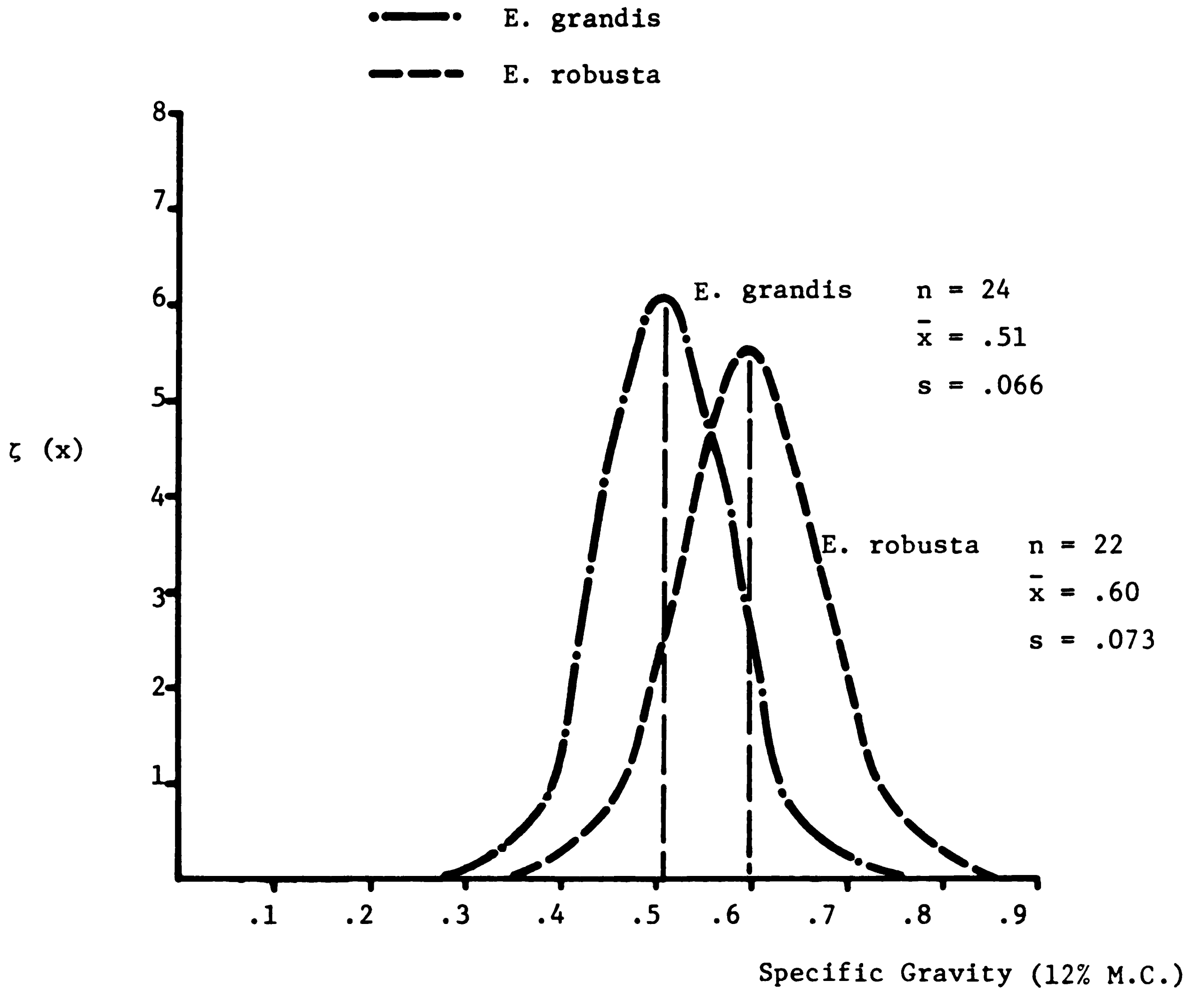


Figure 38. Swelling and Shrinkage - Specific Gravity Distribution.

difference, which means the two species are different as far as average MOE is concerned. Linear regression equations were developed for MOE over specific gravity for both species showing a "good fit" (r= .77 for E. robusta and r = .765 for E. grandis) (Figure 40). Distribution of MOE's is shown in (Figure 39).

A covariance analysis was conducted adjusting MOE means over specific gravity. After this adjustment means were compared at the 1 percent significance level, showing a significant difference. It can be concluded that the significant difference in between MOE's is not only due to specific gravity, but other variables that were not possible to exercise control over in this study also have a definite influence over the MOE of the species.

2.3 - Fiber Length.

Fiber length was obtained for both species. Measurements were made on about 150 fibers after maceration by the Jeffrey Process and a t-test comparing the two overall means conducted at the 1 percent level of significance. No difference in this respect was verified, which means that fiber length does not contribute to the difference in MOE. (Figure 41).

2.4 - Tensile Strength Perpendicular to Grain.

This test was usually carried out as an optional test because the stress is not evenly distributed over the minimum cross section. But it looks to be a good indication of the internal wood matrix resistance or the internal bond of the original solid wood matrix.

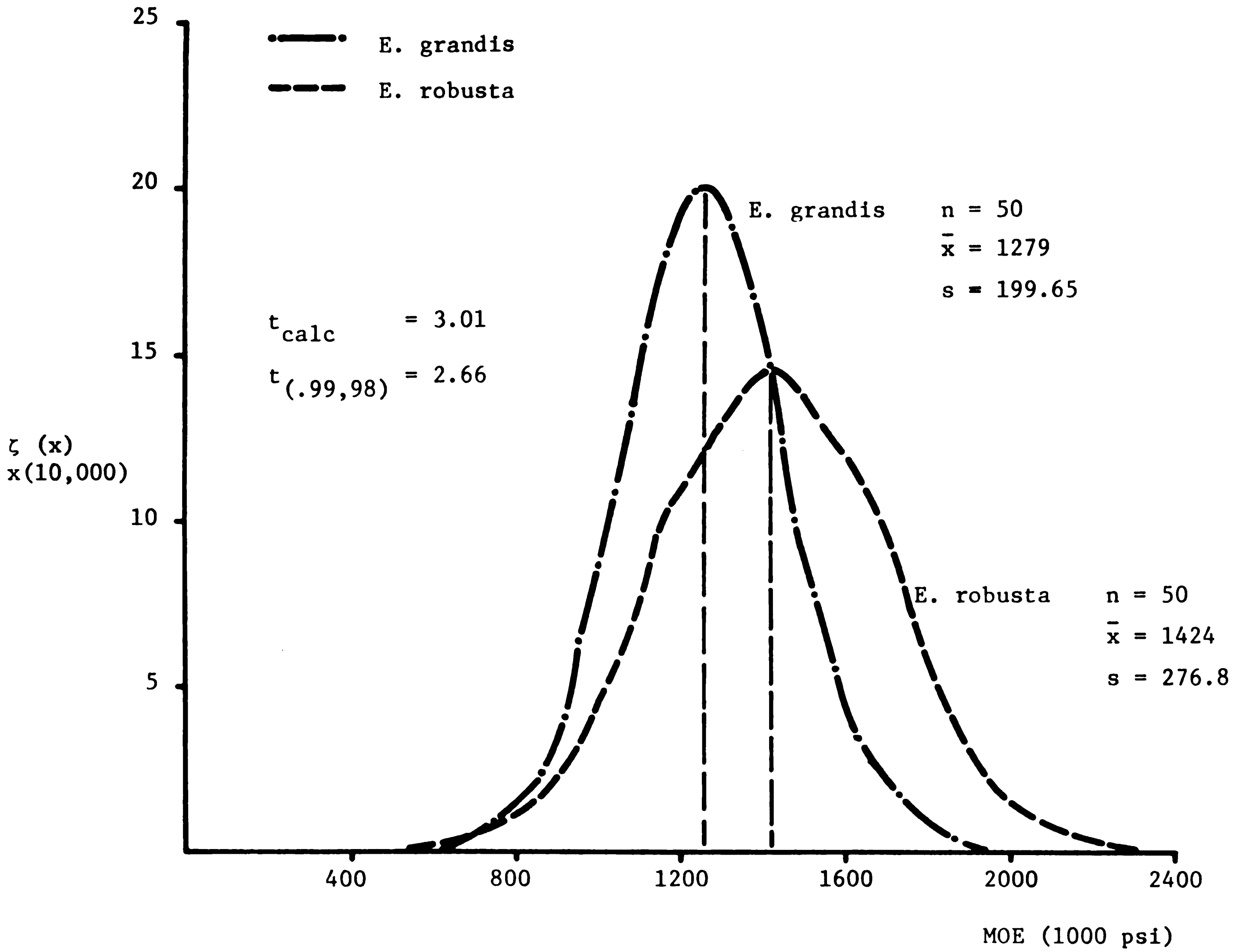


Figure 39. Modulus of Elasticity Distribution

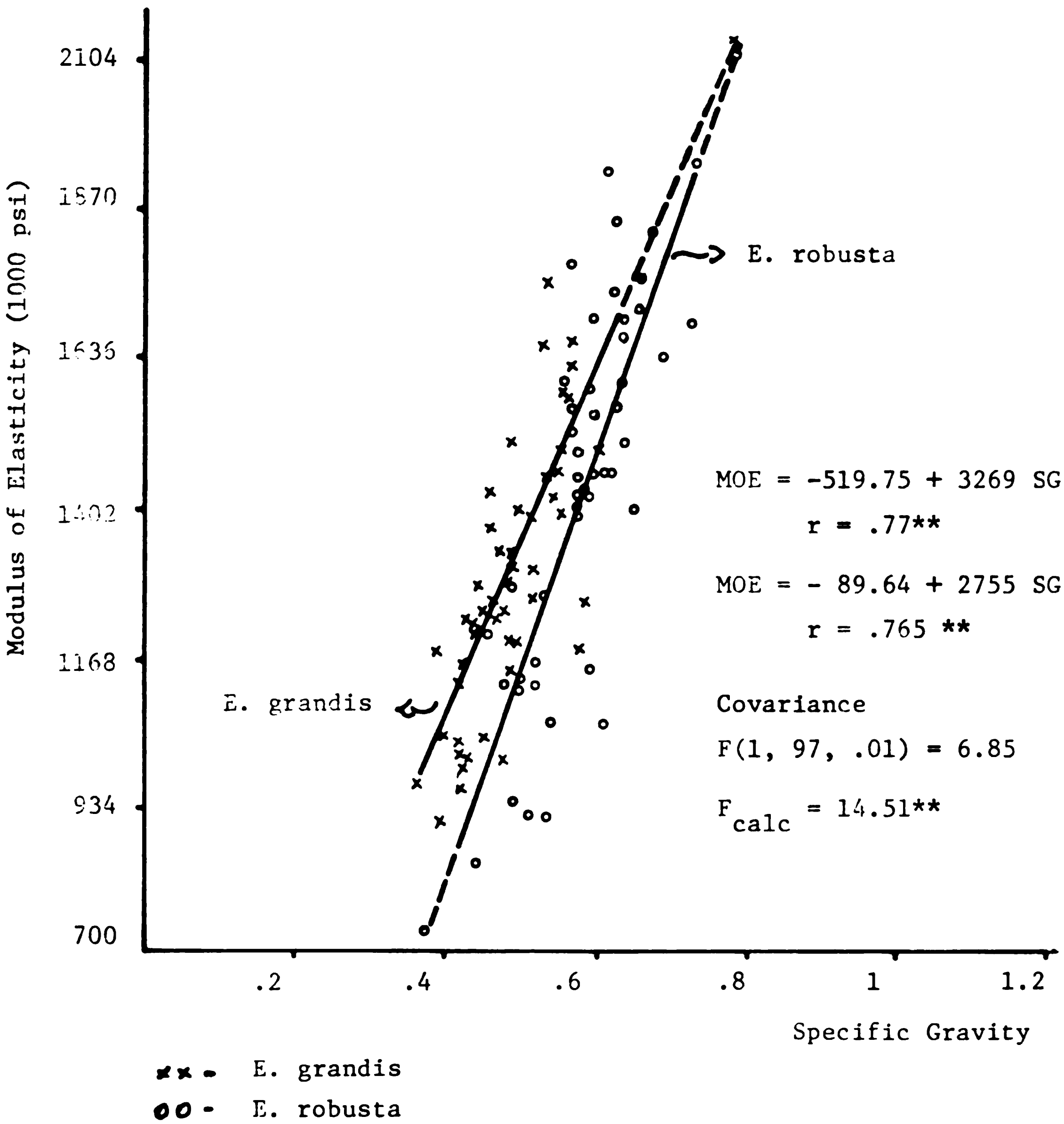


Figure 40. Solid wood Modulus of Elasticity - Regression Lines

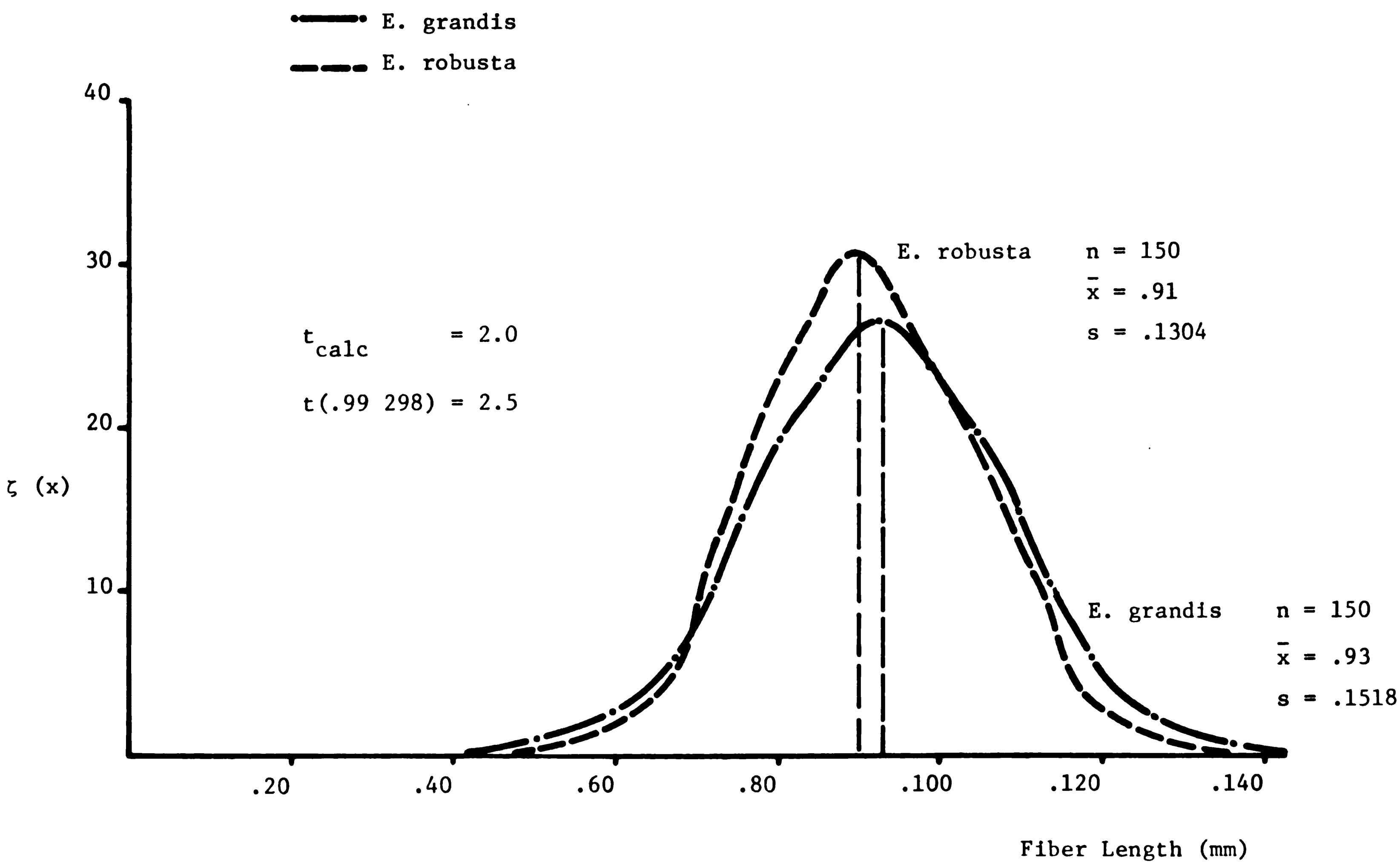


Figure 41. Fiber Lengths - Distribution

Tensile strength was measured loading the specimens, for both species, in the radial and tangential directions. Tensile strength was higher in the tangential direction for both species; in *E. robusta* about 33 percent and *E. grandis* about 40 percent higher (Table 10). According to Killmann, F. 1968 [41] the test carried out in this experiment is not true tensile strength perpendicular to grain but the so called "double cleavage" test. Results are 50 percent lower than the true tensile strength perpendicular to grain. Results obtained in this study are comparable to results reported in his analysis. Looking at the overall mean, *E. robusta* was about 20 percent higher than *E. grandis*. Compared by a t-test at the 1 percent level the two overall means are different. It can be concluded that *E. robusta* tensile strength is different than *E. grandis*. The distribution of tensile strength values around the means is shown in Figure 42.

Linear regression equations of tensile strength over specific gravity were developed showing no significant relationship. The equations are as follows:

$T_{spr} = 28.5 + 716.7\ SG_r \quad r = .42 \quad f = 3.7$ not significant

$T_{spg} = 360.1 + 43.2\ SG_g \quad r = .02 \quad F = .008$ not significant

where

T_{spr} = tensile strength perpendicular for *E. robusta*

T_{spg} = tensile strength perpendicular for *E. grandis*

SG_r = specific gravity for *E. robusta*

SG_g = specific gravity for *E. grandis*

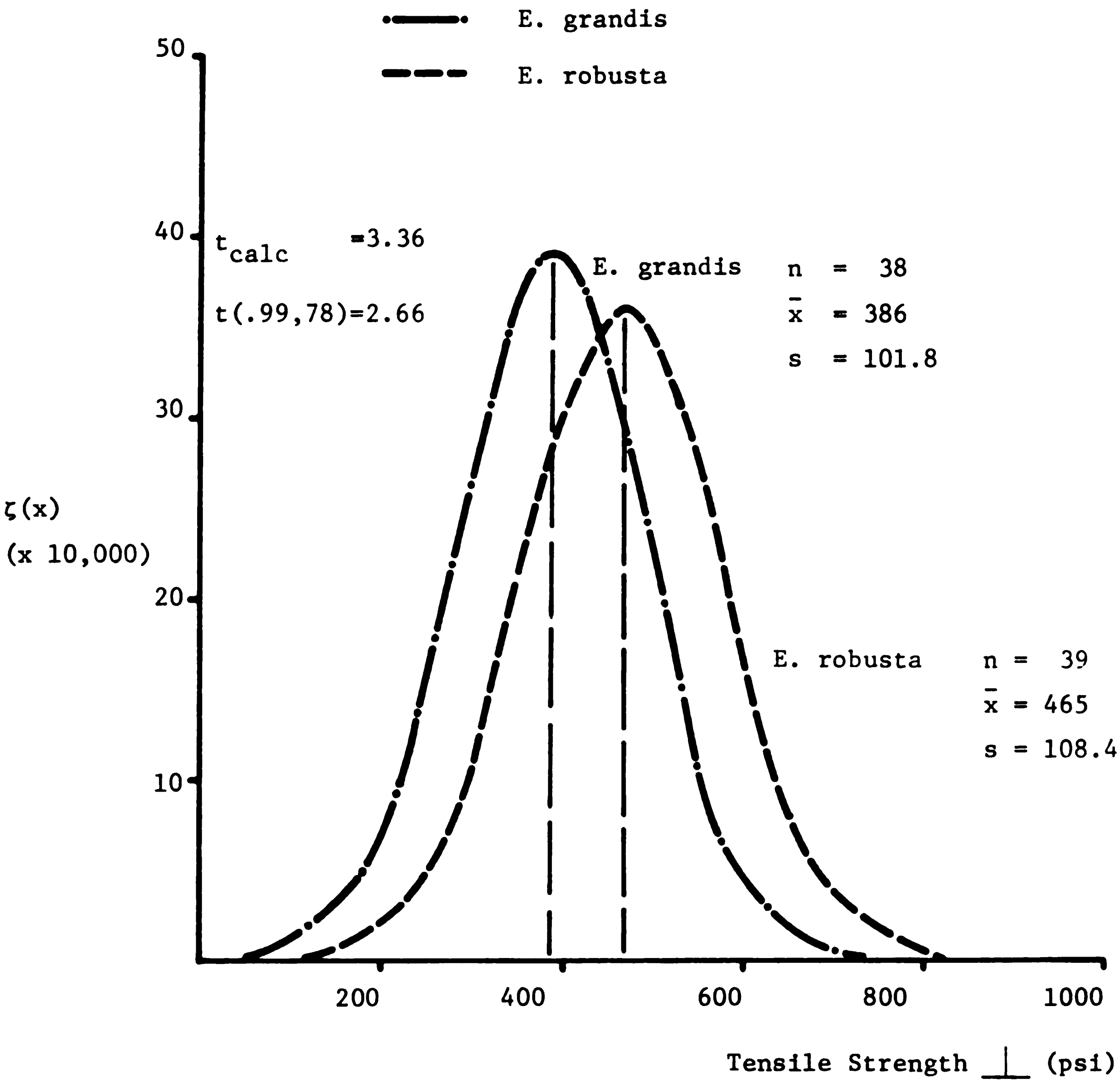


Figure 42. Tensile Strength Perpendicular to Grain Distribution.

No equations for tensile strength perpendicular to grain over specific gravity were found in the literature. These very low correlation coefficients could be well due to irregular stress distribution, difficult orientation of specimens, etc.

2.5 - Shear Strength Parallel to Grain.

The ultimate shearing strength parallel to grain is related to the strength in tension, but the shear test is problematic due to superimposed, mostly bending stresses. Compressive stresses, stress concentrations and internal checks are other factors which may mask a clear picture of the shear phenomenon. Shear strength was measured in both species in the radial and tangential planes. Shear was higher for both species in the tangential plane, about 20 percent higher for E. robusta and about 23 percent higher for E. grandis.

Looking at the overall mean for both species, E. robusta was about 8 percent higher in shear than E. grandis (Table 10). A t-test comparing these two means at the 1 percent significance level was conducted, and due to the large variability in results, no significant difference was verified. This indicates that a larger sample should have been used. The distribution of shear strength values around the mean is shown in (Figure 43).

Linear regression equations of shear strength over specific gravity were calculated showing a significant relationship at the 1 percent level of significance. The equations are as follows:

$SS_r = 16.7 + 2910\ SG_r \quad r = .65^{**} \quad f = 34.06$ significant

$SS_g = 408.8 + 2320\ SG_g \quad r = .52^{**} \quad f = 18.05$ significant

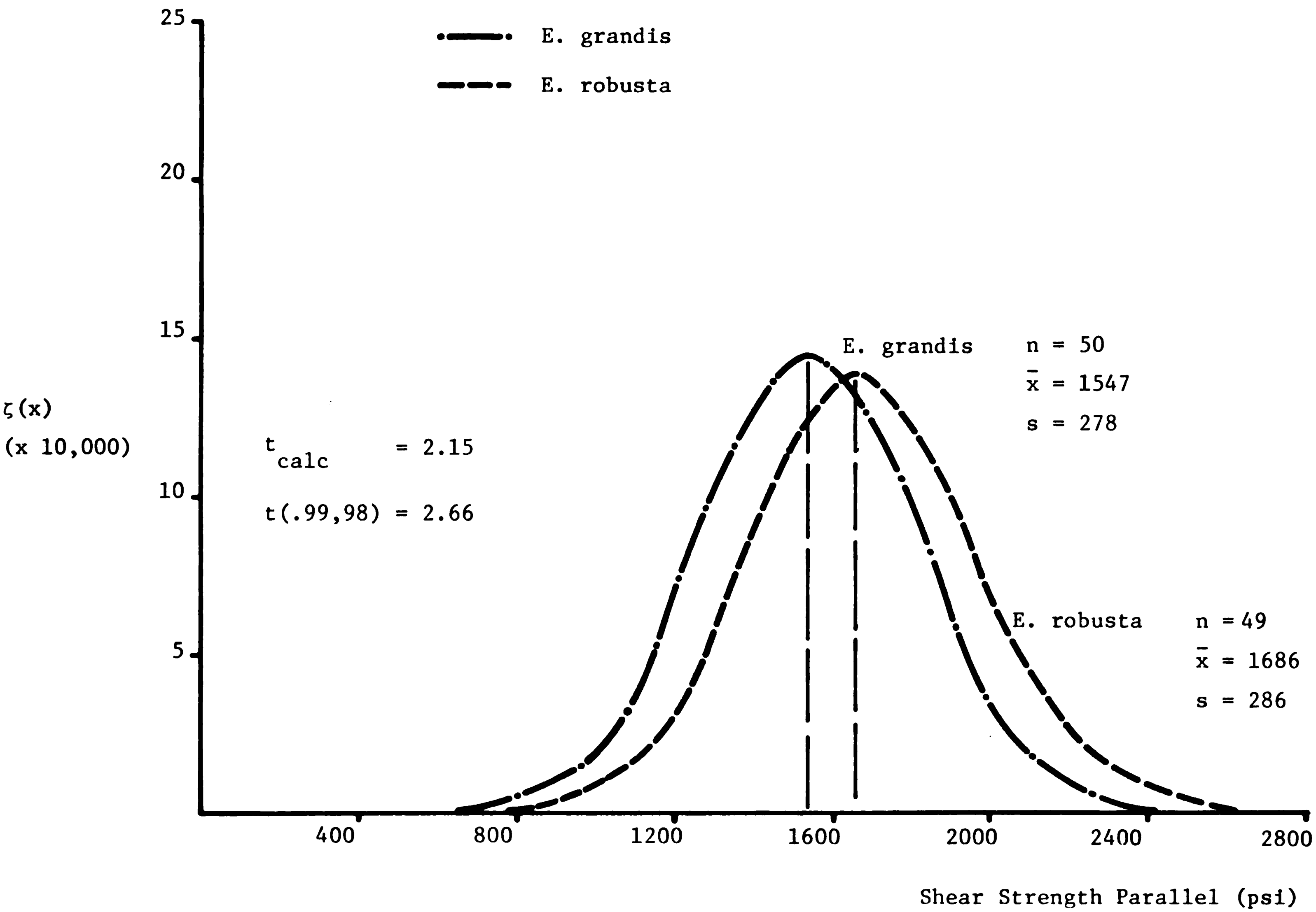


Figure 43. Shear Strength Parallel to Grain Distribution.

where

SS_r = shear strength parallel to grain for E. robusta.

SS_g = shear strength parallel to grain for E. grandis.

2.6 - Swelling and Shrinkage.

Wood is dimensionally stable when the moisture content is above the fiber saturation point. Wood changes dimension as it gains or loses moisture below that point. It shrinks when losing moisture from the cell walls and swells when gaining moisture in the cell walls. This shrinking and swelling can result in defects or performance problems that affect its use. It is therefore important to have a clear picture from where to depart in defining these variables for wood.

Longitudinal, tangential, radial and volumetric swelling and shrinkage were determined for both species. Swelling and shrinkage were higher in every determination for E. robusta over E. grandis (Table 11). A t-test comparing the overall means for shrinkage longitudinal, tangential and radial of the two species at the 1 percent significance level showed a significant difference in all cases. The distribution of shrinkage values around the mean for both species are shown in (Figures 44, 45, 46, 47).

Linear regression equations were developed for shrinkage over specific gravity, showing no significant correlation. In this case, no equations will be presented.

In general, most properties, with the exception of shear strength parallel to grain, showed a significant difference in between species.

Table 11. Solid Wood Properties.

Swelling and Shrinkage

[Mean Values]

Eucalyptus robusta.

Shrinkage (%)													Swelling (%)						
Longitudinal				Radial		Tangential				BT/BR**	Volumetric		Radial		Tangential		Volumetric		S.G.
12% M.C. to Ovendry	Green to Ovendry	MC_1 (%)	MC_2 (%)	12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	MC_1 (%)	MC_2 (%)		12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	Average Specific Gravity
.11	.28	11	94	4.2	9.8	9.8	22.9	11	96	2.3	12.1	27.7	4.4	10.3	11	25.7	13.0	30.3	.60
(.032)	(.049)			(.89)	(2.09)	(3.22)	(7.5)			(.59)	(1.65)	(3.7)	(.97)	(2.3)	(4.0)	(9.4)	(1.94)	(4.4)	(.073)

Eucalyptus grandis.

Shrinkage (%)													Swelling (%)						
Longitudinal				Radial		Tangential				BT/BR**	Volumetric		Radial		Tangential		Volumetric		S.G.
12% M.C. to Ovendry	Green to Ovendry	MC_1 (%)	MC_2 (%)	12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	MC_1 (%)	MC_2 (%)		12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	12% M.C. to Ovendry	Green to Ovendry	Average Specific Gravity
.090	.25	11	88	3.1	7.2	7.2	16.7	11	96	2.4	10.2	23.8	3.2	7.40	7.8	18.2	10.9	25.4	.51
(.03)	(.045)			(.55)	(1.3)	(1.4)	(3.3)			(.43)	(1.85)	(4.3)	(.60)	(1.4)	(1.65)	(3.8)	(2.1)	(4.9)	(.066)

* Numbers in parentheses are standard deviations.

** BT/BR = Ratio of tangential shrinkage or swelling to radial shrinkage or swelling.

*** Shrinkage and swelling green to oven dry were empirically calculated by the formula: $\frac{\text{shrinkage or swelling 12\% M.C.}}{12} \times 28$

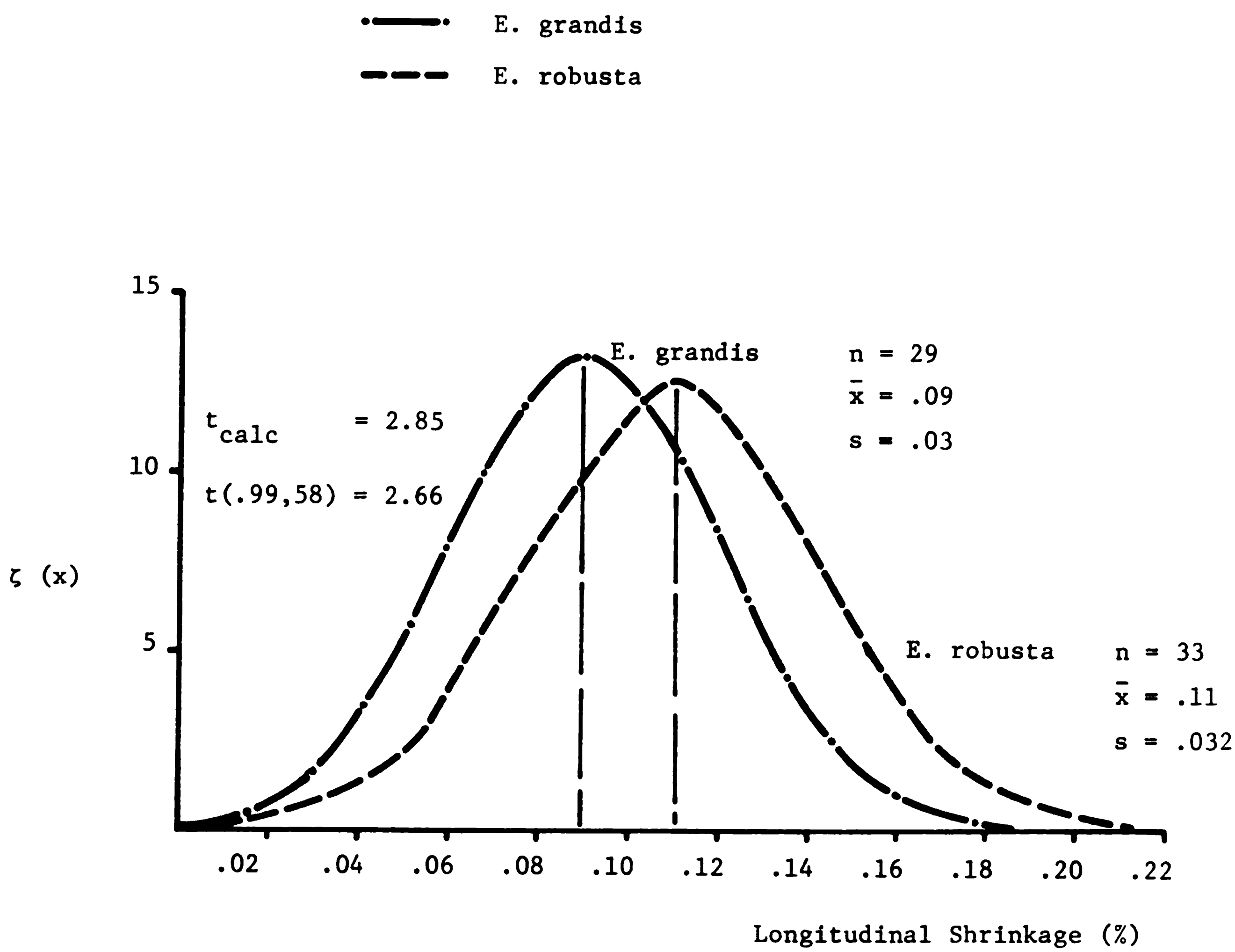


Figure 44. Longitudinal Shrinkage Distribution.

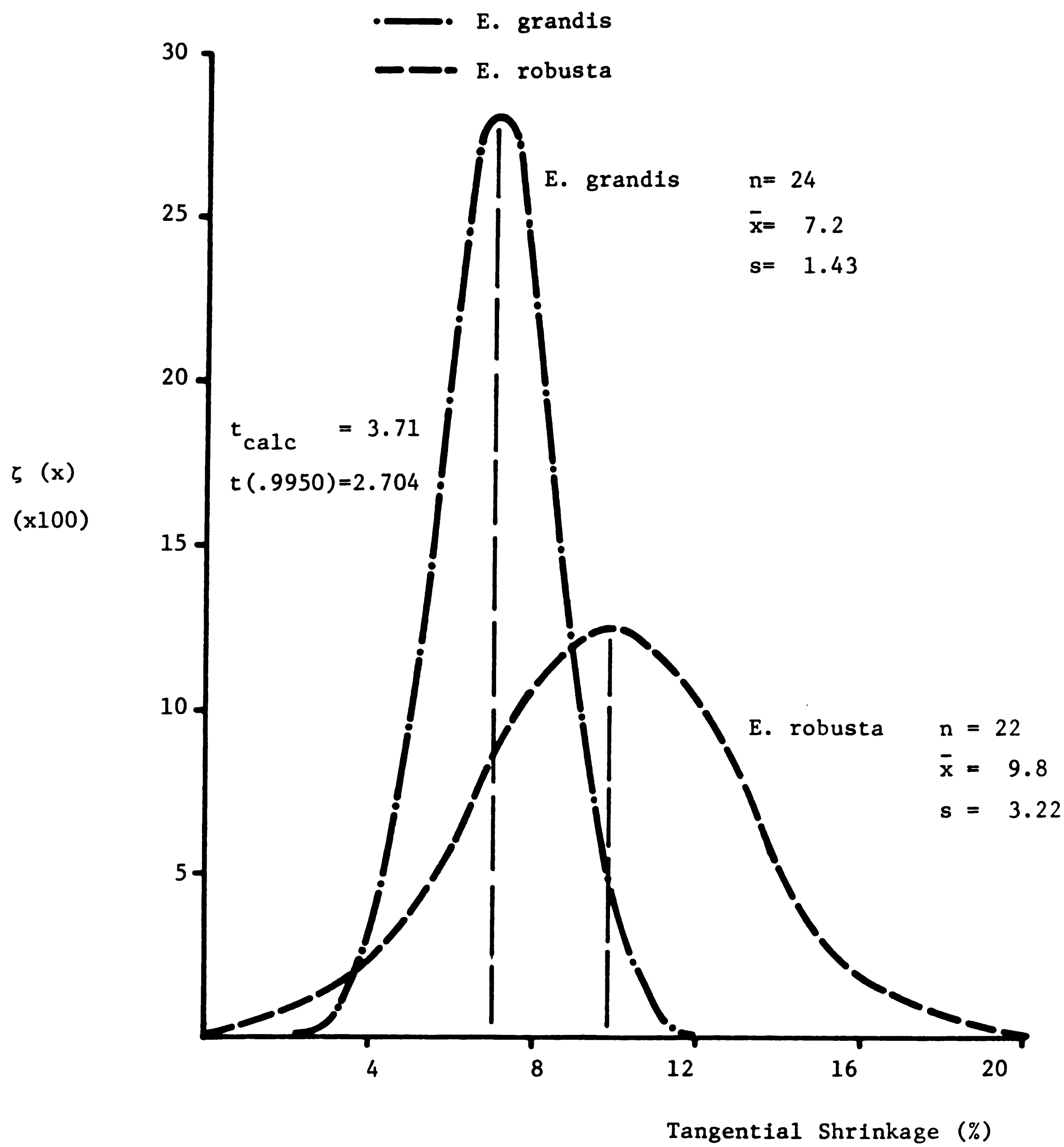


Figure 45. Tangential Shrinkage Distribution.

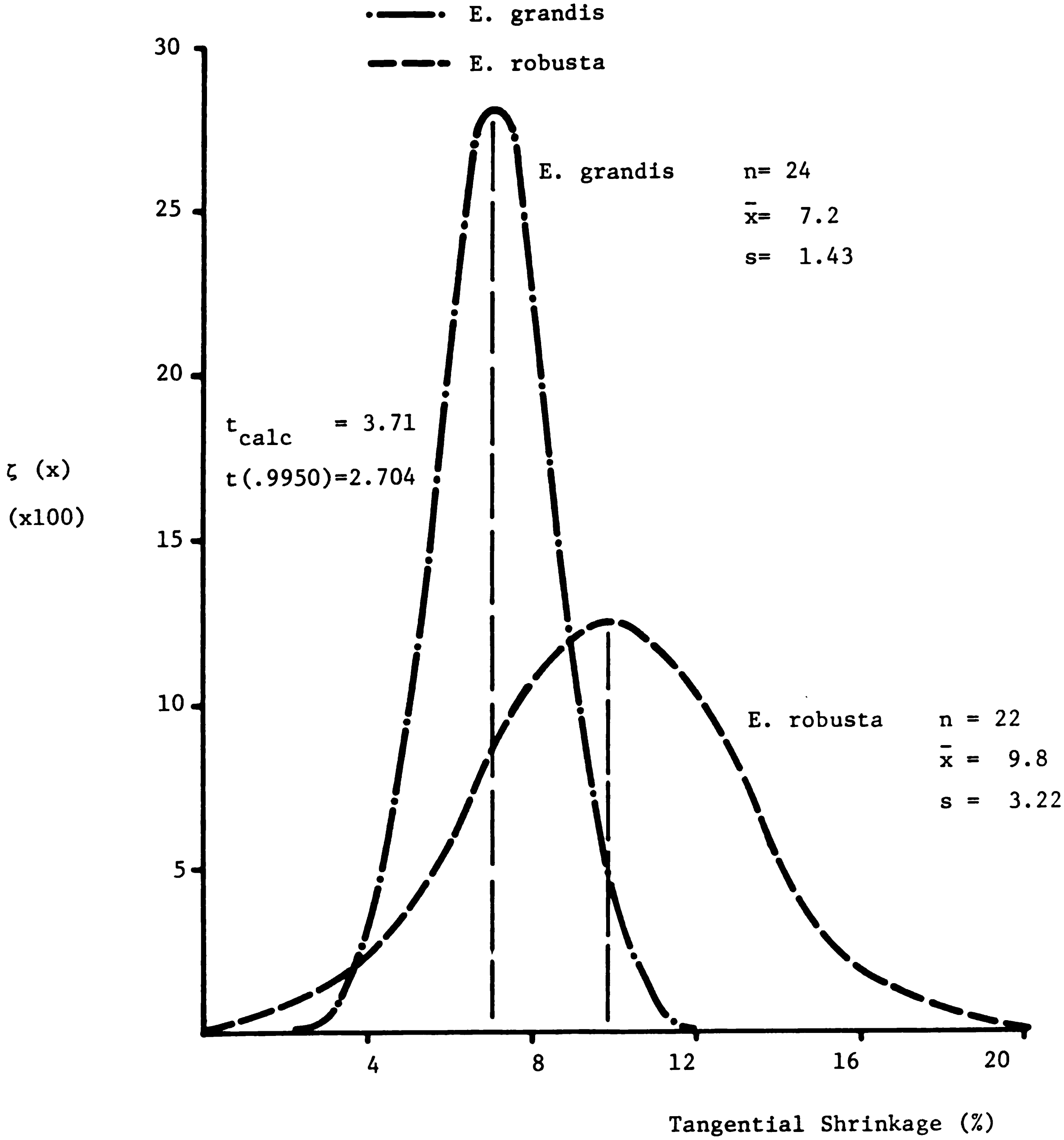


Figure 45. Tangential Shrinkage Distribution.

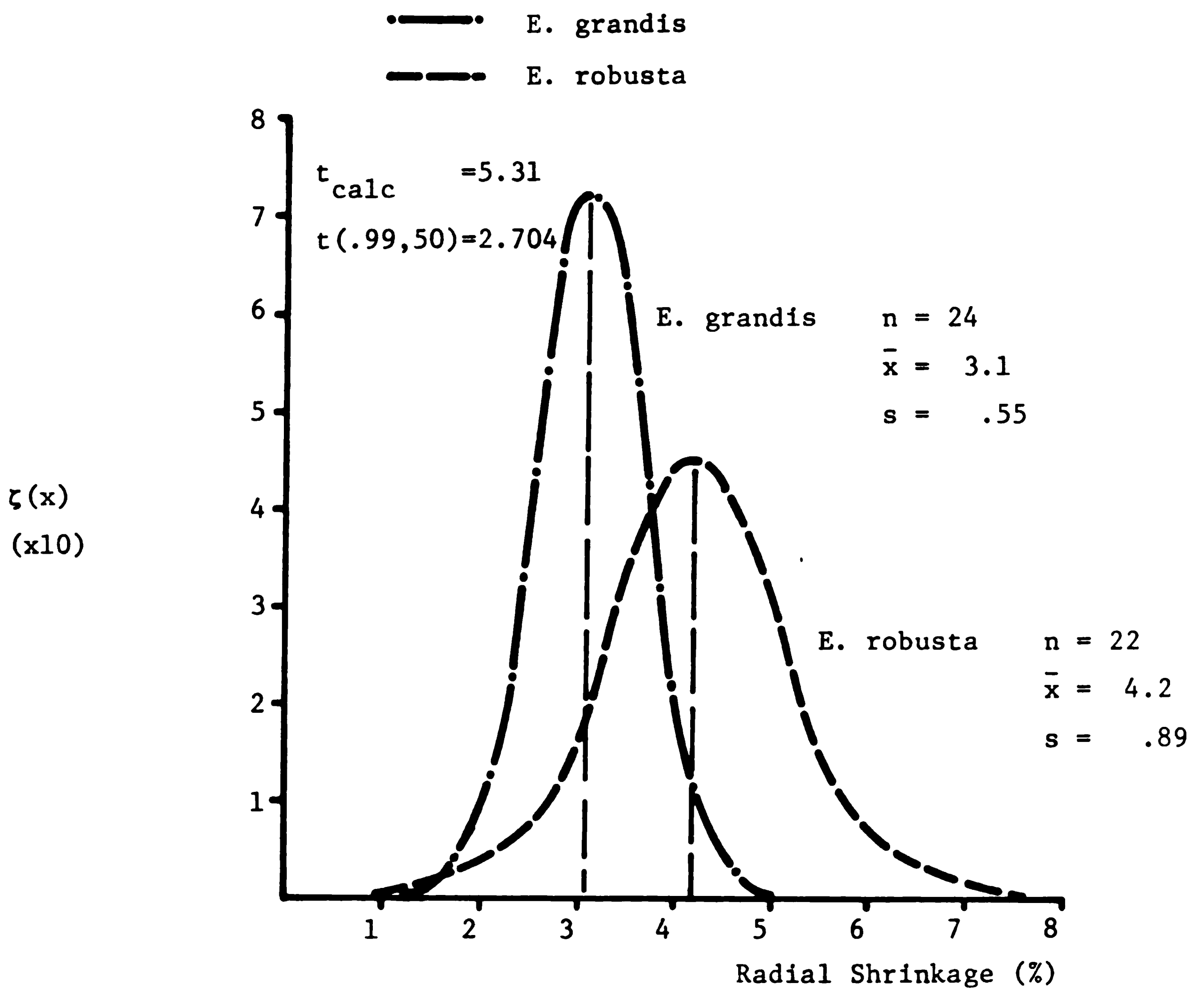


Figure 46. Radial Shrinkage Distribution.

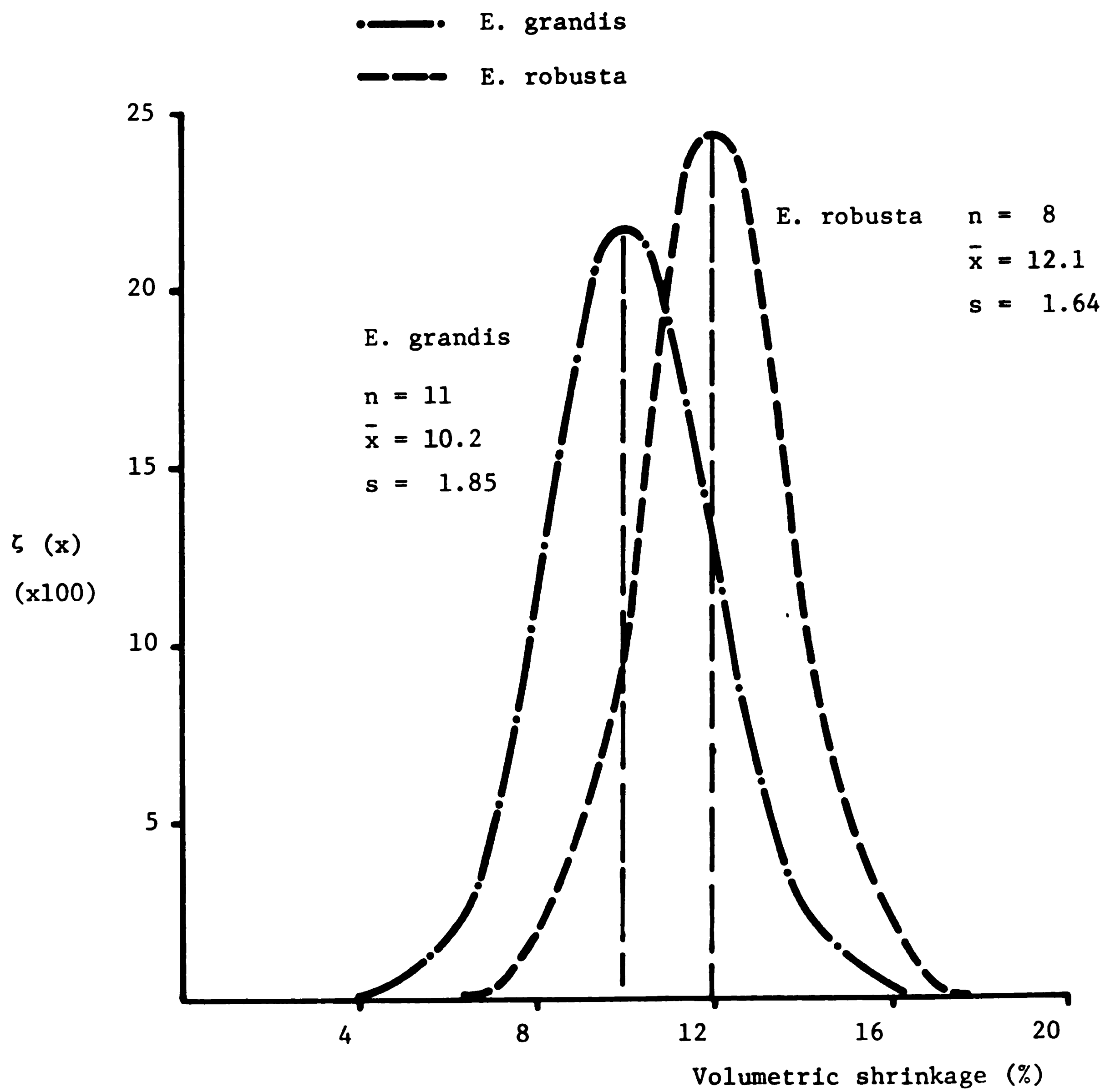


Figure 47. Volumetric Shrinkage Distribution.

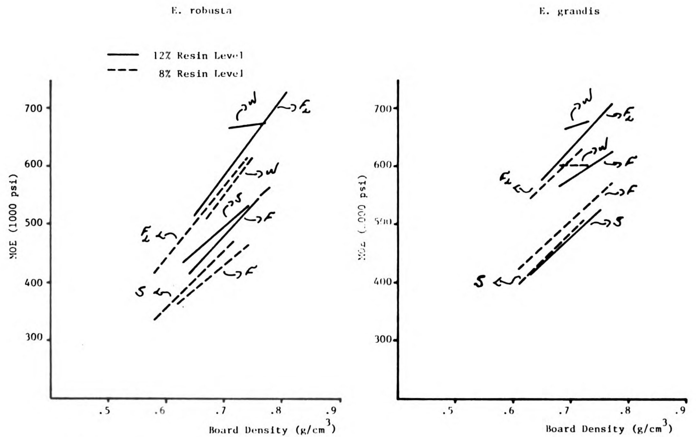
shear strength not being different could be best explained by the inherent variability of specific gravities within the wood structure. Cell wall thickness and cell cross section dimensions are directly related to specific gravity of the wood and, together with ring widths and earlywood-latewood proportions, define specific gravity variations. In this study, specific gravity was determined not looking deep into the specific gravity differences within the wood structure. Practically the significant difference in between the average specific gravities of E. robusta and E. grandis in this particular study was not sufficient to explain all the differences in properties. In conclusion, when looking at differences in properties, where the species variability in respect to specific gravity, is somewhat large, a larger and much more careful selected sample and a more detailed look at the distribution of specific gravities within the structure should be taken.

3) Composition Board Properties

3.1 - Modulus of Elasticity and Rupture.

3.1.1 - Actual Values.

Modulus of elasticity (MOE) and modulus of rupture (MOR) are two important board properties particularly for structural applications. It is well documented in the literature that both properties increase with board density. In this study MOE and MOR increased as board density increased for fiberboards, flakeboards, sliverboards and waferboards at 8 and 12 percent resin levels, for both species E. robusta and E. grandis (Figures 48, 49). MOE average values range from 338,000



W = Waferboard   Fl = Flakeboard
S = Sliverboard   F = Fiberboard

Figure 48. MOE Mean Values - Lowest and Highest Average Board Densities

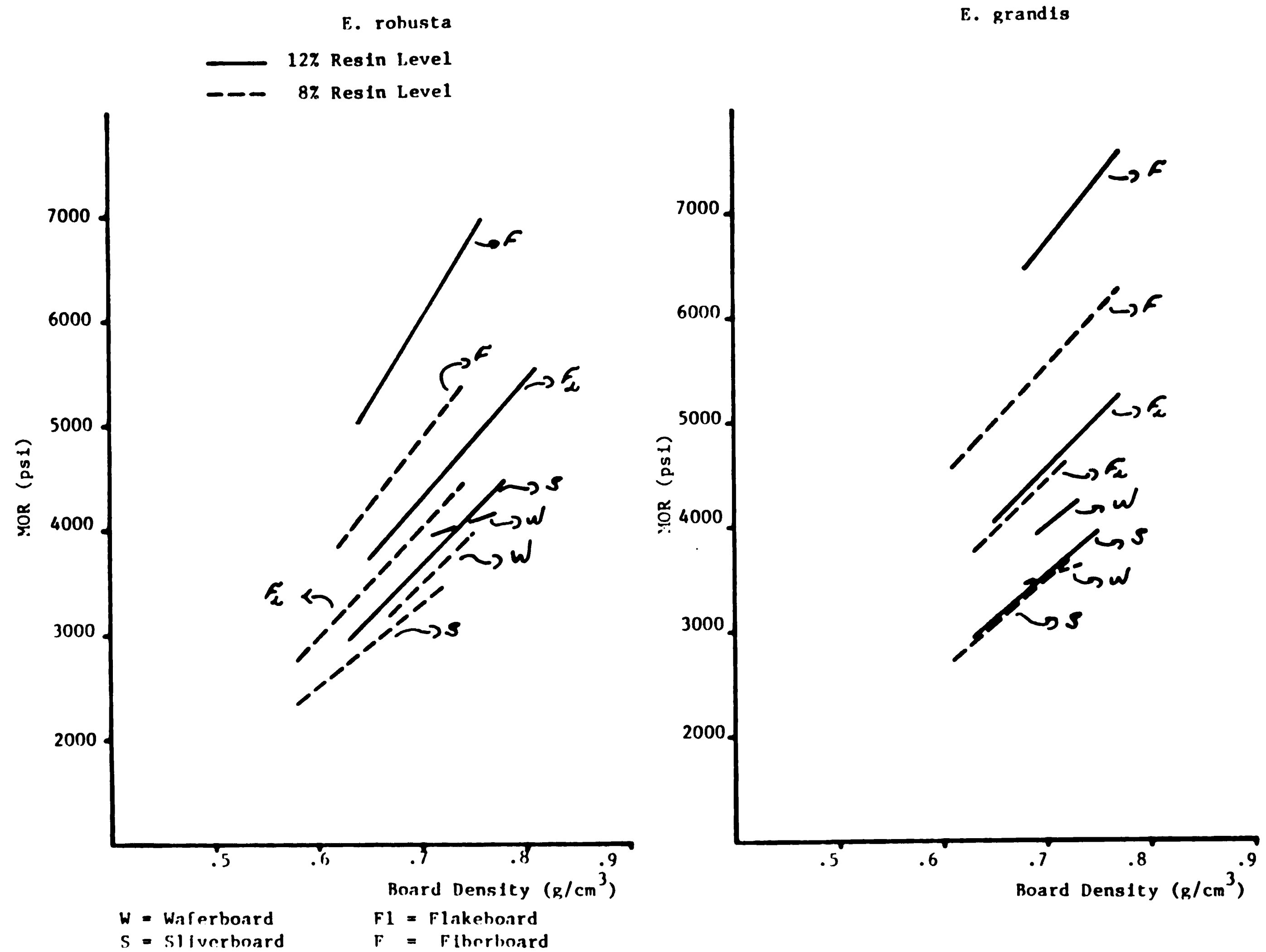


Figure 49. MOR Mean Values - Lowest and Highest Average Board Densities.

psi to 728,000 psi for boards made out of E. robusta and from 400,000 psi to 704,000 psi for boards made out of E. grandis. (Table 12). MOR average values range from 2,775 psi to 6,960 psi for boards made out of E. robusta and from 2,711 psi to 7,599 psi for boards made out of E. grandis. (Table 13). These values are in accordance to standard CS 236-66 1B2 for mat formed particleboard and NPA 4-73 for medium density fiberboard. It can be seen from (Figures 48, 49) that average MOE and MOR values for every kind of board made are very close to each other for the two different resin levels 8 and 12 percent.

3.1.2 - Regression Analysis.

Linear regression equations were developed only for modulus of elasticity over board density for all composition boards and both species. Equations are as follows:

E. grandis.

Fiberboards - MOE = -242.6 + 1116.3 D R = .83** - significant.

Flakeboards - MOE = -215.4 + 1204.5 D R = .86** - significant.

Sliverboards- MOE = -210.6 + 994.8 D R = .94** - significant.

Waferboards - MOE = 111.6 + 741.2 D R = .46 - not significant.

E. robusta.

Fiberboards - MOE = -309.4 + 1091.1 D R = .87** - significant.

Flakeboards - MOE = -382.3 + 1369.0 D R = .97** - significant.

Sliverboards- MOE = -231.8 + 1001.5 D R = .91** - significant.

Waferboards - MOE = -159.8 + 1075.3 D R = .55** - significant.

All coefficients were tested by means of an F-test at the 1 percent significance level. Most of the equations show a "good fit" in

Table 12. Composition Board Properties.

Modulus of Elasticity

[Mean Values]

Eucalyptus robusta.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.62 (.016)	.74 (.030)	.64 (.028)	.76 (.045)	.58 (.038)	.74 (.032)	.65 (.039)	.81 (.025)	.58 (.042)	.72 (.025)	.63 (.055)	.78 (.037)	.67 (.023)	.75 (.016)	.71 (.019)	.77 (.033)
MOE (1000 psi)	362 (24.42)	461 (67.94)	415 (47.40)	544 (78.82)	417 (67.86)	612 (63.5)	516 (92.57)	728 (46.13)	338 (71.97)	473 (36.63)	436 (84.13)	562 (41.93)	510 (41.88)	616 (54.94)	669 (64.2)	672 (72.07)
Moisture Content (%)	10	11	12	9	8	7	9	9	8	8	8	8	7	8	8	8
MOE Adjusted Means (1000 psi)	417		490		522		609		412		481		562		662	

Eucalyptus grandis.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.61 (.045)	.77 (.040)	.68 (.052)	.77 (.049)	.63 (.018)	.72 (.049)	.65 (.037)	.77 (.028)	.61 (.059)	.72 (.052)	.63 (.037)	.75 (.069)	.68 (.023)	.73 (.045)	.69 (.031)	.73 (.021)
MOE (1000 psi)	425 (109.22)	571 (78.29)	568 (79.6)	625 (55.12)	548 (26.34)	631 (105.3)	579 (79.3)	704 (52.44)	400 (86.55)	504 (56.7)	416 (51.05)	527 (72.01)	601 (23.45)	601 (48.05)	666 (48.87)	679 (72.04)
Moisture Content (%)	14	11	13	10	8	8	8	8	8	8	8	8	8	8	8	8
MOE Adjusted Means (1000 psi)	491		587		581		655		444		483		602		680	

Table 13. Composition Board Properties.

Modulus of Rupture

[Mean Values]

Eucalyptus robusta.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density g/cm^3	.62 (.016)	.74 (.030)	.64 (.028)	.76 (.045)	.58 (.038)	.74 (.032)	.65 (.039)	.81 (.025)	.58 (.042)	.72 (.025)	.63 (.055)	.78 (.037)	.67 (.023)	.75 (.016)	.71 (.019)	.77 (.033)
MOR (psi)	3834 (388.3)	5393 (1238.5)	5024 (667.0)	6960 (891)	2775 (442.2)	4416 (598.2)	3723 (845.7)	5506 (415.5)	2330 (639.2)	3445 (249)	2986 (687.8)	4470 (338.3)	3200 (511.9)	3977 (753.1)	3949 (556)	4151 (841.7)
Moisture Content (%)	10	11	12	9	8	7	9	9	8	8	8	8	7	8	8	8

Eucalyptus grandis.

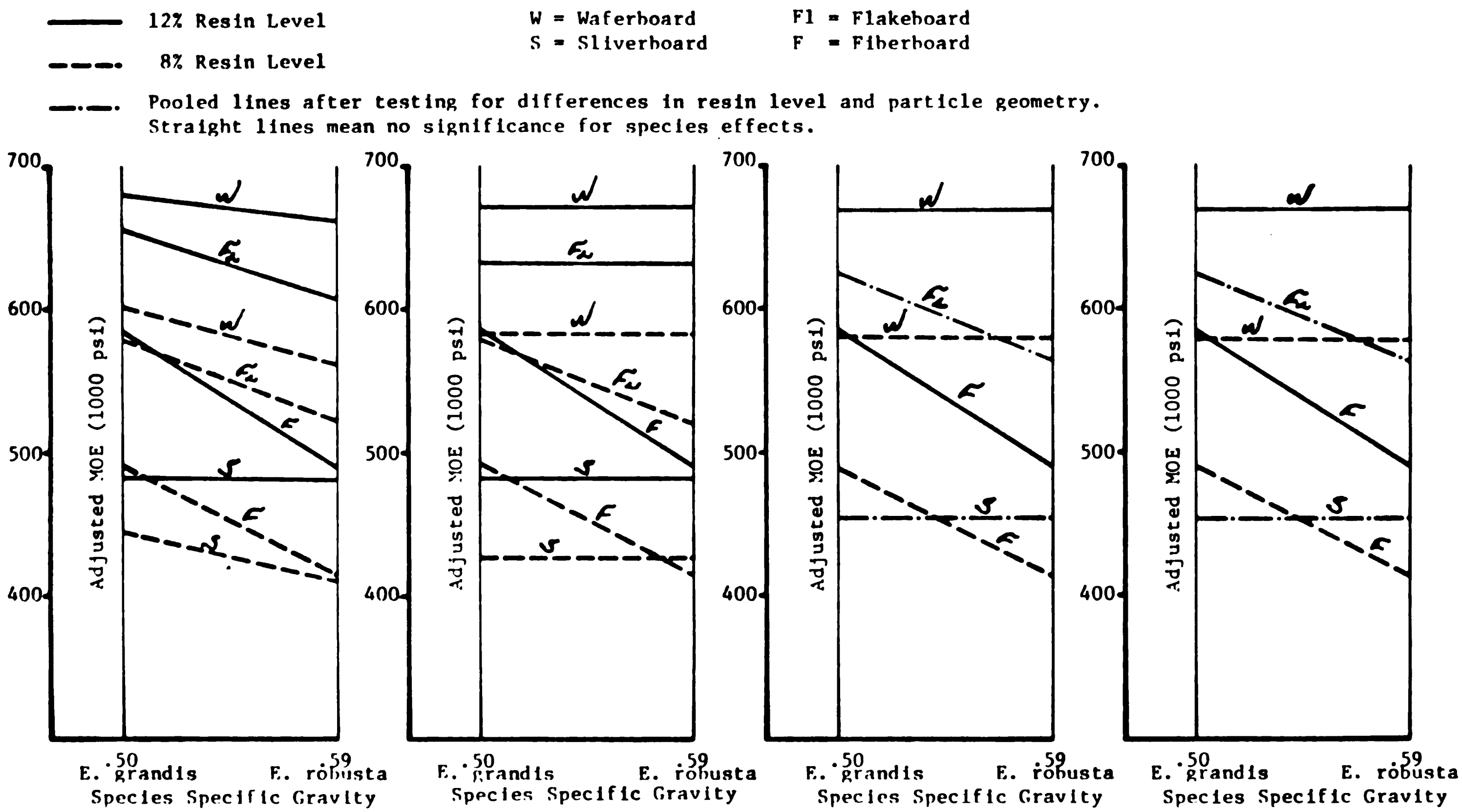
Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density g/cm^3	.61 (.045)	.77 (.040)	.68 (.052)	.77 (.049)	.63 (.018)	.72 (.049)	.65 (.037)	.77 (.028)	.61 (.059)	.72 (.052)	.63 (.037)	.75 (.069)	.68 (.023)	.73 (.045)	.69 (.031)	.73 (.021)
MOR (Psi)	4575 (1000.5)	6286 (1219)	6480 (848.7)	7599 (1025)	3788 (385.2)	4614 (1034)	4032 (480.2)	5356 (743.2)	2711 (742.4)	3692 (627.8)	2924 (262.9)	3941 (921)	3459 (460.9)	3639 (640.9)	3917 (386.9)	4266 (528.5)
Moisture Content (%)	14	11	13	10	8	8	8	8	8	8	8	8	8	8	8	8

relationship to board density. Composition boards at constant average density possess higher MOE values as the wood density decreases or the compaction ratio increases. Due to large variation in process variables, it is impossible to manufacture two equal boards to the same constant average density.

3.1.3 - Covariance Analysis.

In order to make a valid comparison of the two species composition boards, all properties had to be adjusted to a constant average density. This was possible through a very valuable tool called covariance analysis. This adjustment was made at three different stages to allow comparisons of the effect of variables like species, resin level and particle geometry over the different board properties. At this point only the adjustment of modulus of elasticity over board density is going to be discussed.

At first, modulus of elasticity was adjusted over board density to allow comparisons of the species effects on this property. The first conclusion can be drawn from Figure 50: as the density of the species decreases modulus of elasticity for all composition boards increases. When these two adjusted modulus of elasticity means were compared to verify if the species effects were significant at 1 percent significance level, only the fiberboards at the 8 and 12 percent resin levels and flakeboards at the 8 percent resin level were significantly different, this means that as the species specific gravity decreases for fiberboards (8 and 12 percent resin levels) and flakeboards (8 percent resin level), modulus of elasticity increases significantly (Figure 50).



A - Adjusted Means

B - Tested for differences due to species.

C - Tested for differences due to resin level.

D - Tested for differences due to particle geometry.

Figure 50a, b, c, d. Modulus of Elasticity - Covariance Analysis.

From this important observation if we were supposed to draw a graph like the one developed by Klauditz [39] (Figure 51) for modulus of elasticity at the 12 percent resin level (Figure 52), it could be concluded that the effect due to species gravity over bending strength, MOE or any other property is not necessarily true for all composition boards.

In this study for example, Klauditz' relationship is only true in the case of fiberboards. This could mean that fiberboards are more responsive to anatomical differences within and between species as far as influence over its physical properties are concerned.

In the second stage MOE values were adjusted over board density to observe differences in between the 8 and 12 percent resin levels for every kind of composition board. Higher adhesive contents normally increase modulus of elasticity. This is the case for this study: as the resin level increased from 8 to 12 percent modulus of elasticity increased for all composition boards.

When these two adjusted modulus of elasticity means were compared to verify if the difference in resin level significantly increased this property at the 1 percent significance level, only the fiberboards and the waferboards increased significantly due to the 4 percent difference in resin level (Figure 50). After the second stage many results were pooled.

In the third stage, MOE values were adjusted over board density to observe differences due to the four different particle geometries. In general, as the length of the particles increased, modulus of

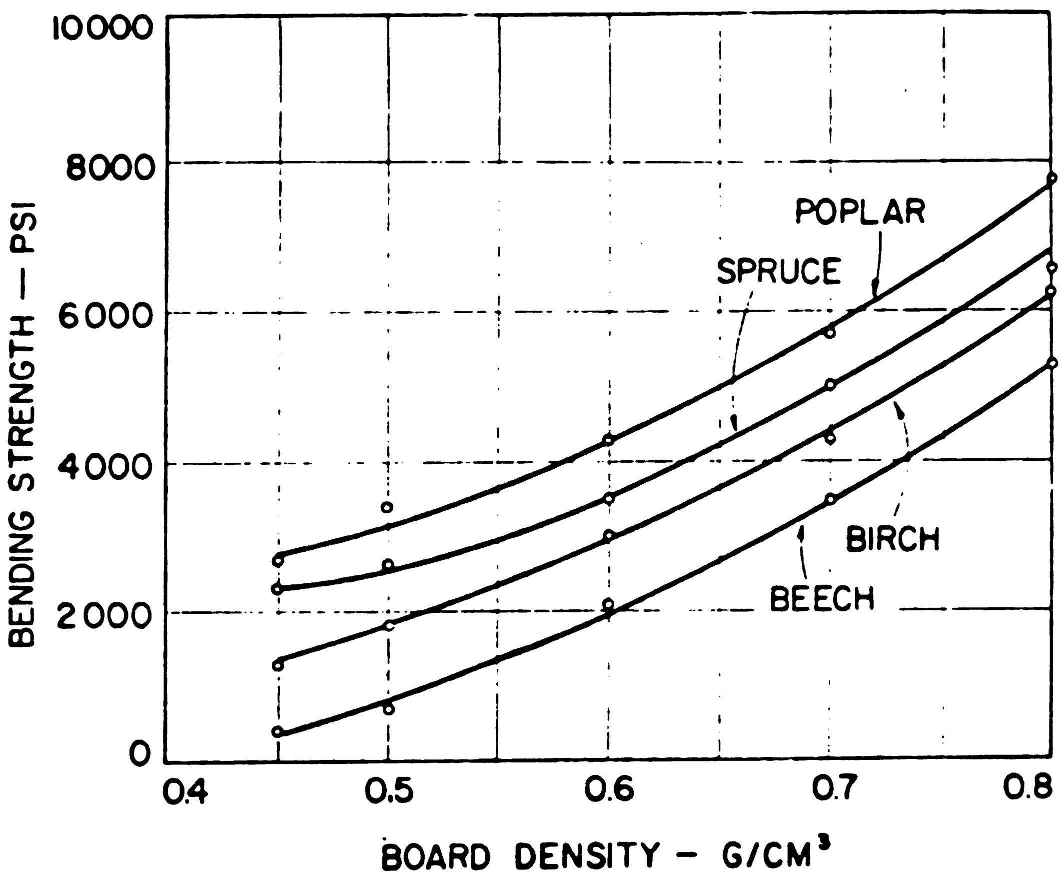


Figure 51. Relationship between board density and bending strength of particleboard made from various species (Klauditz and Stegmann, 1957).

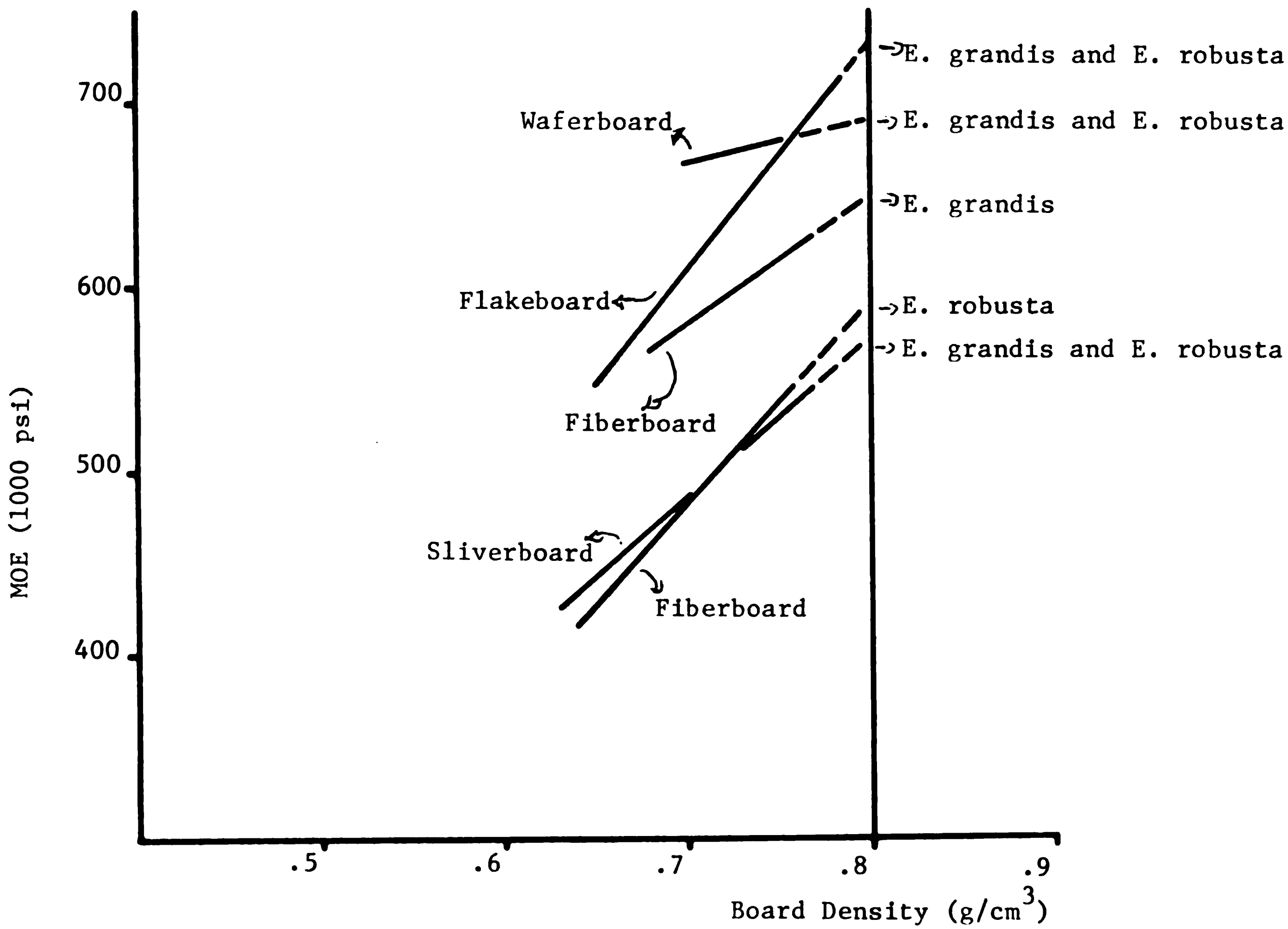


Figure 52. Relationship between board density and Modulus of Elasticity of composition boards made from E. grandis and E. robusta.

elasticity increased. When these adjusted modulus of elasticity means were compared to verify the difference mentioned above, at the 1 percent significance level, a real difference was obtained among all composition boards. The analysis for particle geometry in some of the cases was made with the pooled lines; waferboards having the highest MOE and sliverboards the lowest (Figure 50).

The low MOE of the sliverboards could be explained by the breakdown in width after hammermilling and somewhat because of the high thickness of the particles.

Density profile was determined in all boards (Figures 53, 54, 55, 56). Not very much difference can be observed, this fact could be expected because the process parameters were kept quite uniform.

3.2 - Internal Bond.

3.2.1 - Actual Values.

The internal bond (IB) or tensile strength perpendicular to the board surface, is a widely determined property and a very controversial one in terms of the analysis of results as is well documented in the literature. In this particular study, looking at the overall results, in general there is a tendency of internal bond to increase with increasing board density for all composition boards at 8 and 12 percent resin levels for both species E. robusta and E. grandis (Figure 57).

Although this tendency is not a very clear one in all cases, internal bond average values range from 137.3 psi to 219.09 psi for boards made out of E. robusta and 118.5 psi to 223.7 psi for boards made out of E. grandis (Table 14). These values exceed the minimum values of

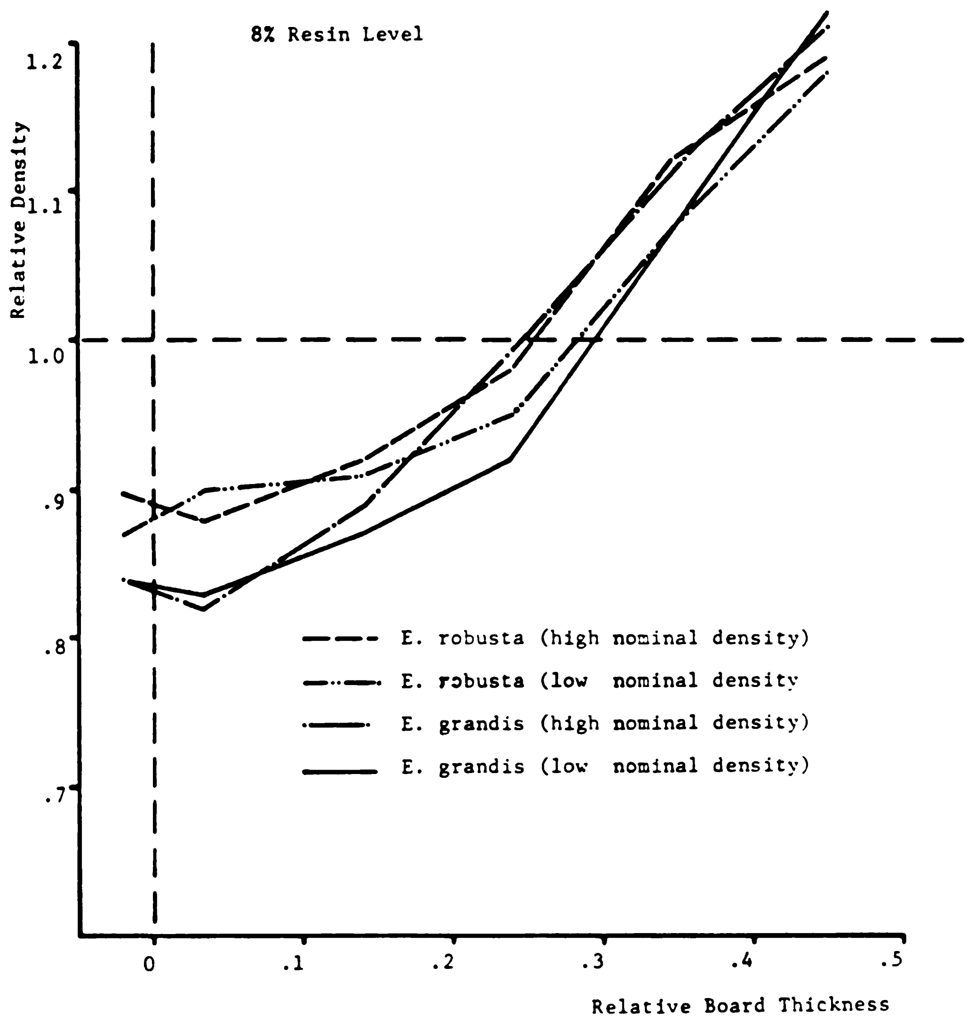


Figure 53. Fiberboards Density Profile

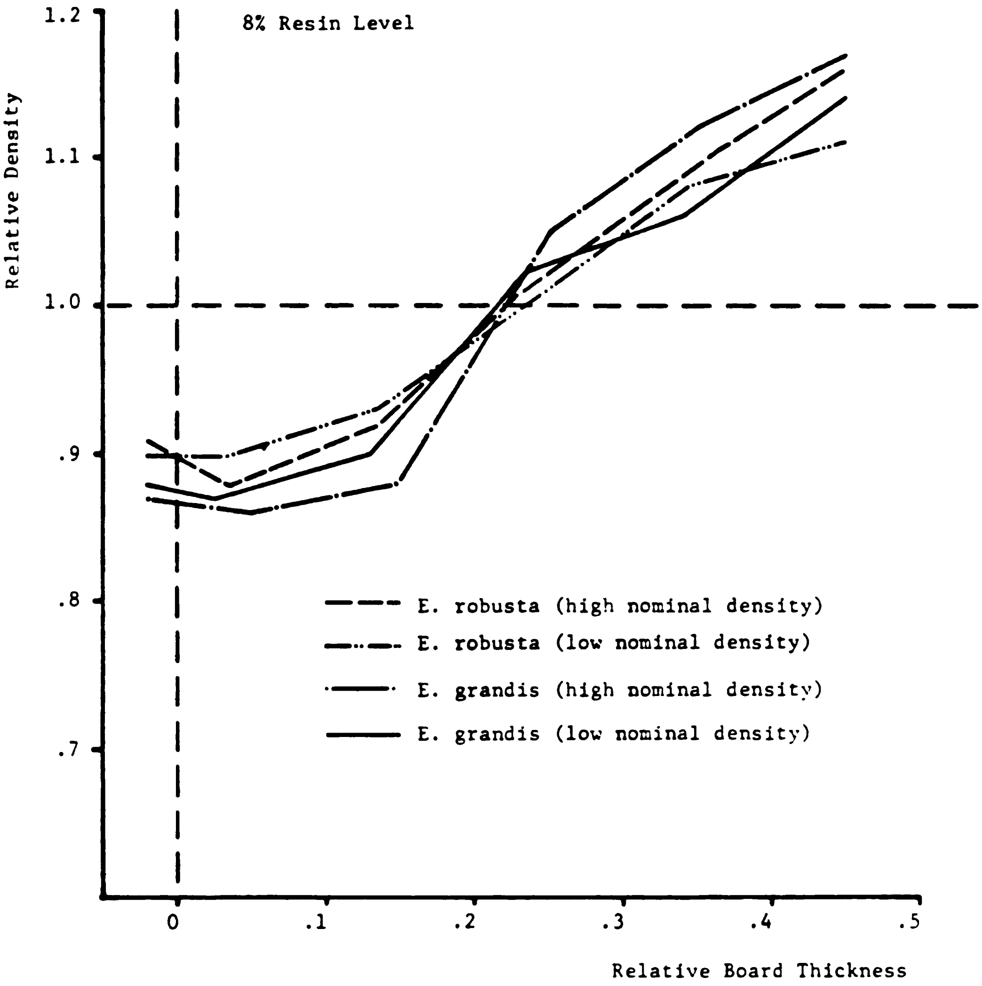


Figure 54. Sliverboards Density Profile

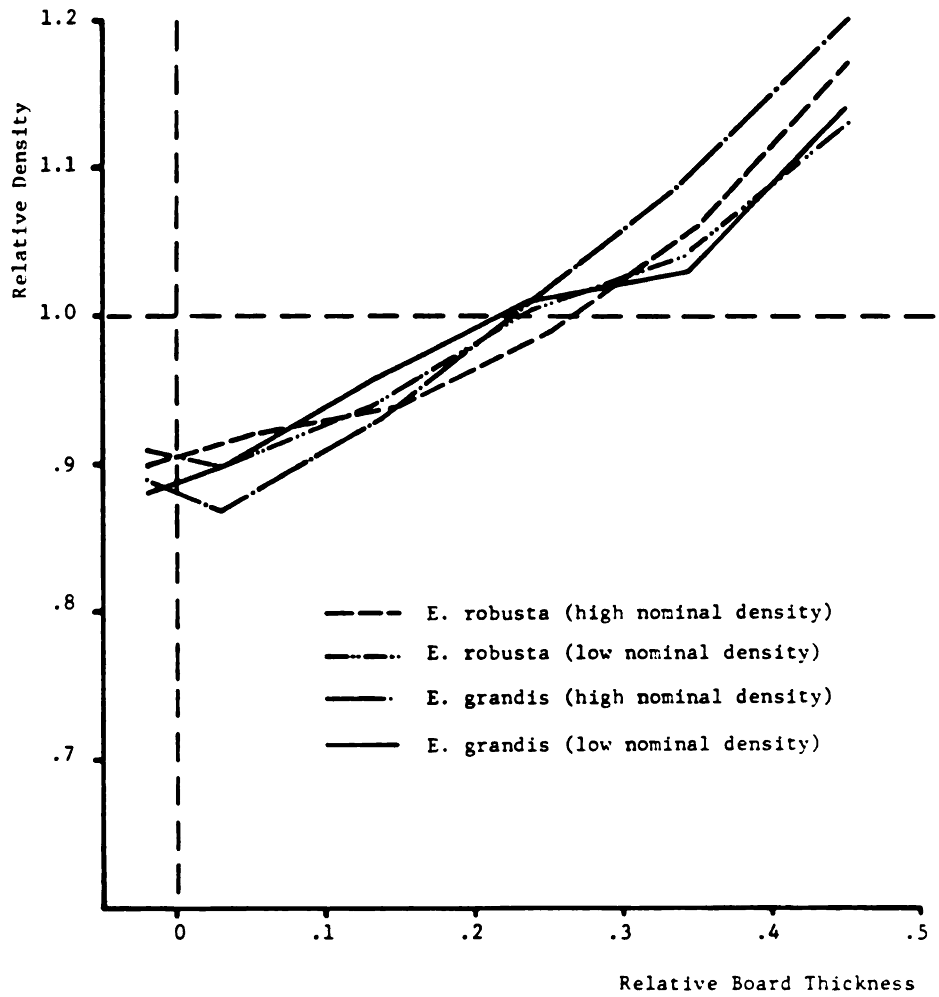


Figure 55. Flakeboards Density Profile.

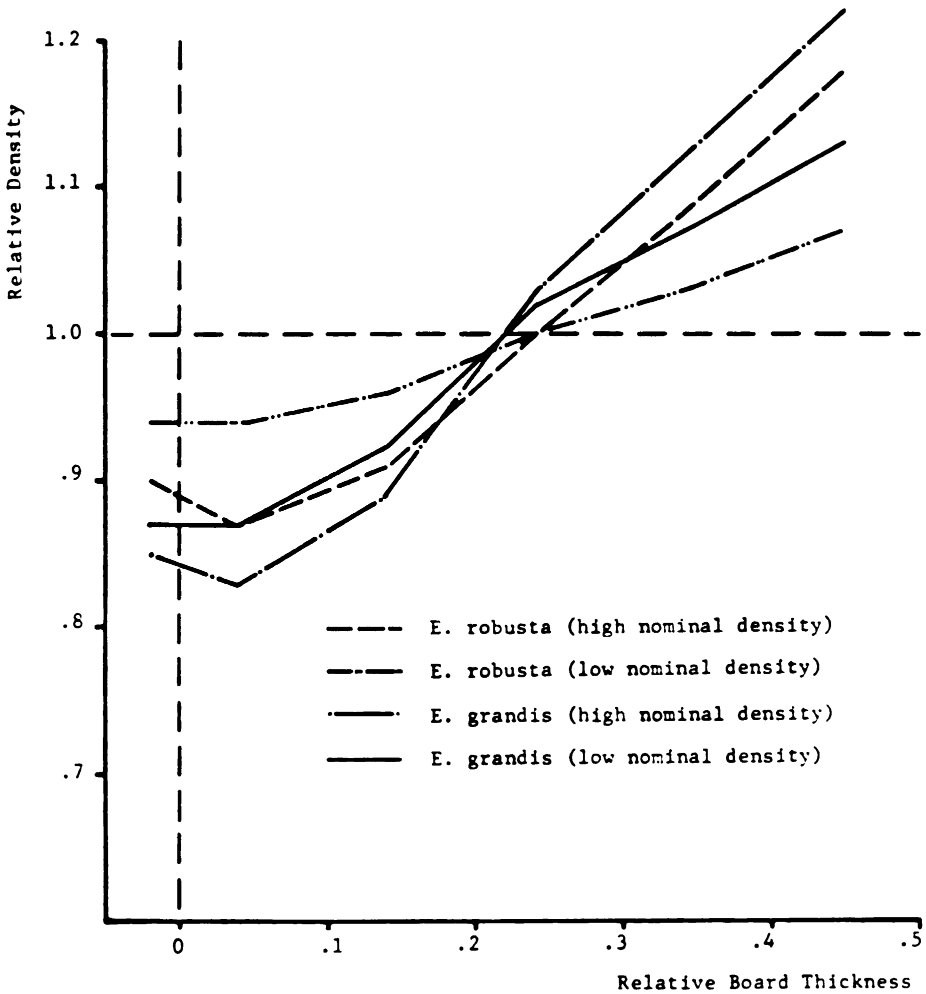
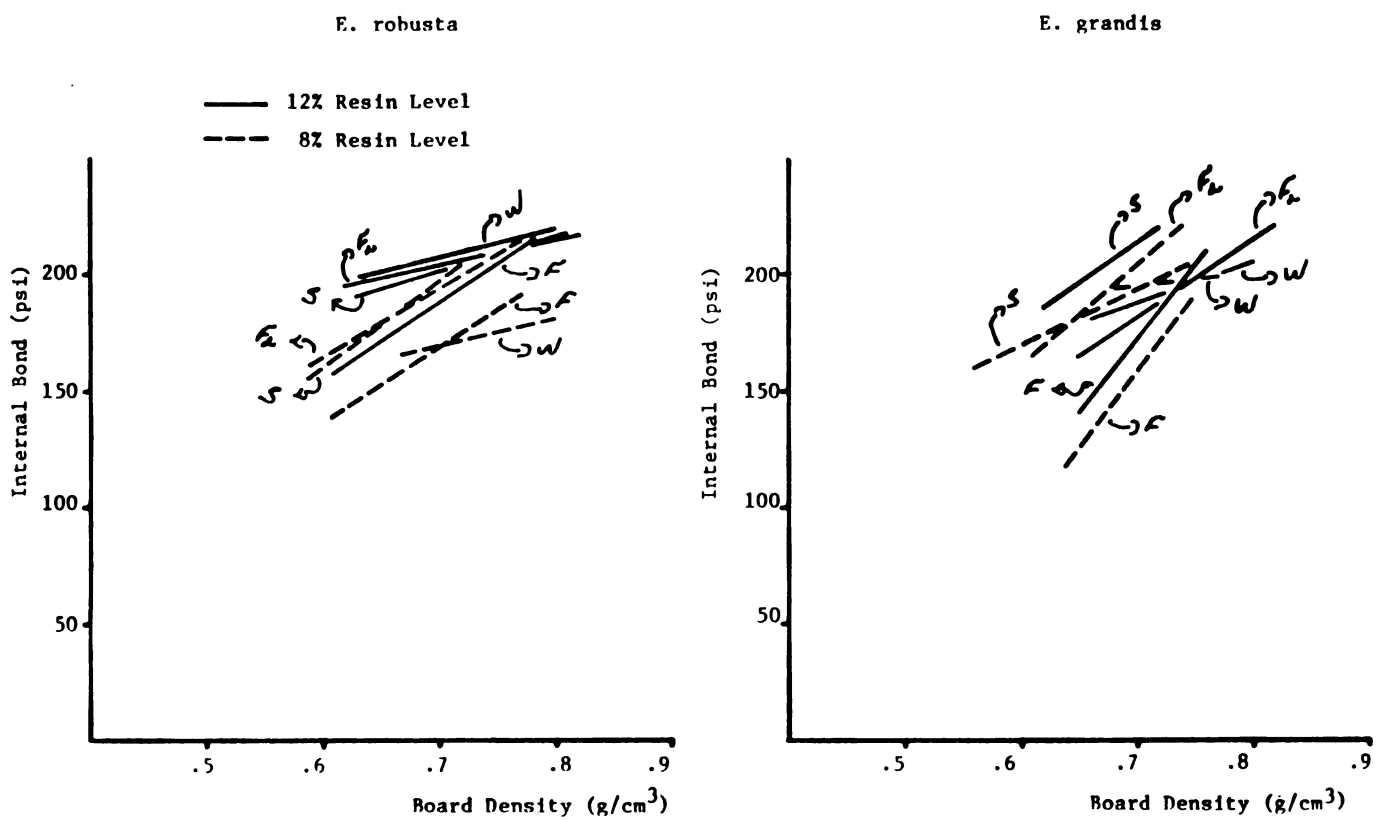


Figure 56. Waferboards Density Profile



W = Waferboard Fl = Flakeboard
S = Sliverboard F = Fiberboard

Figure 57. Internal Bond Mean Values - lowest and highest average board densities.

Table 14. Composition Board Properties.

Internal Bond

[Mean Values]

Eucalyptus robusta.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm)	.61 (.037)	.77 (.045)	.61 (.035)	.79 (.040)	.59 (.020)	.78 (.06)	.62 (.05)	.82 (.035)	.59 (.021)	.74 (.025)	.63 (.071)	.81 (.057)	.67 (.012)	.80 (.046)	.64 (.017)	.80 (.03)
Internal Bond (psi)	137.3 (15.6)	191.1 (21.3)	159.6 (13.8)	219.09 (25.2)	163.4 (13.8)	216.3 (24.1)	194.6 (9.5)	216.3 (18.2)	156.2 (23.5)	212.9 (9.2)	191.1 (29.5)	217.7 (11.9)	168.0 (33.9)	183.3 (36.6)	197.7 (41.8)	217.4 (7.01)
Moisture Content (%)	8	7	8	7	8	8	8	9	8	8	8	8	9	8	9	8
IB Adjusted Means (psi)	162		194		196		204		183		206		175		207	

Eucalyptus grandis.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.64 (.05)	.75 (.03)	.65 (.052)	.76 (.046)	.61 (.035)	.74 (.053)	.65 (.015)	.82 --	.56 (.057)	.75 (.11)	.62 (.09)	.72 (.09)	.68 (.058)	.77 (.01)	.66 (.09)	.80 (.035)
Internal Bond (psi)	118.5 (19.7)	190.0 (13.6)	141.7 (25.6)	210.8 (39.5)	165.6 (8.1)	223.3 (17.8)	165.0 (7.9)	223.7 (8.5)	160.6 (21.5)	204.2 (38.2)	187.2 (30.6)	220.0 (33.9)	194.6 (18.2)	198.7 (24.1)	181.2 (20.2)	207.2 (21.1)
Moisture Content (%)	7	7	8	7	8	8	9	9	8	8	9	8	8	8	8	8
IB Adjusted Means (psi)	142		164		190		183		182		197		197		193	

CS 236-66, 1-3-2, for mat formed particleboard and NPA 4-73 for medium density fiberboard.

3.2.2 - Regression Analysis.

Linear regression equations were developed for internal bond over board density for all composition boards and both species. Equations are as follows:

E. grandis.

Fiberboards - IB = -139.6 + 427.5 D R = .64** significant

Flakeboards - IB = - 47.9 + 344.7 D R = .86** significant

Sliverboards - IB = 45.2 + 224 D R = .62** significant

Waferboards - IB = 159.3 + 49.1 D R = .18 not significant

E. robusta.

Fiberboards - IB = -88.3 + 391.2 D R = .85** significant

Flakeboards - IB = 56.4 + 201.3 D R = .78** significant

Sliverboards - IB = 7.3 + 271.2 D R = .80** significant

Waferboards - IB = 65.9 + 169.9 D R = .37 not significant

All coefficients were tested by means of an f-test at the 1 percent significance level. Most of the equations show a "good fit" in relationship to board density with the exception of the waferboards.

3.2.3 - Covariance Analysis.

A covariance analysis was developed for internal bond in the same fashion as for modulus of elasticity. At first internal bond was adjusted over board density to allow comparisons of the species effects on this property. The first conclusion can be drawn from Figure 58 a :

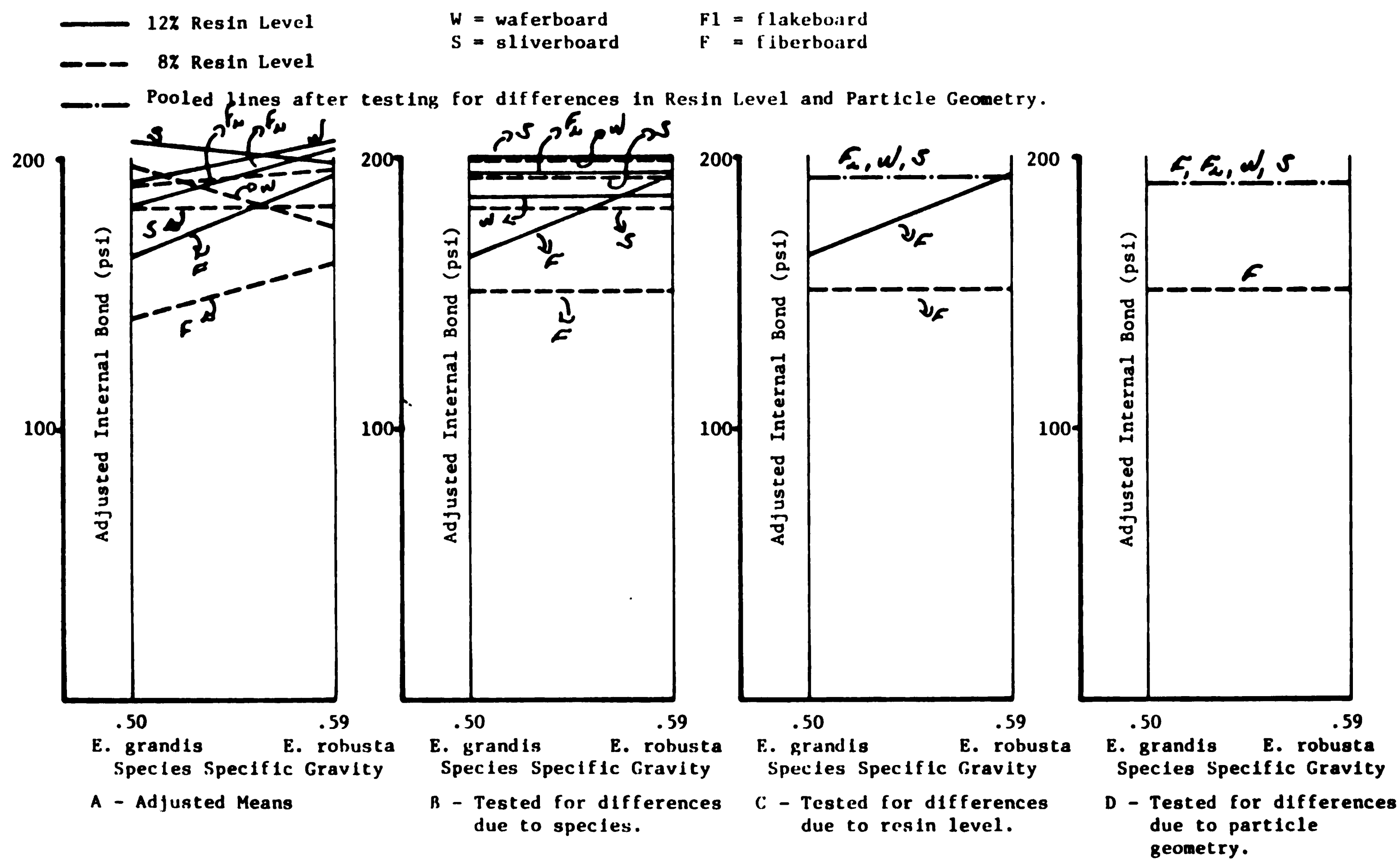


Figure 58a, b, c, d. Internal Bond Covariance Analysis.

no clear relationship exists as far as the specific gravity of the species are concerned for the composition boards at 8 and 12 percent resin levels.

When these two adjusted internal bond means were compared to verify influence of specific gravity of the species at the 1 percent significance level, only the fiberboards at the 12 percent resin level were significantly different. This means that as the specific gravity of the species decreases, internal bond decreases for fiberboards (12 percent resin level) significantly (Figure 58 b).

In the second stage IB values were adjusted over board density to observe differences between the 8 percent and 12 percent resin levels for every kind of composition board. When tested at the 1 percent significance level, only the fiberboards increased significantly due to the 4 percent difference in resin level (Figure 58c). After the second stage of testing, the non-significant lines were pooled together.

In the third stage IB values were adjusted over board density to observe differences due to the four different particle geometries. When the adjusted IB means were compared at the 1 percent significance level, no real difference was obtained among any composition boards, this means that in this study particle geometry did not significantly affect the property internal bond (Figure 58 d). So only the fiberboards were affected by changing variables as far as internal bond is concerned.

3.3 - Linear Expansion.

3.3.1 - Actual Values.

Linear expansion like MOE and MOR is a very important property when panels are used for structural purposes. Some scientists have found linear expansion to increase along with increasing board density, some have found no clear relationship. In this study, no clear relationship between linear expansion and density exists for all composition boards at 8 and 12 percent resin level for both species *E. robusta* and *E. grandis* (Figure 59).

Linear expansion average values range from .124 percent to .397 percent for boards made out of *E. robusta* and from .145 percent to .344 percent for boards made out of *E. grandis*. Most of the composition boards are in accordance with standard CS 236-66 and NPA 4-73 with the exception of the sliverboards which exceeded the maximum average allowed (Table 15).

3.3.2 - Regression Analysis.

Linear regression equations were developed for linear expansion over board density, for all composition boards and both species. Equations are as follows:

E. grandis.

Fiberboards - $LE = -.014 + .276\,D$ $R = .75^{**}$ significant

Flakeboards - $LE = -.047 + .290\,D$ $R = .63$ not significant

Sliverboards - $LE = .368 - .051\,D$ $R = .05$ not significant

Waferboards - $LE = .028 + .234\,D$ $R = .19$ not significant

E. robusta.

Fiberboards - $LE = -.079 + .343\,D$ $R = .73^{**}$ significant

Flakeboards - $LE = .00009 + .321\,D$ $R = .43$ not significant

Sliverboards - $LE = .199 + .163\,D$ $R = .19$ not significant

Waferboards - $LE = .123 + .164\,D$ $R = .19$ not significant

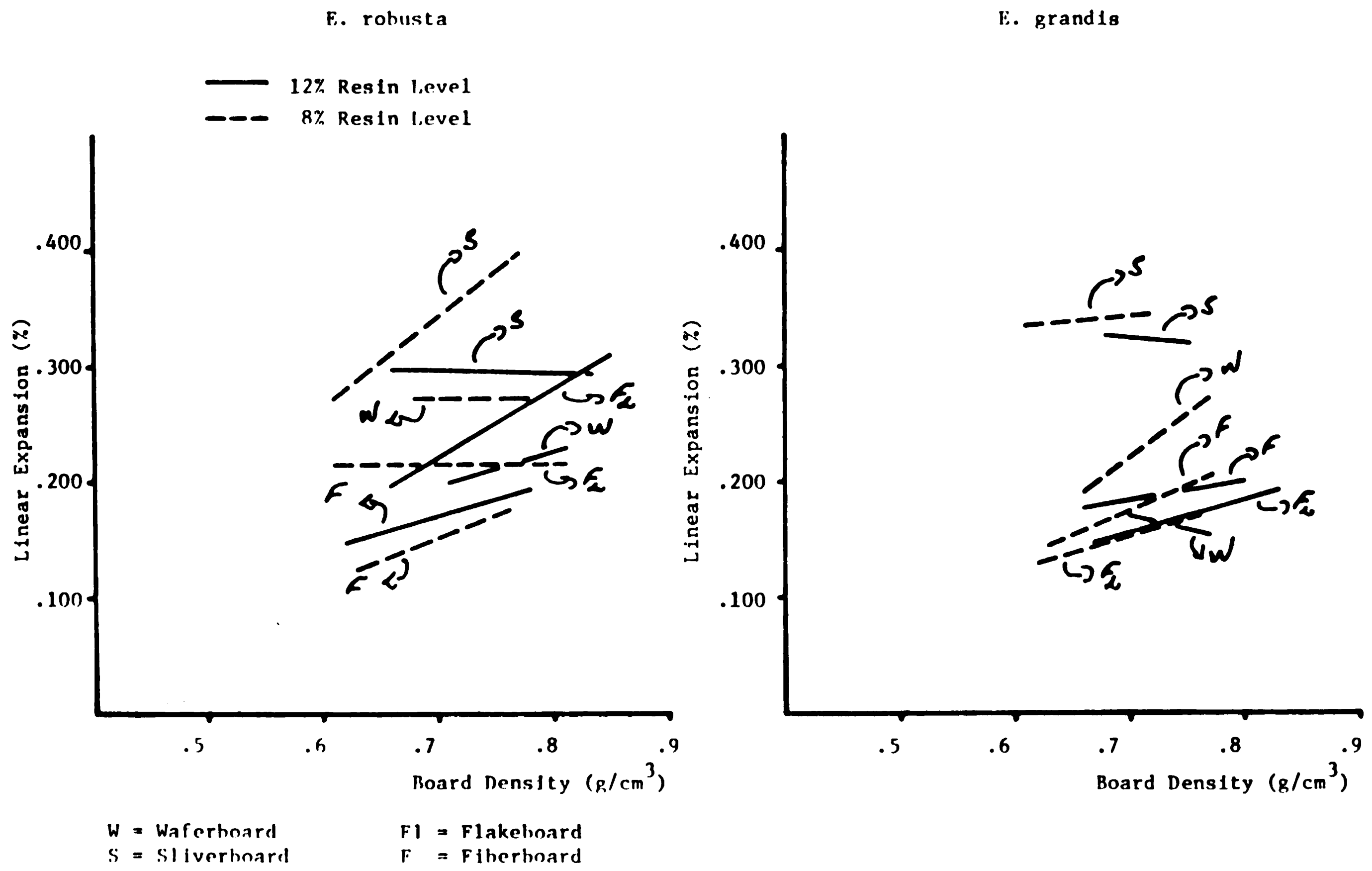


Figure 59. Linear Expansion Mean Values - lowest and highest average densities.

Table 15. Composition Board Properties.

Linear Expansion

[Mean Values]

Eucalyptus robusta.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.63 (.031)	.76 (.044)	.59 (.038)	.78 (.035)	.61 (.012)	.81 (.037)	.66 (.026)	.85 (.02)	.61 (.040)	.77 (.030)	.66 (.050)	.83 (.01)	.68 (.026)	.78 (.051)	.71 (.038)	.81 (.052)
Linear Expansion (%)	.124 (.034)	.176 (.036)	.149 (.018)	.193 (.027)	.216 (.037)	.218 (.011)	.199 (.036)	.310 (.14)	.273 (.056)	.397 (.052)	.299 (.13)	.295 (.033)	.273 (.025)	.274 (.099)	.202 (.039)	.232 (.030)
Moisture Content (1)%	7.7	7.9	8.3	8.2	8.8	9.1	9.1	9.6	8.5	8.8	9.0	9.4	8.6	8.7	9.0	8.9
Moisture Content (2)%	16.9	16.6	16.9	16.2	21.8	20.3	21.4	20.9	21.0	21.8	22.6	22.1	21.2	22.3	21.8	20.7
Linear Expansion Adjusted Means (%)	.150		.174		.215		.252		.330		.298		.270		.216	

Eucalyptus grandis.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.63 (.04)	.77 (.03)	.66 (.034)	.80 (.033)	.62 (.029)	.76 (.045)	.67 (.032)	.83 (.006)	.61 (.046)	.72 (.066)	.68 (.085)	.75 (.085)	.66 (.006)	.77 (.02)	.70 (.006)	.77 (.023)
Linear Expansion (%)	.145 (.024)	.205 (.017)	.178 (.016)	.201 (.009)	.131 (.045)	.172 (.029)	.148 (.017)	.194 (.052)	.337 (.89)	.344 (.15)	.328 (.046)	.321 (.081)	.190 (.054)	.274 (.070)	.172 (.048)	.154 (.01)
Moisture Content (1) %	7.8	7.7	8.0	8.1	8.3	8.6	8.9	9.5	8.7	8.9	9.1	9.1	8.5	8.8	8.6	9.6
Moisture Content (2) %	16.4	15.9	16.6	15.1	20.5	20.0	23.0	20.1	22.4	21.8	22.3	21.2	21.2	22	21.4	20.8
Linear Expansion Adjusted Means (%)	.175		.186		.153		.173		.345		.323		.236		.164	

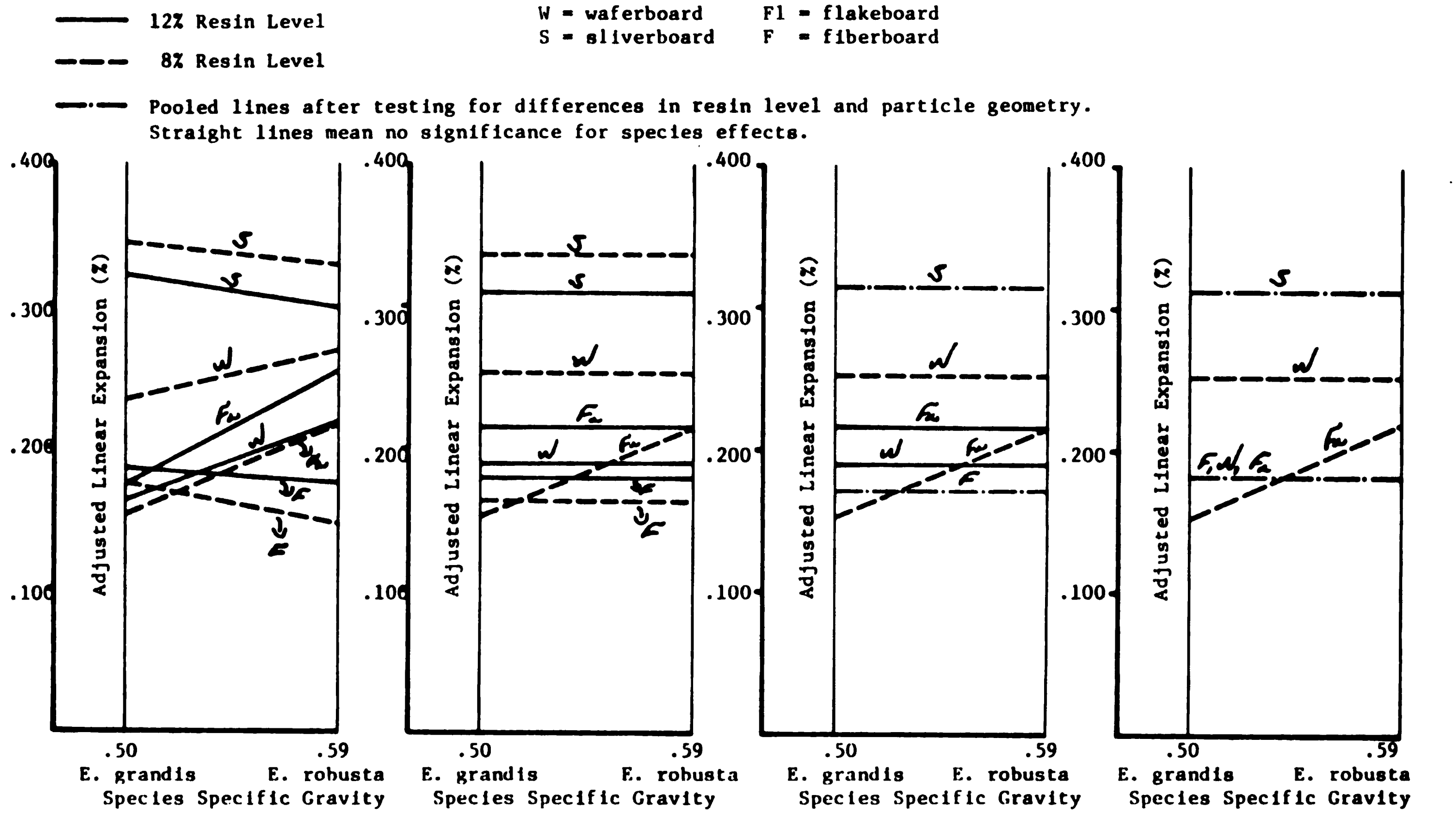
All coefficients were tested by means of an f-test at the 1 percent significance level. Most of the equations show a "bad fit" with the exception of the fiberboards for both species showing a good correlation to board density. Even where correlation is high, practical significance is very low.

3.3.3 - Covariance Analysis.

A covariance analysis was developed for linear expansion looking at the same three variables effects, species specific gravity, resin level and particle geometry. At first linear expansion was adjusted over board density to allow comparisons of the species effects on this property. The first conclusion can be drawn from Figure 60 a: no clear relationship exists as far as the specific gravities of the species are concerned for the composition boards at 8 and 12 percent resin levels.

When these two adjusted linear expansion means were compared to verify influence of specific gravity of the species at the 1 percent significance level, only the flakeboards at the 8 percent resin level were significantly different. This means that as the specific gravity of the species decreases, linear expansion in this single case decreases significantly (Figure 60 b).

In the second stage LE values were adjusted over board density to observe differences between the 8 percent and 12 percent resin levels for every kind of composition board. When tested at the 1 percent significance level the flakeboards increased linear expansion significantly due to the 4 percent difference in resin level (Figure 60 c).



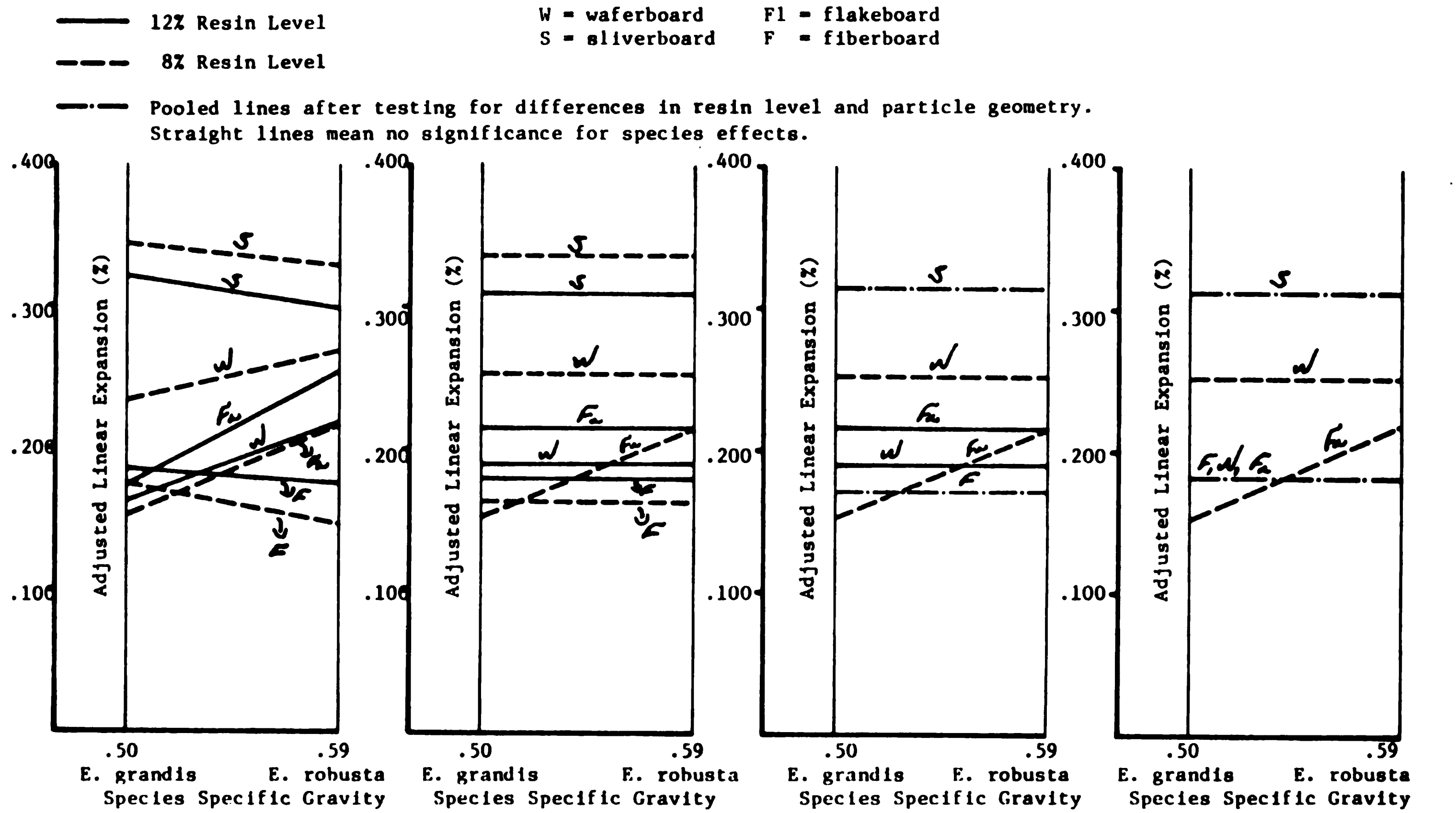
A - Adjusted Means

B - Tested for differences due to species.

C - Tested for differences due to resin level

D - Tested for differences due to particle geometry.

Figure 60 a, b, c, d. Linear Expansion Covariance Analysis.



A - Adjusted Means

B - Tested for differences due to species.

C - Tested for differences due to resin level

D - Tested for differences due to particle geometry.

Figure 60 a, b, c, d. Linear Expansion Covariance Analysis.

After the second stage of testing, the non-significant lines were pooled together.

In the third stage LE values were adjusted over board density to observe differences due to the four different particle geometries. When the adjusted LE means were compared at the 1 percent significance level, only the sliverboards had a very high and significant linear expansion. This very high linear expansion could be well explained by the breakdown in width after hammermilling and somewhat because of the high thickness of the particles (Figure 60 d). This is not in complete agreement with Bryan [7] who found that as the length of the particle increases, LE decreases.

3.4 - Thickness Swelling.

3.4.1 - Actual Values.

Thickness swelling is another very important property when considering most of the uses of composition boards. It is well documented in the literature that there is no clear relationship of this property to board density. Sorption curves for thickness swelling for both resin levels, densities and species are shown in Figures 61, 62, 63, 64 . From the figures we can see that the increasing size of the particles increased thickness swelling, and that in general as resin level increased, thickness swelling decreased for both species. In this study looking at the overall means, there is no clear relationship between thickness swelling and board density for all composition boards at 8 and 12 percent resin level for both species *E. robusta* and *E. grandis* (Figure 65).

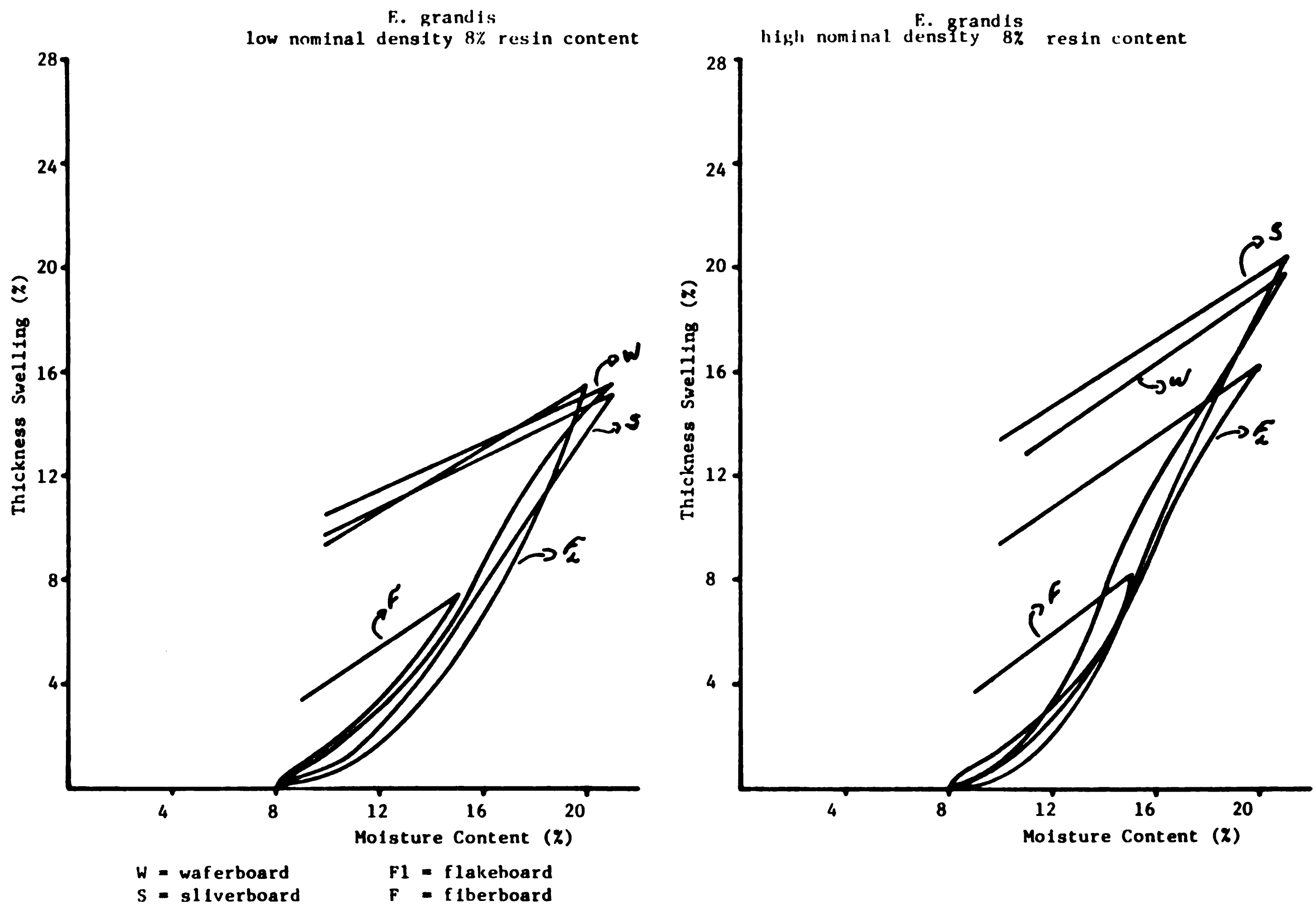
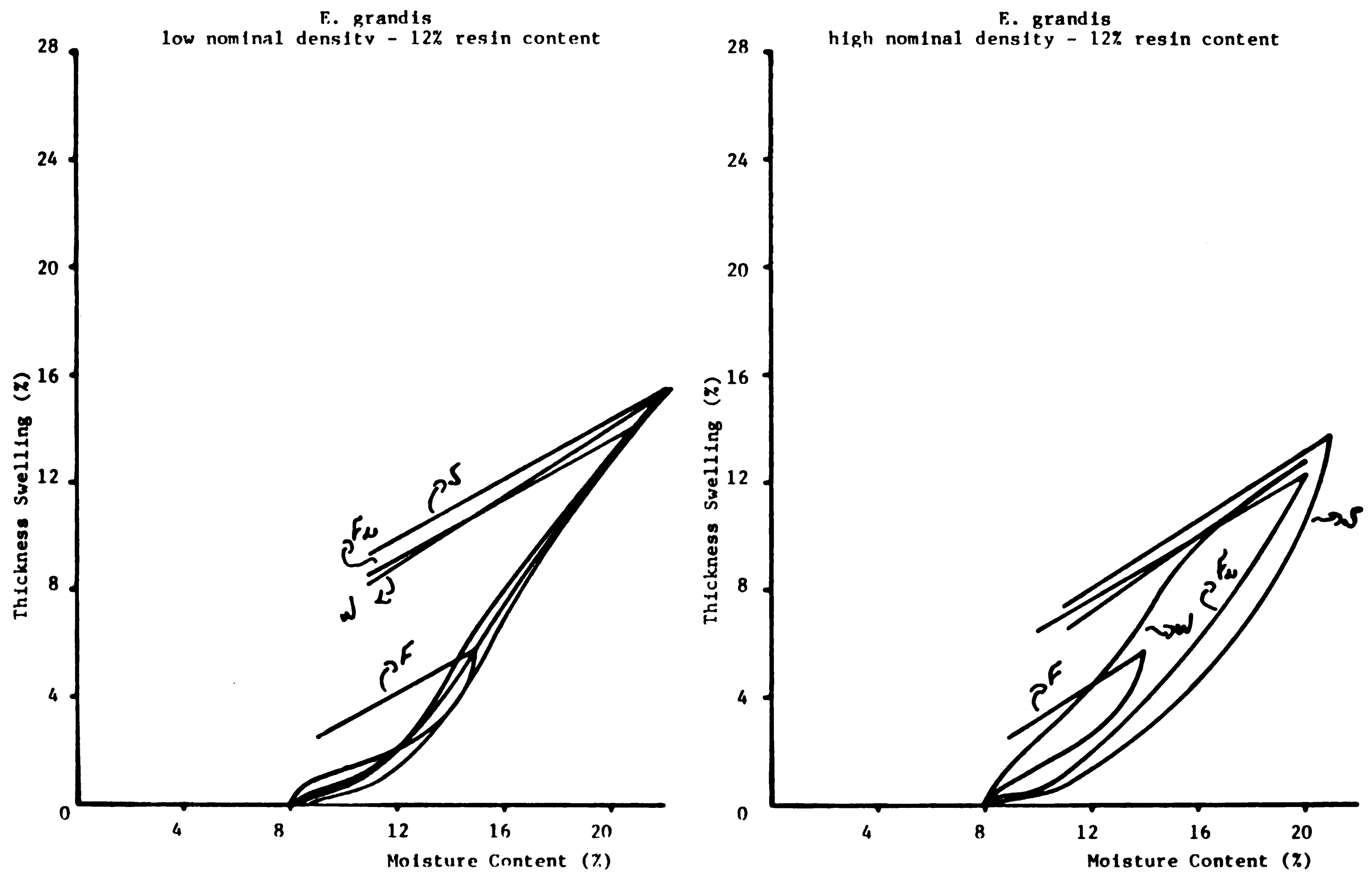
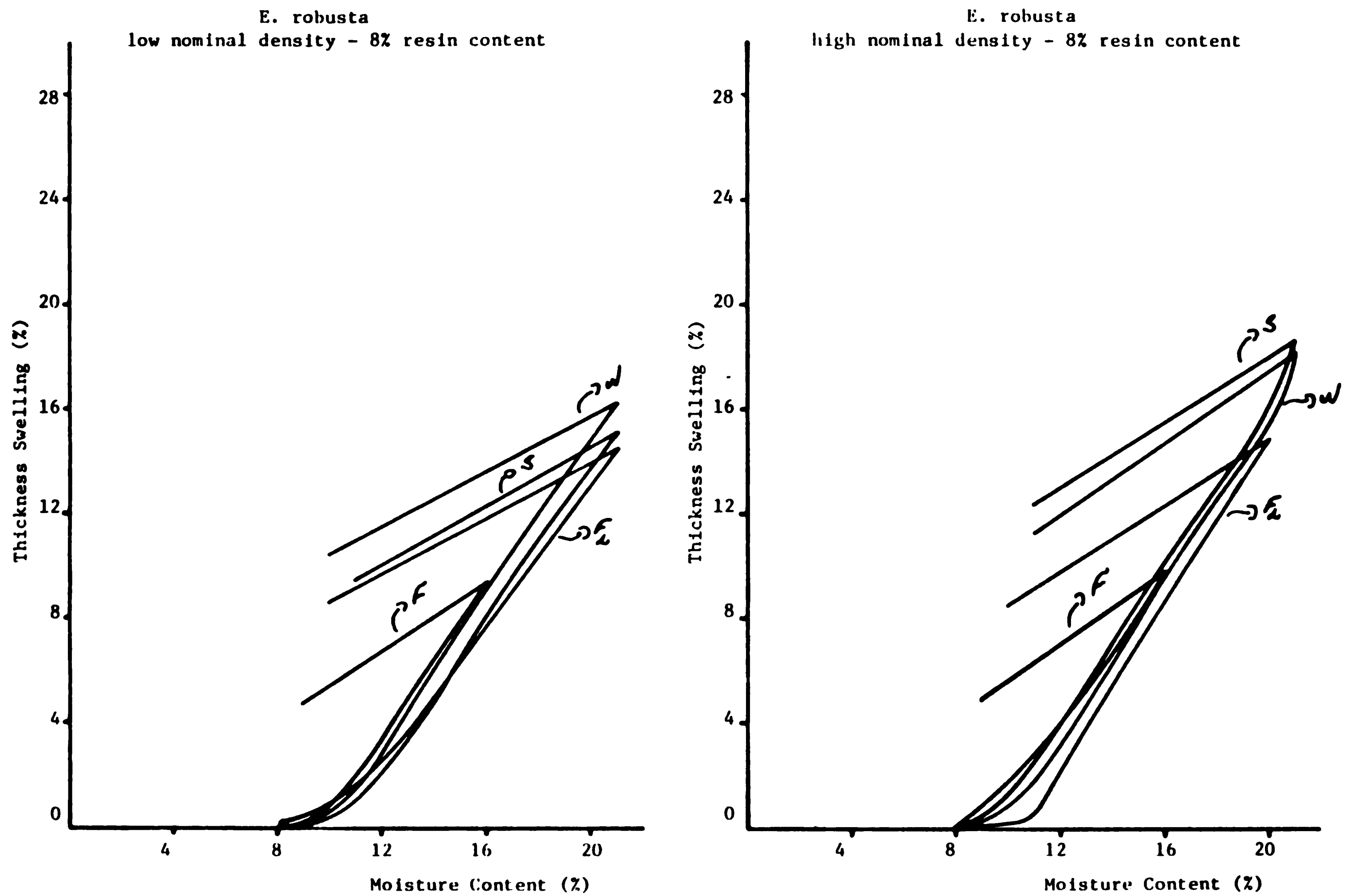


Figure 61. Thickness Swelling - sorption curves. (E. grandis composition boards - 8% resin level).



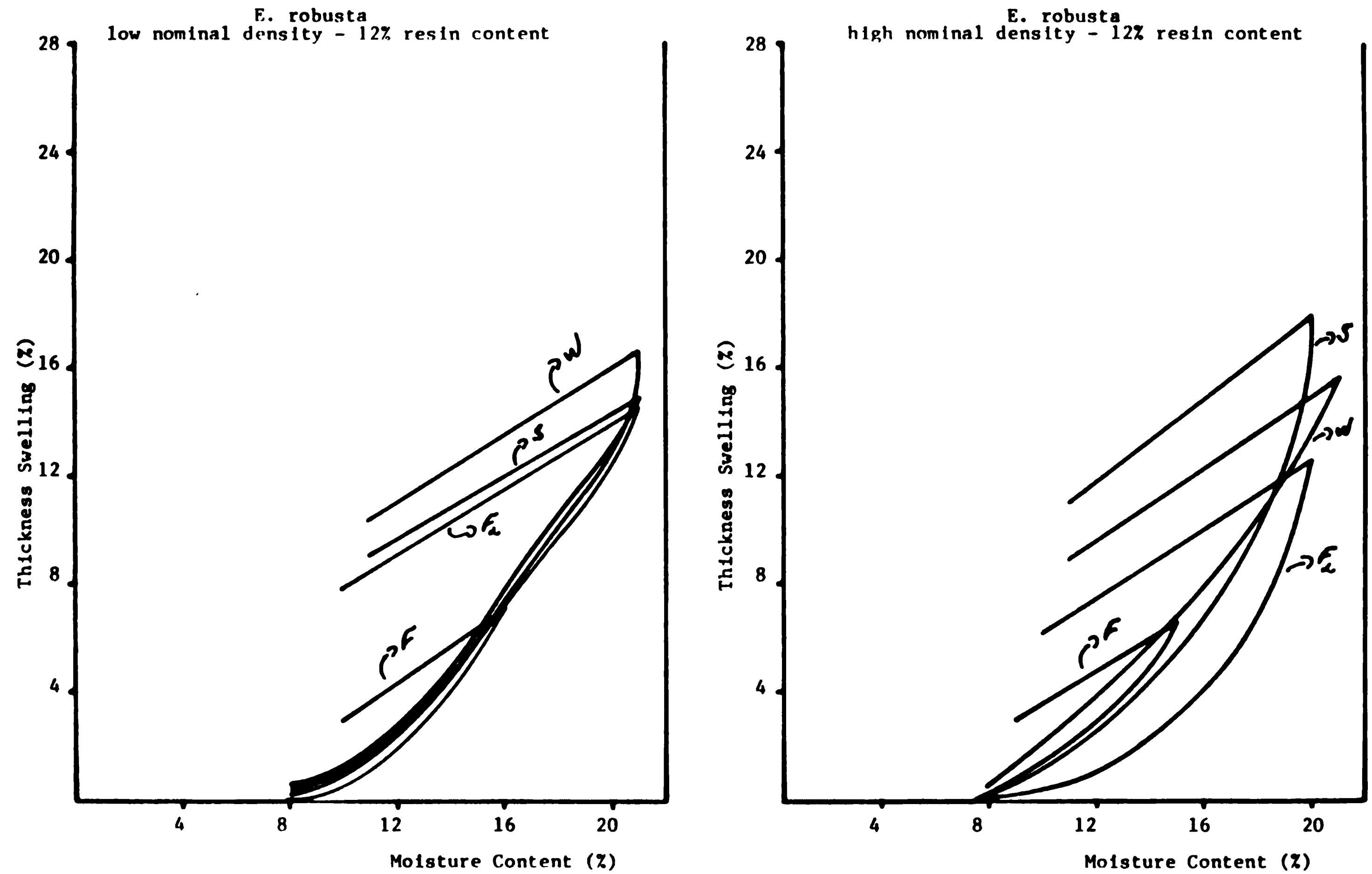
W = waferboard　　Fl = flakeboard
S = sliverboard　　F = fiberboard

Figure 62. Thickness Swelling - sorption curves. (E grandis composition boards, 12% resin level).



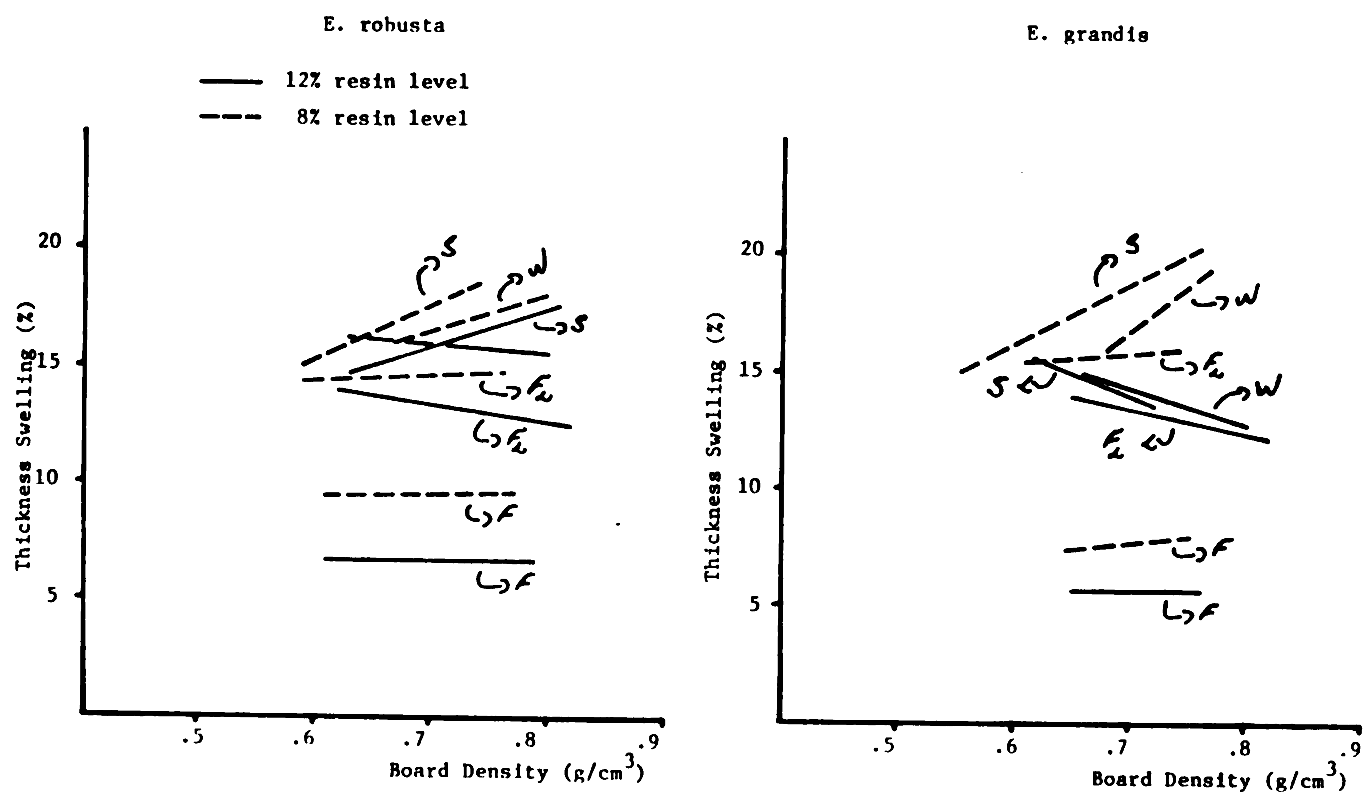
W = waferboard
S = sliverboard
Fl = flakeboard
F = fiberboard

Figure 63. Thickness Swelling - sorption curves. (E. robusta composition boards - 8% resin level).



W = waferboard   Fl = flakeboard
S = sliverboard   F = fiberboard

Figure 64. Thickness Swelling - sorption curves (E. robusta composition boards - 12% resin level).



W = waferboard   Fl = flakeboard
S = sliverboard   F = fiberboard

Figure 65. Thickness Swelling Mean Values - lowest and highest average board densities.

Thickness swelling average values range from 6.65 percent to 18.52 percent for boards made of E. robusta and 5.77 percent to 20.42 percent for boards made of E. grandis. Thickness swelling is a property that is not covered by the standard CS 236-66 or NPA 4-73 (Tables 16, 17). Compared with commercial particleboards in the study made by Suchsland, O. [71] some of these average values, like for the sliverboards, waferboards and flakeboards are relatively high.

3.4.2 - Regression Analysis.

Linear regression equations were developed for thickness swelling over board density for all composition boards and both species. Equations are as follows:

E. grandis.

Fiberboards - $TS = 8.5 - 2.4\ D$ $R = .13$ not significant

Flakeboards - $TS = 21.0 - 9.2\ D$ $R = .38$ not significant

Sliverboards - $TS = 8.7 + 9.00\ D$ $R = .34$ not significant

Waferboards - $TS = 12.4 + 4.5\ D$ $R = .08$ not significant

E. robusta.

Fiberboards - $TS = 9.8 - 2.4\ D$ $R = .12$ not significant

Flakeboards - $TS = 16.0 - 2.8\ D$ $R = .18$ not significant

Sliverboards - $TS = 5.5 + 16.3\ D$ $R = .74^{**}$significant

Waferboards - $TS = 12.7 + 5.4\ D$ $R = .12$ not significant

All coefficients were tested by means of an f-test at the 1 percent significance level. Most of the equations show a "bad fit" in relation to board density what could be expected.

Table 16. Composition Board Properties.
Thickness Swelling
[Mean Values]

Eucalyptus robusta.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.61 (.037)	.77 (.045)	.61 (.035)	.79 (.040)	.59 (.020)	.78 (.06)	.62 (.05)	.82 (.035)	.59 (.021)	.74 (.025)	.63 (.071)	.81 (.057)	.67 (.012)	.80 (.046)	.64 (.017)	.80 (.03)
Thickness Swelling (%) Conditioned R.H. (%) Reconditioned to R.H. (%)	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓	↓
47 - 93	9.53 (.79)	9.74 (1.69)	6.87 (.74)	6.65 (1.18)	14.43 (2.41)	14.85 (.68)	14.22 (1.72)	12.49 (1.55)	15.15 (3.07)	18.52 (.67)	14.78 (2.14)	17.66 (.68)	16.26 (3.05)	18.23 (3.44)	16.6 (4.5)	15.65 (6.09)
47	4.81 (.67)	5.11 (1.64)	2.89 (.62)	2.97 (1.15)	8.77 (2.04)	8.47 (.53)	7.94 (1.24)	6.12 (1.42)	9.39 (2.75)	12.35 (1.04)	8.98 (2.09)	11.22 (1.13)	10.48 (2.76)	11.38 (2.43)	10.24 (3.58)	8.85 (5.48)
86	5.21 (.44)	5.41 (.83)	4.02 (.44)	3.98 (.63)	9.17 (.97)	7.18 (1.09)	7.16 (.96)	5.2 (.54)	8.08 (.56)	10.09 (1.59)	7.93 (.96)	8.73 (1.89)	9.20 (1.09)	10.3 (1.23)	7.14 (.17)	6.54 (.76)
47	3.53 (.46)	3.17 (.35)	2.43 (.60)	2.20 (.73)	5.76 (1.20)	4.10 (.91)	4.71 (1.09)	2.41 (1.09)	5.20 (.86)	6.79 (1.40)	5.24 (.97)	5.98 (1.69)	6.28 (1.09)	7.21 (.99)	4.72 (.68)	3.63 (1.00)
66	1.05 (.19)	1.12 (.15)	.76 (.30)	1.00 (.31)	1.09 (.48)	.43 --	.83 (.43)	.70 --	1.16 (.31)	1.31 (.56)	1.17 (.18)	1.92 (1.42)	1.76 (.44)	1.89 (.48)	1.51 (.28)	2.26 (.45)
47	.39 (.15)	.43 (.15)	.23 (.15)	.36 (.22)	.48 (.46)	.16 --	.22 (.098)	.16 --	.39 (.25)	.59 (.60)	.38 (.19)	.59 (.49)	.82 (.29)	.97 (.43)	.67 (.33)	.85 (.64)
M.C. - 47%	8	7	8	7	8	8	8	9	8	8	8	8	9	8	9	8
M.C. - 93%	16	16	16	15	21	20	21	20	21	21	21	20	21	21	21	21
47	9	9	10	9	10	10	10	10	11	11	11	11	10	11	11	11
M.C. - 86	13	13	14	13	17	15	16	17	16	16	16	16	16	16	16	15
47	10	10	10	9	11	11	11	11	11	11	11	12	11	11	11	11
M.C. - 66	10	9	10	9	10	11	10	11	11	10	10	11	11	11	11	10
47	9	8	9	8	9	10	9	10	9	9	9	9	10	9	10	9

* Numbers in between parentheses are standard deviations.

Table 17. Composition Board Properties.
Thickness Swelling
[Mean Values]

Eucalyptus grandis.

Board Type	Fiberboard				Flakeboard				Sliverboard				Waferboard			
Resin Level (%)	8	8	12	12	8	8	12	12	8	8	12	12	8	8	12	12
Actual Density (g/cm^3)	.64 (.05)	.75 (.03)	.65 (.052)	.76 (.046)	.61 (.035)	.74 (.051)	.65 (.015)	.82 --	.56 (.047)	.75 (.11)	.62 (.09)	.72 (.09)	.68 (.058)	.77 (.01)	.77 (.09)	.80 (.035)
Thickness Swelling (%) Conditioned R.H. (%) Reconditioned to R.H. (%)																
93	7.41 (1.32)	8.09 (1.08)	5.77 (.57)	5.79 (.88)	15.46 (1.13)	16.29 (1.32)	14.01 (.74)	12.23 (2.99)	15.19 (2.77)	20.42 (2.61)	15.61 (2.42)	13.78 (3.33)	15.58 (1.92)	19.60 (2.74)	14.84 (2.39)	12.83 (6.34)
47	3.47 (1.05)	3.70 (1.08)	2.52 (.76)	2.53 (.79)	9.45 (.88)	9.57 (1.50)	8.51 (.98)	6.48 (2.44)	9.66 (1.66)	13.66 (2.71)	9.49 (1.59)	7.43 (2.74)	10.46 (1.37)	12.9 (1.51)	8.33 (2.14)	7.05 (4.16)
86	4.57 (.71)	4.36 (.58)	3.62 (.46)	3.69 (.67)	8.45 (.86)	7.81 (2.16)	7.79 (.60)	5.28 (2.35)	9.18 (1.88)	8.47 (1.54)	8.03 (.55)	5.83 (1.15)	10.73 (2.71)	10.0 (1.26)	6.83 (.54)	8.78 (5.43)
47	2.74 (.89)	2.77 (.58)	2.08 (.36)	2.00 (.88)	5.91 (1.01)	4.35 (1.14)	5.49 (.34)	2.33 (2.38)	5.96 (1.67)	6.12 (1.49)	5.45 (.39)	3.39 (1.03)	9.03 (1.37)	6.47 (.70)	4.68 (1.58)	6.18 (5.20)
66	.96 (.14)	1.05 (.19)	.90 (.28)	.83 (.53)	.99 (.28)	1.01 (.63)	1.37 (.35)	.49 --	1.53 (1.28)	.98 (.50)	1.34 (.33)	.77 (.51)	1.54 (.35)	.97 (.50)	.56 (.28)	2.55 (1.67)
47	.33 (.17)	.39 (.091)	.33 (.17)	.36 (.36)	.32 (.28)	.27 (.20)	.68 (.53)	.16 --	.76 (.90)	.44 (.48)	.50 (.44)	.27 (.20)	.71 (.35)	.27 (.19)	.22 (.10)	1.73 (1.76)
M.C. at 47%	7	7	8	7	8	8	9	9	8	8	9	8	8	8	8	8
M.C. 93	15	15	15	14	20	20	21	20	21	21	22	21	21	21	21	20
47	9	9	9	9	10	10	11	10	10	10	11	11	10	11	11	11
M.C. 86	13	13	14	13	17	15	16	15	17	15	16	17	17	15	15	15
47	9	9	10	9	11	10	11	10	11	11	11	11	11	10	10	10
M.C. 66	9	9	9	9	11	10	11	10	11	11	11	11	10	10	10	10
47	8	8	8	8	9	9	10	9	9	9	10	9	9	9	9	9

3.4.3 - Covariance Analysis.

A covariance analysis was conducted to observe the property thickness swelling in relation to the three factors mentioned in other sections before. At first thickness swelling was adjusted over board density to allow comparisons of the two species effects over this property.

The first conclusion can be drawn from Figure 66 a : no clear relationship exists as far as the specific gravity of the species are concerned for the composition boards at 8 and 12 percent resin levels. When these two adjusted thickness swelling means were compared to verify influence of specific gravity of the species at the 1 percent significance level only the fiberboards at the 8 percent resin level were different. This means that as the specific gravity of the species decreases thickness swelling for the fiberboards at this 8 percent resin level decreases significantly (Figure 66 b).

In the second stage TS values were adjusted over board density to observe differences in between the 8 percent and 12 percent resin levels for every kind of composition board. In general, thickness swelling decreases as the resin level increases. This is the case in this study for all composition boards. When tested at the 1 percent significance level only the fiberboards decreased thickness swelling significantly as the resin level increased (Figure 66 c). After the second stage of testing, the non significant lines were pooled together.

In the third stage TS values were adjusted over board density to observe differences due to four different particle geometries. When the adjusted TS means were compared at the 1 percent significance level only the fiberboards had a very low and significant thickness swelling, which could be well explained by the uniformity of raw material, the fibers being the ultimate form of wood element making the springback behavior of the board matrix smaller in relationship to the other increasing size of particles (Figure 66 d).

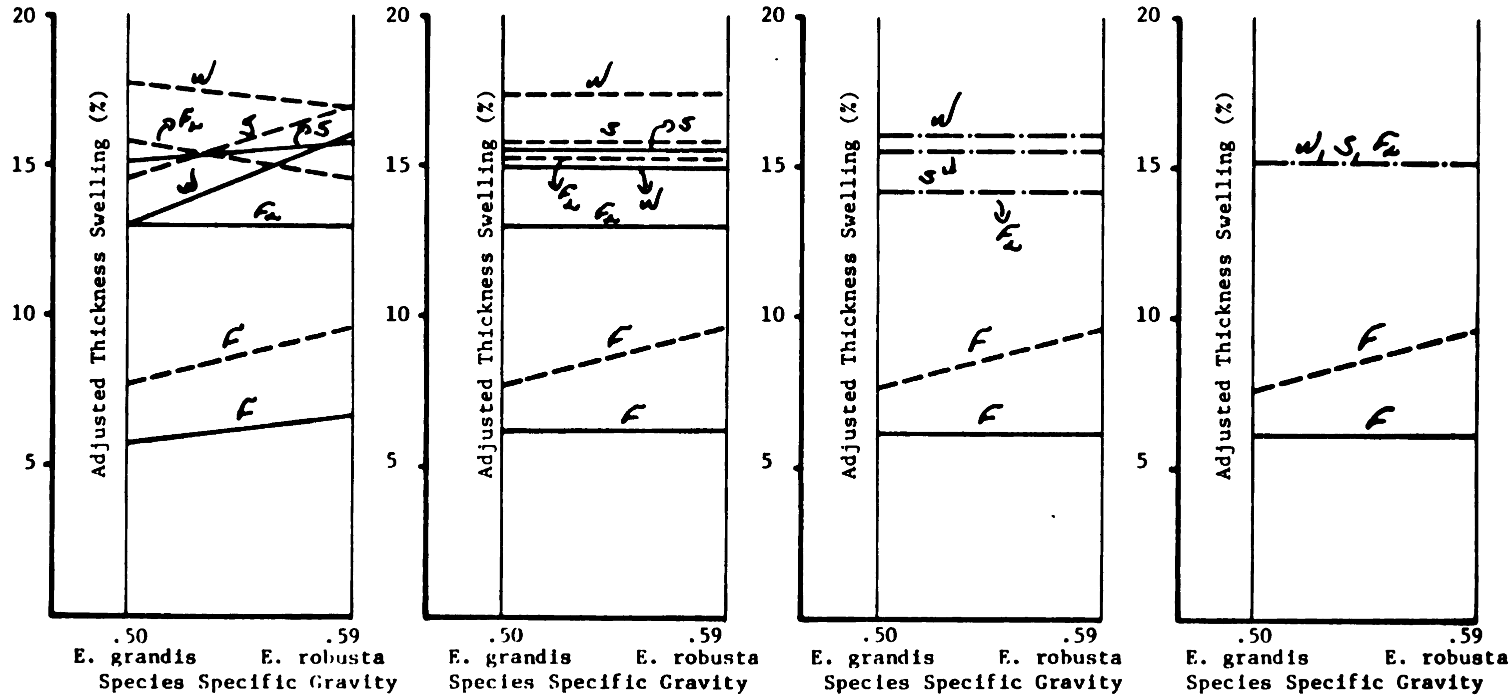
—— 12% resin level

– – – 8% resin level

—·— Pooled lines after testing for differences in resin level and particle geometry. Straight lines mean no significance for species effects.

W = waferboard
S = sliverboard

Fl = flakeboard
F = fiberboard



A - Adjusted Means

B - Tested for differences due to species.

C - Tested for differences due to resin level.

D - Tested for differences due to particle geometry.

Figure 66 a, b, c, d. Thickness Swelling Covariance Analysis.

CHAPTER VII

CONCLUSIONS

1) The two Eucalyptus species *Eucalyptus robusta* and *Eucalyptus grandis* show significant differences in several of their physical and mechanical properties. The most important one is the difference in specific gravity. This difference is reflected in most of the other tested solid wood properties. The relationship between specific gravity and physical and mechanical properties are similar to those found in other species.

2) Sufficiently high mechanical property levels and adequate physical properties can be developed in a wide range of composition boards manufactured from the two species within reasonable limits of board density and binder addition. Compliance with particleboard specifications such as those in the National Particleboard Association Commercial Standard CS 236-66 can readily be achieved with all particle configurations.

3) The dominating variable as far as most board properties are concerned is clearly the board density. It is also a variable which is most difficult to control under laboratory conditions, both between boards and within boards. In order to study the effects of species specific gravity and resin level on board properties, these board properties must be adjusted for density variations by means of a covariance analysis, the board density being the covariant. The

results of the covariance analysis indicate that variables like species specific gravity are of secondary significance at least within the variation given by the two species used. The most responsive to species specific of the four particle configurations is the fiber. This is in contradiction to other findings which indicate that fiberboard is less sensitive to species specific gravity than particleboard. In fact, this is one of the important attributes of medium density fiberboard which allows the utilization of heavier hardwoods without undue increases in board density.

In the case of this study, the greater sensitivity of fiberboard to species specific gravity may be due to the fact that it might have been possible to form the fiberboard mats with much greater uniformity, thus reducing the variability of the board density.

5) Linear expansion of particleboard and fiberboard cannot readily be related to the major raw material and process variables. While it must, at least theoretically, derive from the swelling and shrinkage characteristics of the solid wood, there are probably too many interactions obscuring the first order relationships. Complicating the matter is the severity of exposure conditions. The high humidity condition and the long term of exposure cause relaxation of stresses, and deterioration of glue lines.

Thickness swelling is less complex. In this study, fiberboards had the lowest thickness swelling values due to uniformity of structure.

6) With regard to future work in this important area of the relationships between raw material characteristics and board properties, this final conclusion is offered: while most mechanical properties of composition board can easily be adjusted to the required level by changing the compression ratio of the particles, some physical properties like linear expansion cannot be so adjusted. Only very careful study of all the interactions and possibly modification of measuring technique will be successful here.

APPENDICES

APPENDIX A

Particle Geometry Nomenclature. - Definitions of the various types of particles have been developed by the American Society for Testing and Materials as a part of the "Standard Definition of Terms Relating to Wood - Based Fiber and Particle Panel Materials" ASTM Designation D 1554. The following definitions are important in defining the geometries used in this research.

Fibers. - The slender threadlike elements or groups of wood fibers or similar cellulosic material resulting from chemical or mechanical fiberization, or both, and sometimes referred to as fiber bundles.

Flake. - A small wood particle of predetermined dimensions specifically produced as a primary function of specialized equipment of various types with a cutting action across the grain (either radially, tangentially or at an angle between). The action being such as to produce a particle of uniform thickness, essentially flat and having the fiber direction essentially in the plane of the flakes, in overall character resembling a piece of veneer.

Slivers. - Particles of nearly square or rectangular cross section with a length parallel to grain of the wood of at least four times the thickness.

Wafers - There is no standard definition for this geometry. For the purpose of this study wafers will be defined as a longer thicker flake used in composition boards for structural purposes.

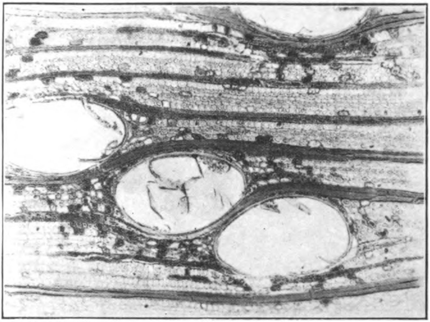
APPENDIX B

"E. grandis Anatomical Description - pores large, varying in number from 129-165 per area of approximately 20 square mm.' rays large, 17-30 cells high, numbering 57-89 per square mm., in majority of samples near 80, biseriate rays common, average 40 percent, some triseriate rays present in half samples examined; parenchyma not abundant and mostly paratracheal; practically no resin in parenchyma cells, ray cells only half filled with resin, cells generally open, lumina of wood fibres free from resin, giving a more open appearance distinctive from such woods as E. marginata, E. resinifera, E. tereticornis, and others -- wood practically identical in most respects with that from E. saligna, and no attempt has been made to separate these two species. For general cell structure see photomicrographs of E. saligna, Plate No. 1. Dadswell and Burnell (1932) [12].

E. robusta Anatomical Description - pores medium to small in size, not numerous, averaging 150 per area of approximately 20 square mm.; rays large, broad and up to 24 cells high, averaging 70 per square mm., biseriate and triseriate rays common, ray cells mostly filled with resin; parenchyma abundant, mostly diffuse but some paratracheal, cells containing some resin; lumina of wood fibres and vessels generally free from resin, vellels tylosed. For typical cell structure see Plant No. 2." Dadswell and Burnell (1932) [12].

Plate No. 1

E. saligna (Sydney bluegum).



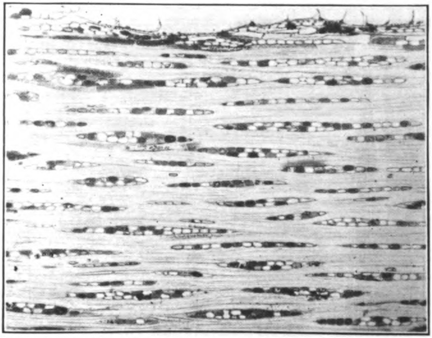


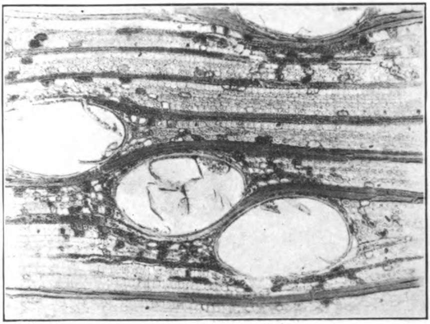
Fig. 1 (top).—Transverse Section. × 95.

Fig. 2 (bottom).—Tangential Section. × 95.

Notes.—(*a*) Large tylosed vessels. (*b*) Long biseriate rays, the cells of which are only partly resin filled. *E. grandis* has a similar structure. Compare with *E. haemastoma* and *E. botryoides.*

Plate No. 1

E. saligna (Sydney bluegum).



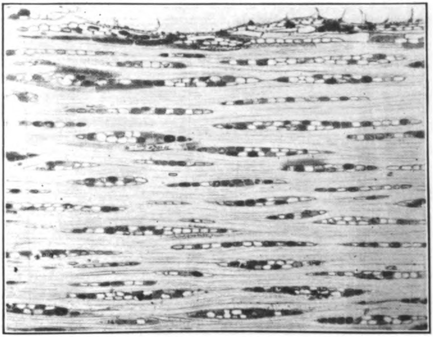


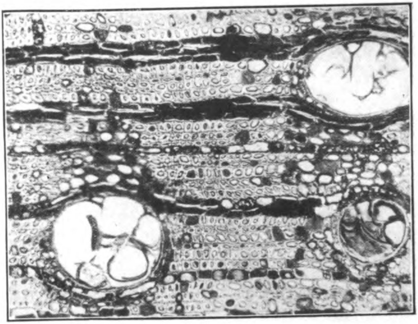
FIG. 1 (top).—Transverse Section. × 95.

FIG. 2 (bottom).—Tangential Section. × 95.

NOTES.—(*a*) Large tylosed vessels. (*b*) Long biseriate rays, the cells of which are only partly resin filled. *E. grandis* has a similar structure. Compare with *E. haemastoma* and *E. botryoides*.

Plate No. 2

E. robusta (swamp mahogany).



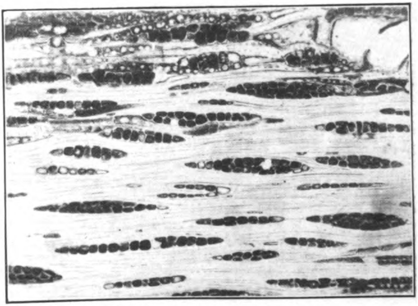


Fig. 1 (top).—Transverse Section. × 95.

Fig. 2 (bottom).—Tangential Section. × 95.

Notes.—(*a*) Abundance of parenchyma cells, some of which are resin-filled. (*b*) Pores tylosed and containing resin, some of the fibres containing resin in their lumina. (*c*) Presence of broad rays, some of which are triseriate.

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