EVALUATING LOG STIFFNESS USING ACOUSTIC TECHNOLOGY FOR MANUFACTURING STRUCTURAL ORIENTED STRAND BOARD

by

TRACYE MURPHY

(Under the Direction of Laurence Schimleck)

ABSTRACT

Wood has a wide range of properties that vary by species, within species, and even within a tree. It is used for many kinds of applications from paper to decorative items to high strength construction materials. This creates a need to be able to monitor wood quality, especially for certain markets like construction where the end product is used in structural applications.

Due to an increased demand for wood, most of the logs purchased by oriented strand board (OSB) and other engineered wood companies are low quality tops and young trees with low stiffness mixed with higher quality logs. Common practices are to visually grade logs as they enter a manufacturing site, followed by mechanical testing of the finished product after processing. Since these methods are expensive, produce waste, and result in reduced productivity, non-destructive evaluation (NDE) techniques using acoustics have been adopted in the veneer and sawmill industries to improve quality control but so far are not common in the engineered wood industries.

The overall goal of this project was to determine if the log quality affects the final product and if acoustic NDE technology is a satisfactory tool for determining log stiffness prior to entering the manufacturing process. It was found that low stiffness logs produced panels with low stiffness while high and medium stiffness logs produced panel with similar properties. The

HM 200 was a satisfactory tool for determining log stiffness. Further studies need to be done to determine how to incorporate NDE tools into the manufacturing process.

INDEX WORDS: Acoustic log stiffness, oriented strand board, log sorting, log quality, engineered wood products

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TRACYE MURPHY

BS University of Georgia Warnell School of Forest Resources, 2000

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TRACYE MURPHY

Major Professor:	Laurence Schimleck
Committee:	Richard Daniels Russell Gentry

Electronic Version Approved:

Maureen Grasso
Dean of the Graduate School
The University of Georgia
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CHAPTER 1

INTRODUCTION

The United States is the world's largest producer, consumer, and importer of wood products. It is also the second largest exporter of wood products after Canada with the southern US producing approximately 16% of the world's timber market (Wear and Greis 2002) and 60% of the nation's forest products. (Prestemon and Abt 2007). An important component of the forest products output includes engineered wood products (Figure 1.1) such as beams, or panels that are made by breaking up solid wood into veneers, flakes, chips etc. and constructing a product that eliminates the detrimental effects of knots, cracks, or other natural irregularities of wood (Herajarvi et al. 2004).

Oriented strand board (OSB) is an engineered panel product formed by layering strands of resinated wood in specific orientations into a mat, then pressing the mat at a high temperature to form a panel of desired strength and stiffness. The mat consists of approximately 90-95% soft or hard wood, 3-8% exterior grade resins and 1-5% wax products. In 1980, North American OSB panel production was 751 million square feet (3/8" basis). By 1990, annual production was 7.6 billion square feet and had increased to 25.0 billion square feet by 2005 (Figure 1.2) (http://www.osbguide.com/osbfacts.html). Recently US production of OSB exceeded production of structural plywood (Figure 1.3). In the year 2000 there were approximately 100 structural plywood mills in the US and 50 OSB mills (Timber Mart South 2008).

OSB shares many characteristics with plywood but is manufactured from a lower-value forest resource, hence it can out-compete plywood on a direct-cost basis. OSB manufacturing facilities are able to utilize small diameter logs from thinning operations and waste from harvesting while maintaining equivalent strength and stiffness to plywood in the process described below. Figure 1.4 gives an overview of the process.

ORIENTED STRAND BOARD MANUFACTURING PROCESS

Log Sorting

After harvest, whole logs are delivered to the mill's wood yard, then visually sorted by species and sometimes by length (most logs are delivered truck length, but ½ truck lengths are accepted as well depending on availability of material). No true grading of the logs takes place prior to processing, but scale operators are allowed to reject incoming material due to excessive visual defects such as rot or insect infestation.

Debarking

Logs are fed through a debarker to remove bark. The removed bark is collected and later used as wet fuel for energy.

Stranding

The strands are cut from whole logs into dimensions of up to six inches long (or up to 12" for OSL) and three inches wide, with thickness ranging from around 0.015" to 0.04". Strand geometry is crucial to final panel properties and is dependent on wood species, growth type, typical log diameter, season of log harvest, and log length entering the strander. There are various types of stranders but OSB facilities typically use either disc or drum.

Wet Bins

Strands are deposited into wet bins for a varying amount of time depending on bin size and number of wet bins available but can range from 15 minutes to a few hours. Regardless of the time, it is never long enough for the green flakes to become moldy.

Drying

Strands are then dried at approximately 450 °F for up to 10 minutes until the appropriate moisture content is reached, typically between 2-9%, depending on the product being made. Two standard types of dryers are used, rotary dryers or conveyor dryers. The two types of rotary dryers are single pass, where the strands enter one end of the dryer and either exit from the opposite end with only one pass through the dryer, or triple pass where the strands pass through the dryer 3 times. Some OSB facilities screen flakes after the drier prior to blending to remove "fines" or material less than 1/8" long. The majority of the fines are typically burnt for fuel and a small percentage used as filler in the core of the panel.

Blending

Strands are blended with wet and/or dry phenolic and/or isocyanate resin binders and a small amount of wax, which is used to enhance the panel's resistance to moisture and water absorption. Table 1.1 gives typical levels of resin and wax use.

Forming Line

Strands go through the forming line where cross-directional layers are formed through multiple forming heads. Each forming head represents a panel layer and can range from 3-5 heads depending on the size of the manufacturing facility.

Pressing

Layers of multi-directional strands are pressed under heat to form a stiff, dense structural panel of OSB. A ¾" panel might be pressed at 410° F for 4-5 minutes depending on resin type. Typically pressure is dependent on the amount of time needed to reach the desired panel thickness. Hence, pressure will vary between products, panel densities, wood species used, and also between pressloads of the same products. Presses are primarily multiple opening allowing 8 to 16 master mats to be pressed in one operation with 4 to 8 panels per master mat depending on the size of the press. In 1997, continuous presses began producing a continuous ribbon of OSB on certain sites allowing for production of OSB with non-standard lengths, widths, and thicknesses.

Finishing Line

After exiting the press the panel is generally cut to size, with the standard panel size being 4' x 8'. The panels are then grade stamped for use (Table 1.1), with grades including sheathing, structural number 1, or single floor (refer to Appendix A, Table 1 for grade clarification), with panel grades being determined by expected end use and building codes. The panels are then stacked in units and edge coated.

Finished panels are tested internally daily, typical properties that are measured and test standards used are given in Appendix A Table 2. Panels are also subject to a more stringent series of tests by a third party every quarter to ensure quality is maintained.

WOOD USE BY THE FOREST PRODUCTS INDUSTRY

Engineered wood products take solid wood and chip, peel, or strand it to make a product that is more homogenous and predictable with its properties than solid wood. This is achieved by evenly distributing the natural defects of the wood throughout the entire finished product. This allows for longer spans, tighter architectural design values, and higher stiffness and strength properties by volume compared to solid wood. Some of these products such as oriented strand board (OSB), oriented strand lumber (OSL), and laminated strand lumber (LSL) can be made from small-diameter logs or wood waste, (Herajarvi et al. 2004).

Typically, large diameter mature logs are sold at a high price (Figure 1.5) to sawmills and veneer plants for processing into structural lumber and veneers. Most of the small diameter fast grown young trees and tops from sawlogs or peeler logs are sold to a range of industries, such as chip mills, medium density fiberboard (MDF) plants, OSB mills, and pulp mills. These trees are typically of lower quality and do not bring a very high price to the landowner (Figure 1.5).

Using low quality, small diameter logs, some OSB manufacturers are able to produce high quality, specialty products for high end structural uses, such as I-joists, and engineered flooring and roofing systems, which are of much higher value for the manufacturer and the consumer. Wood is a cheap raw material for OSB manufacture, representing approximately 45% of direct operating costs (Table 1.2), while forming the majority of the panel in comparison to resin and wax (Table 1.3). If low quality logs with inherently low stiffness are used to develop high quality specialty products, then manufacturing facilities must compensate for the low stiffness furnish with more expensive materials such as resin and wax to achieve desired product properties. Ideally the OSB industry would take advantage of the variation that exists but it lacks the technology required to rapidly assess log quality.

VARIATION IN WOOD PROPERTIES

It is recognized that wood properties vary among species, within species, within stands, and within individual trees. It is known throughout the wood products industry that species has the largest effect on wood properties due to differences in cell type and arrangement of cells, and growing conditions/site quality. Within-species variation is typically due to site quality, environmental conditions, silvicultural practices, and changes in wood properties resulting from defects (such as knots or wind and insect damage). These differences produce considerable variation in wood properties on a regional basis. For loblolly pine, the primary furnish for OSB produced in the southern USA, regional variation of specific gravity has been the subject of several studies (for example Talbert and Jett 1981, Jordan et al. 2008) and considerable differences in wood properties have been found to exist on a regional basis.

For OSB production another large source of variation is the proportion of juvenile wood in the furnish. Juvenile wood, or corewood, is generally classified as the first 10-15 growth rings surrounding the pith. It characteristically has low density (specific gravity), high moisture content, high microfibril angle, short tracheids, and other properties (low cellulose, high lignin). In combination such properties give lower wood quality, for example low transverse shrinkage with high longitudinal shrinkage, and low strength, making juvenile wood undesirable for many purposes, including structural lumber (Huang et al. 2003, Peters et al. 2002) where it has been shown that its value and performance is restricted by the stiffness of the juvenile wood (Lindstrom et al. 2002). In terms of OSB manufacture, it takes a larger volume of juvenile wood to reach a desired panel density due to lower compaction of the material. For example, Pugel et al. (1990) showed a 20% increase in the amount of fast grown loblolly pine needed to achieve the same panel density as mature loblolly pine. Cloutier et al. (2007) showed that the proportion of juvenile wood also had a significant impact on OSB mechanical properties and that only up to 70% of the oven dry weight could be juvenile wood without significantly impacting thickness swell, linear expansion, internal bond, and stiffness. However, current trends in forestry practices (Figure 1.6) are toward faster grown trees which have a high proportion of juvenile wood in harvested trees (Lindstrom 2004).

While it is recognized that considerable variation exists, rapid assessment is problematic and tools have to be developed that can provide a rapid assessment of log quality for OSB production. In terms of OSB production wood stiffness is of primary importance and in other forest products industries (lumber and plywood for example) it has been demonstrated that non destructive tools based on acoustics can give a rapid measure of log stiffness and subsequent improvement in product quality (Carter and Lausberg 2002).

WHAT IS WOOD QUALITY FOR OSB?

The definition of "wood quality" is not consistent across wood utilization industries and is dependent on the end use of the processed logs. For structural construction applications using OSB, the primary use of the logs examined in this study, high quality will refer to products with high strength, stiffness, compression parallel to the grain, and tension perpendicular to the grain, with good dimensional stability. It is assumed that the quality of the unprocessed wood will have an impact on the quality of the finished product, in our case OSB, so desirable logs will have high strength and stiffness.

NON-DESTRUCTIVE TECHNIQUES FOR ANALYZING WOOD PROPERTIES

The forest products industry employs a variety of NDE techniques to test stiffness properties of engineered wood products and lumber. The three most common NDE methods are covered below with brief descriptions of the static bending/flexure testing and the transverse vibration techniques and a focus on longitudinal stress wave method.

Static Bending (Flexure) Testing

The static bending technique uses the load-deflection relationship of a material with various loading set-ups (Figure 1.7). Stiffness (static modulus of elasticity) is calculated using the material's resistance to deflection under a given force (Wang et al. 2001, Ross and Pellerin 1994, Carter et al. 2005). Static bending is the foundation for lumber stiffness testing since the MOE equation is derived from fundamental material principles (Ross and Pellerin 1994).

Transverse Vibration Technique

The transverse vibration techniques utilize the damping force of a material to calculate the dynamic modulus of elasticity (Wang et al. 2001, and Ross and Pellerin 1994). The technique measures the energy storage and dissipation from a forced vibration. The measurement has been correlated with the static bending properties of clear wood specimens and dimensional lumber, MOE and strength of wood poles, dimensional lumber, and glulam timbers, and tensile strength of clear lumber (Ross and Pellerin 1994).

Longitudinal Stress Wave Technique

The stress wave technique monitors the speed-of-sound through a material from an induced stress wave. It employs the standard wave theory where an impact generates a stress wave (Figure 1.8) that travels the length of the material, upon reaching the end, a tension wave travels back and the velocity of the wave is recorded with an accelerometer (Wang et al. 2001, and Ross and Pellerin 1994). The dynamic modulus of elasticity is calculated from the velocity of the sound wave and the green moisture content of the wood. The transverse vibration and static bending/flexure techniques methods are typically restricted to a lab type setting, but the longitudinal stress wave method can be used in the field on logs or standing trees[1], which prompted its use in this study.

APPLICATION OF ACOUSTIC NDE TECHNOLOGY IN THE FOREST PRODUCTS INDUSTRY

Non-destructive evaluation techniques have shown very positive results in determining log stiffness in the field. The stiffness equation is derived from green log density and the acoustic velocity. Many studies have shown a strong positive relationship between green log

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[1] See Wang et al. 2000 and Carter et al. 2003 for review of standing tree evaluation

stress-wave velocity and static stiffness for many different wood industries and species, including timber stiffness in radiata pine (*Pinus radiata*) (Matheson et al. 2002), veneer stiffness in Douglas-fir peeler cores (Ross et al. 2005), and log stiffness in 5-inch loblolly pine dowels (Shmulsky 2006). Albert et al. (2002) were able to correlate log stiffness values with various paper properties. Ross and Pellerin (1998) also found stress wave speed to correlate well with certain mechanical properties of wood composites.

Log diameter also has a significant negative effect on the stress wave stiffness and static stiffness correlation (probably due to proportion of early wood to late wood, and the presence of juvenile wood) (Wang et al. 2004). However, it has been shown that there is a poor correlation between basic density and stiffness from velocity (Albert et al. 2002).

Carter and Lausberg (2002) found a strong relationship between log grade and lumber quality in a study based on *P. radiata* logs, for structural lumber. They found that the stiffest 32% of logs yielded 82% of the resulting sawn timber meeting premium structural grades of MGP10 and better, compared against 72% for unsegregated logs (Table 1.4). They also reported that the high stiffness logs resulted in production of 51.9% premium DT veneer product, compared to unsegregated logs of 24.1% (Table 1.5). Significant correlations between acoustic speed and a range of pulp and paper properties were also shown by Carter and Lausberg in their 2002 study.

Log segregation based on acoustics has been successful in a range of forest products industries, the application of acoustic technology for determining log quality has not been explored in the OSB industry.

OBJECTIVES

Some common industry beliefs are that all trees from a site or area are similar, bigger logs are better, growth type or species determines log quality, visual log grading is good enough for manufacturing facilities, and that no feasible method of pre-determining log quality for the OSB industry exists. In terms of visual grading Ross et al. (1996) discovered a very poor relationship between the visual sawgrade of eastern spruce and balsam fir logs, and the stiffness of the lumber obtained from the logs.

The overall objective of this project was to determine if acoustic technology could be used to pre-sort logs for manufacturing high stiffness OSB panels. This study focuses on softwoods, specifically shortleaf pine (*Pinus echinata)* and loblolly pine (*Pinus taeda*) since they are commonly used in engineered wood products. In order to carry out the major objective, many others need to be satisfied, including:

- Verify that log stiffness contributes to OSB panel stiffness;
- Establish the effects of log stiffness on other OSB properties;
- Determine the stiffness range and percentage of high and low groups of logs entering the OSB facility;
- Investigate correlations between other physical log properties that could be easier to measure in a manufacturing setting; and
- Determine how to incorporate acoustic technology into normal manufacturing quality control operations.

HYPOTHESES

The overall hypothesis is that pre-sorting logs using acoustic technology will give manufacturers a means of optimizing their current wood use by using high quality logs for structural products. Additional hypotheses are as follows:

- Log stiffness will have no effect on OSB panel properties;
- Logs currently bought by the facility have similar stiffness;
- Log diameter or other physical properties will have a better correlation to panel properties than stiffness;
- Acoustic technology will not adjust to a manufacture-type setting; and
- Log stiffness will affect panel properties but the facility does not get a large enough percentage of high stiffness logs to utilize them for structural products.

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FIGURES AND TABLES FOR CHAPTER 1

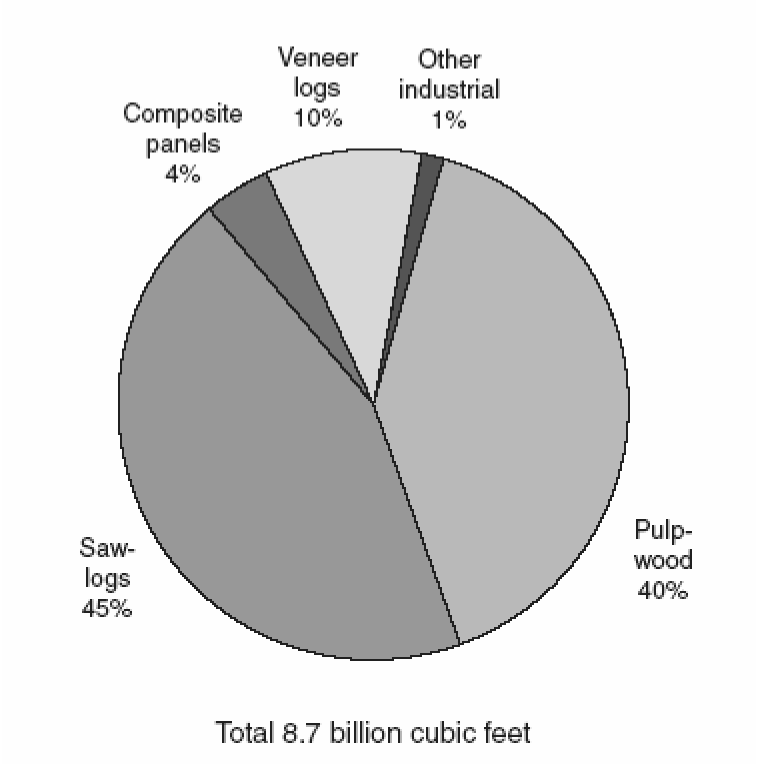


Figure 1.1. Roundwood production by type of product (Timber-Mart South 2008).

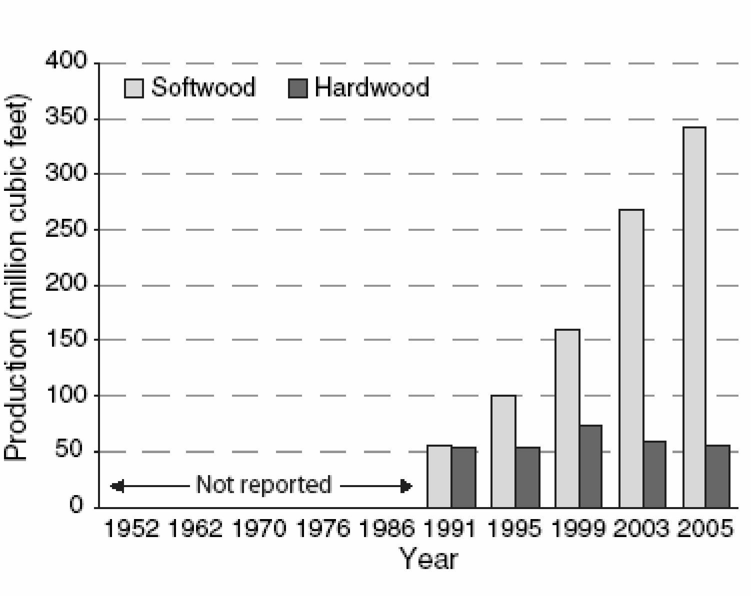


Figure 1.2. Roundwood usage for composite panel production (Johnson et al. 2008).

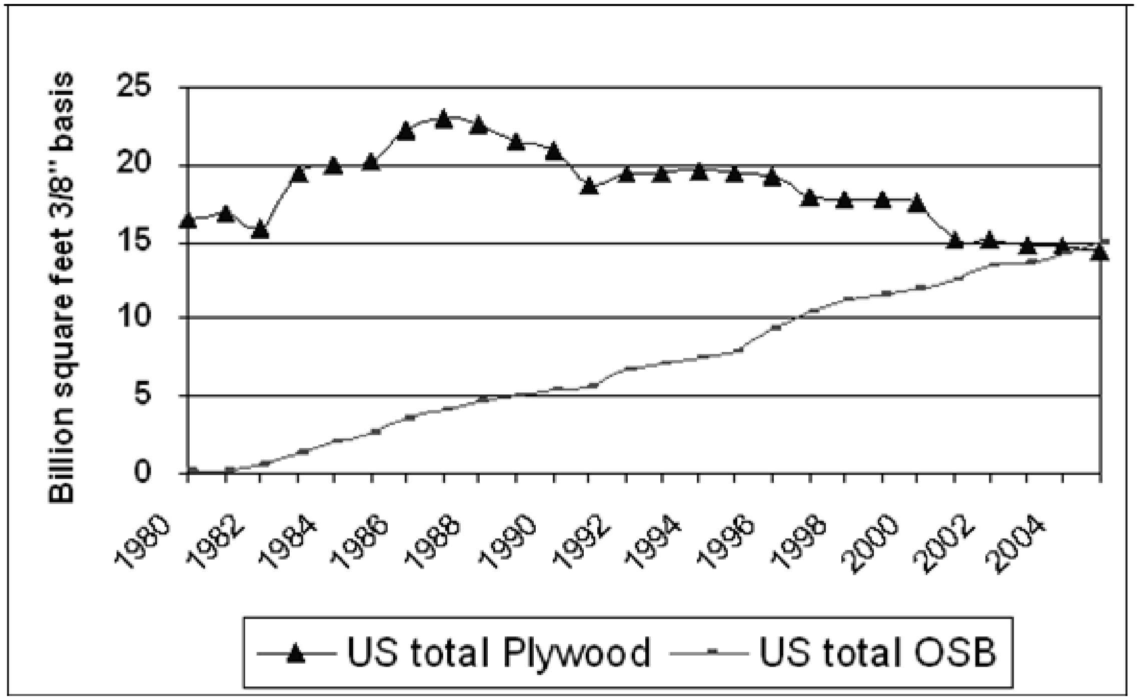


Figure 1.3. Annual US panel production from 1980 to 2006. (TimberMart-South 2008).

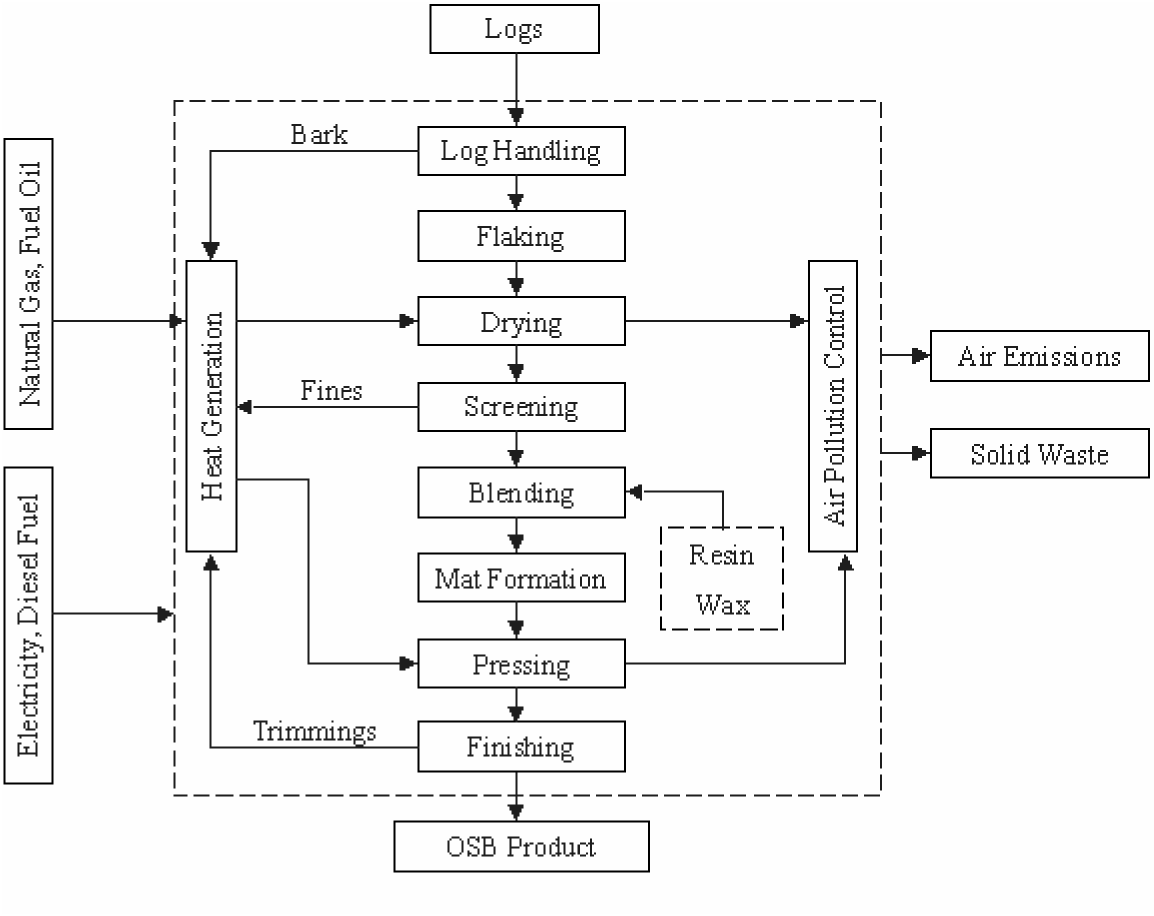


Figure 1.4. Overview of the OSB manufacturing process (Kline 2002).

Table 1.1. Table of OSB end use and span ratings (PSII 2000).

End Use	Span Rating	Thickness
Sheathing	Roof – 24	3/8"
	Roof - 24/Subfloor -16	7/16"
	Roof - 32/Subfloor -16	15/32" & 1/2"
	Roof - 40/Subfloor -20	19/32" & 5/8"
	Roof - 48/Subfloor -24	23/32" & 3/4"
Structural I	3/8 in	
	7/16 in	
	15/32 in	
	1/2 in	
	19/32 in and 5/8 in	
	23/32 in and 3/4 in	
Single Floor	Single Floor - 16	9/16"
	Single Floor - 20	19/32" & 5/8"
	Single Floor - 24	23/32" & 3/4"
	Single Floor - 32	7/8" & 1"
	Single Floor - 48	1" - 1 1/4"

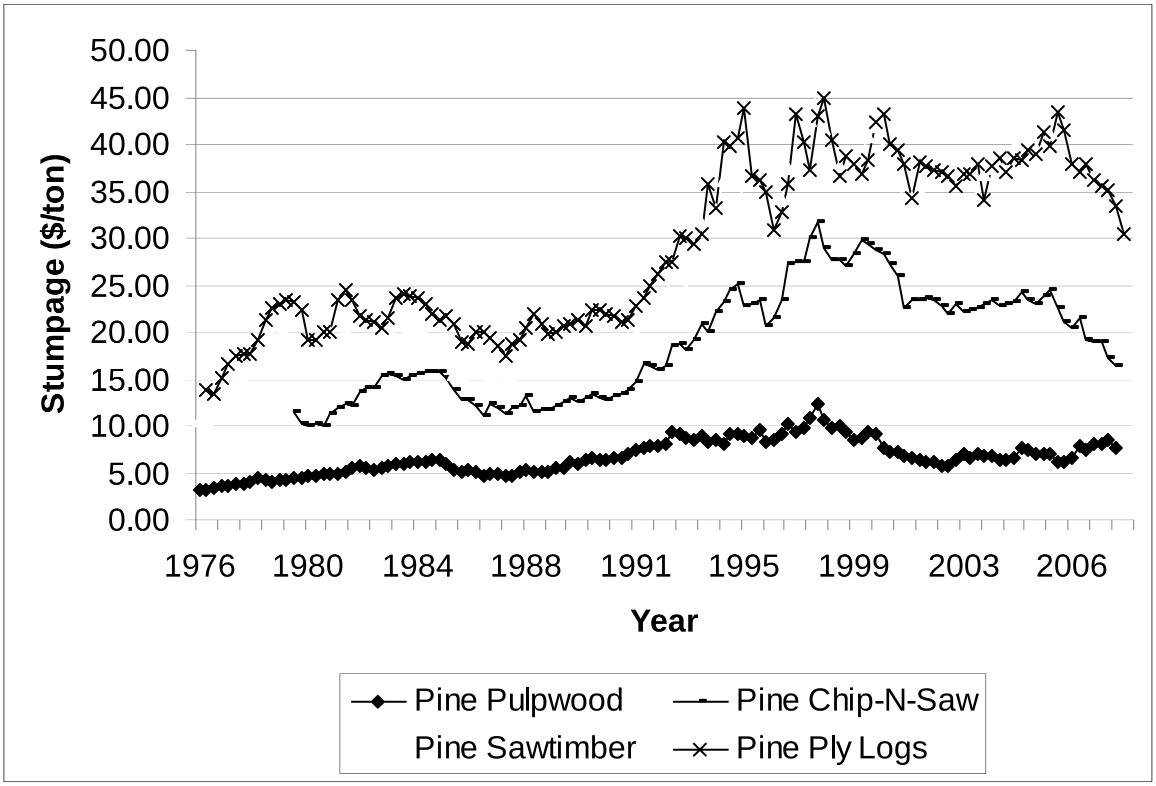


Figure 1.5. South-Eastern stumpage averages by timber type from 1976 to 2007 (Timber Mart South 2008).

Table 1.2. OSB costs for north-central mills from 2000-2006 (Spelter et al. 2006).

	% Direct Operating Cost						
	2000	2001	2002	2003	2004	2005	2006
Wood	44.8%	43.2%	42.7%	41.7%	43.5%	47.0%	46.9%
Labor	16.0%	16.0%	16.1%	14.6%	13.6%	12.2%	12.6%
Resin	14.4%	15.2%	15.3%	18.1%	17.5%	17.7%	16.6%
Wax	4.8%	4.8%	4.8%	4.9%	4.5%	4.4%	4.0%
Energy	8.8%	10.4%	9.7%	10.4%	11.0%	10.5%	10.9%
Supplies	11.2%	11.2%	11.3%	10.4%	9.7%	8.3%	8.6%

Table 1.3. Average OSB resin and wax consumption (Spelter et al. 2006).

	% OD Wood	
Resin Type	Face	Core
Powder PF	2.3	2.35
Liquid PF	3.82	3.66
PMDI	----	2.28
Wax	1.14	1.14

PF= phenol formaldehyde
PMDI= polymeric diisocyanate

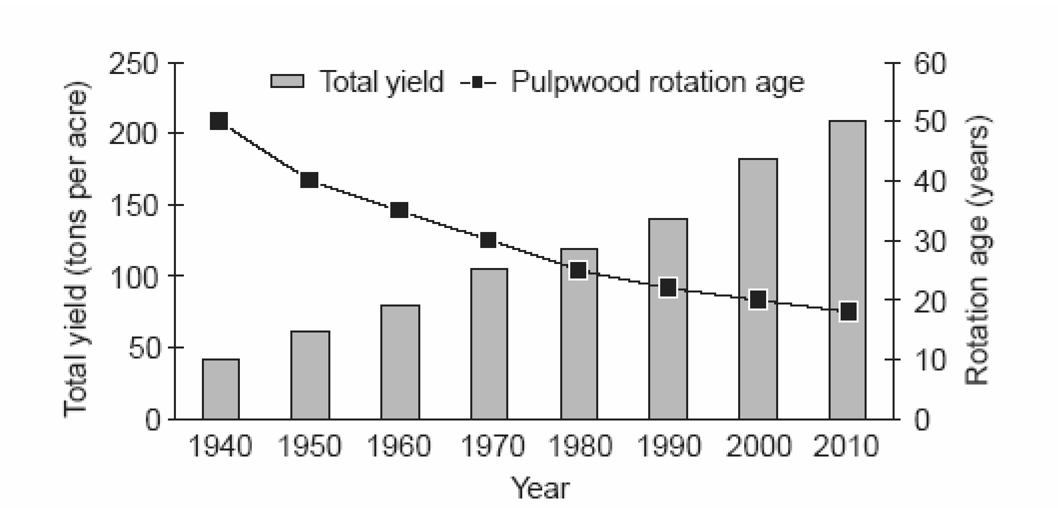
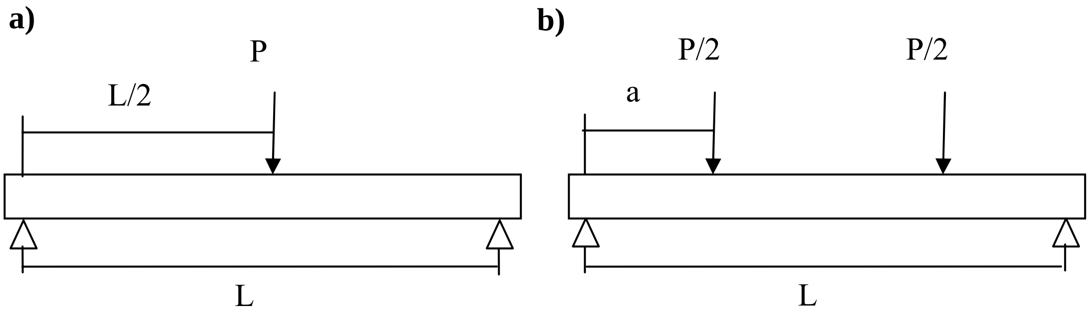


Figure 1.6. Estimated yield and rotation age in south-east pine plantations from 1940-2010 (Fox et al. 2004).



a) center point static bending:

$$\text{MOE} = \frac{PL^3}{48\delta I}$$

b) General static bending (typically used with specimens of longer length)

$$\text{MOE}= \frac{Pa(3L^2 - 4a^2)}{48\delta I}$$

L= support span
P= load
a= distance from load to support

Figure 1.7. Options for static bending testing

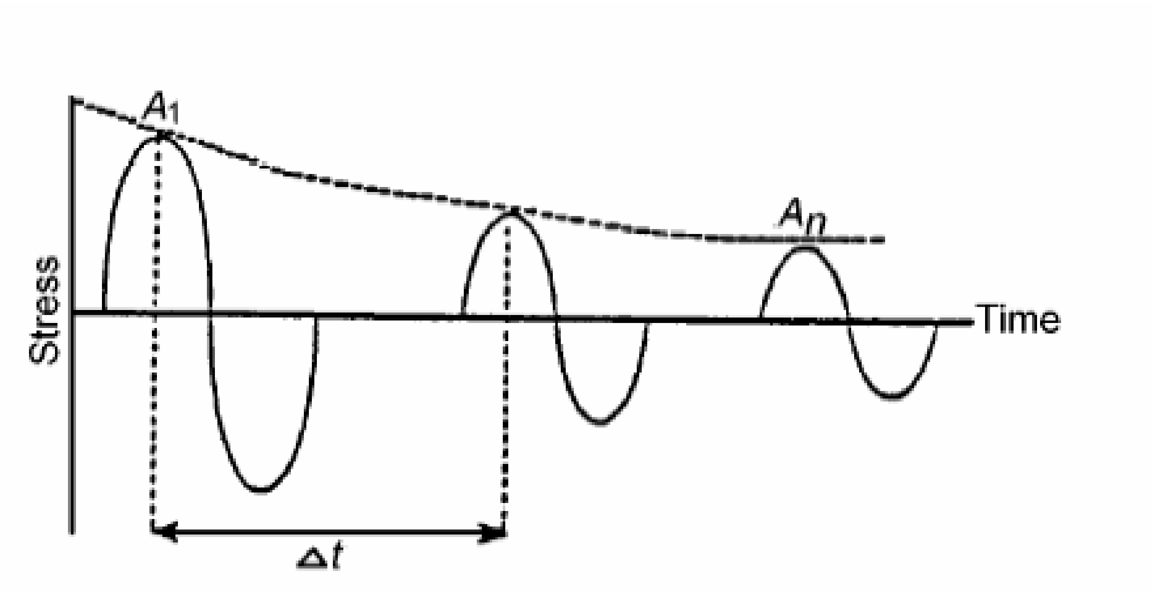


Figure 1.8. Theoretical propagating stress wave (Ross and Pellerin 1994).

Table 1.4. Proportion of sawn out-turn by sawn timber grade (Carter and Lausberg 2002).

Kopu HITMAN® trial	Proportion of sawn out-turn by sawn timber grade					
Log Grade	Utility	F4	MGP10	MGP12	MGP15	% logs in class
Red (low velocity)	12%	39%	46%	4%	0%	19
Blue (med. velocity)	4%	24%	56%	16%	0%	49
Green (high velocity)	2%	16%	55%	25%	2%	32
Unsegregated	5%	25%	54%	16%	1%	100

Table 1.5. Proportion of veneer grade (Carter and Lausberg 2002).

Veneer type	DT	DFB	DT +DFB	D
Low speed logs	3.80%	25.90%	29.70%	70.30%
Medium logs	15.30%	34.20%	49.50%	51.50%
Fast logs	51.90%	34.30%	86.20%	13.20%
Unsegregated	24.10%	32.00%	56.10%	43.90%

CHAPTER 2

EXPERIMENTAL DESIGN AND METHODS

SUMMARY OF STUDY DESIGN

Research was conducted in the southeast OK-AK area. Samples were taken from approximately 250 mile radius. All sample locations were recorded to determine if there was a site effect on log velocities (Table 2.1). Two treatments were investigated, naturally grown shortleaf pine (*Pinus echinata*) and plantation grown loblolly pine (*Pinus taeda*). Ideally, three stiffness groups (represented by high, medium, and low velocities respectively) would emerge from each growth type. Our goal was to make 7-10 OSB 4’ x 8’ x ¾” lab panels based on logs selected from each group.

BASELINE MEASUREMENTS

Baseline measurements were taken on logs from different sites to determine how velocity varied. A minimum of 30 measurements from both growth types (natural and plantation) were taken. All baseline data was compiled, keeping growth type separate, and interquartile ranges and 95% confidence intervals for the mean were calculated using Minitab Statistical Software (version 15) to determine starting points for the three groups for each growth type, and high, medium, and low velocity ranges. All measurements were in imperial units.

FIELD SAMPLING METHOD

Trucks entered the manufacturing facility and site locations along with growth type were recorded for locating velocity trends by site. A grapple load of logs (from 5-10 logs) was unloaded from the truck and set aside in a pile (the truck continued further to complete unloading as standard for the manufacturing facility). Log lengths were measured in the pile as accurately as possible, and the Director HM 200 acoustic tool used to measure velocity. Logs that fell into the desired velocity groups were marked with a sequential number. A total of 372 trees were tested for velocity from 72 trucks from 21 different counties, and 3 different states (see Table 2.1 for locations).

Logs were spread out on the ground and the same trees were measured a second time to record an accurate length. If velocity was still within one of the target groups, the tree was labeled with a color code in addition to the log number and was sampled for further testing:

- blue = high velocity natural growth
- orange = low velocity natural growth
- purple = high velocity plantation growth
- green = medium velocity plantation growth
- red = low velocity plantation growth

*note: no middle velocity group was clearly seen for the natural growth type, so only high and low groups were chosen during the initial sampling.

In addition, a random selection of logs was measured multiple times for multiple velocity readings to check repeatability of the Director HM 200 acoustic equipment. Logs that were used for further testing were sampled as follows:

- The first 4 to 6” of wood was trimmed from the butt;
- Two 1 to 2” thick disks were cut for moisture content, age, and diameter determination;
- The following 2’ was sampled for clear lumber testing; and
- 10’ bolts cut for OSB manufacture.

The above strategy was used to continuously sample up the tree.

- All disks, 2’ bolts, and 10’ bolts were labeled with a color code for sorting by velocity group, tree number relating to site of origin, and location in the tree.
- Refer to drawing below for clarification (Figure 2.1)

The 2’ bolts were sent to UGA for clear specimen lumber testing and the determination of additional wood quality data. A small sub-sample was collected from the 2’ bolts for conversion to static bending samples used for modulus of elasticity (MOE) and modulus of rupture (MOR) measurement, this data was used to create near infrared (NIR) spectroscopic calibrations for MOE and MOR which were used to predict the MOE and MOR of the remaining bolts. Both sets of disks were sent to UGA for determination of tree green moisture content, specific gravity, tree age, and butt diameter.

Trees were sampled from all velocity groups and growth types until the desired weight (approximately 3,200 lbs) was collected from the 10’ bolts. The desired weight was calculated based on the amount of material needed to manufacture a minimum of 7 4’ x 8’ x ¾” panels. A 50% waste factor was included in the calculations to compensate for the indeterminate green moisture content of the logs and the waste during each pilot plant process.

PILOT PLANT AND LAB METHODS

From the trees that were sampled a total of 85 2’ bolts were available for clear sample static bending analysis. From these 85 bolts, a 20 specimen sub-sample was selected for processing. From each a 2” thick slab was cut from bark-to-bark through the pith for processing into short-clear samples. The slabs were dried to 12 percent equilibrium moisture content (EMC) and as many short-clear samples as possible, sized 1” x 1” x 16”, were cut from the slabs. The short-clear samples were conditioned to 12 percent EMC before testing. A total of 49 short-clear samples were obtained.

An additional 65 slabs remained and from these pith to bark samples, approximately 2" tangentially x 2" longitudinally (radial dimension depended on the radius of the bolt the slab was cut from), were cut. These samples were used for NIR analysis and the prediction of MOE and MOR.

The 10' bolts were sent to the University of Maine (UM) for de-barking, stranding, and drying. Debarking was done by hand using a draw knife once the logs arrived at UM, and then the debarked logs were sprayed periodically with water to keep them from drying out prior to stranding. Stranding was completed using a Carmanah 12/48 ring strander capable of processing logs up to 13" diameter to a target flake thickness of 0.025" Flake length was targeted at approximately 6" Width was difficult to control owing to variable log diameter, so only a visual target was used (acceptable or not acceptable). Prior to drying, fines (material less than 0.125") were screened out using an Acrowood Trillium Diamond Roll screen. A Koch Bros. Low Temperature Conveyor Dryer was used to dry strands to approximately 8-10% moisture content. Strands were passed through the dryer at 340 °F at 3' per minute, giving a 3.3 min residence time for the 10' long dryer.

The strands (in approximately 50 plastic-lined Gaylord boxes) were sent to the Alberta Research Council (ARC) test facility in Edmonton, Canada for OSB manufacture. Strands were re-dried upon arrival at ARC in a hot air box dryer to 8% moisture content. After drying, strands were batch blended in a Coil blender and a liquid isocyanate resin was applied with a single atomizing head; emulsified wax was applied with an air atomization system at loadings similar to that used by Spelter et al. (2006), Table 1.3. After blending, the furnish (resinated flakes) was put in three different forming bunkers and another batch of flakes was blended while the first panels were being formed (three blends made 6-7 4' x 8' x 3/4" panels). Three layer panels were produced on a single opening hot oil press at 420 °F with the surface orientation being parallel and the core orientation perpendicular, i.e. typical orientation for OSB production. After pressing for approximately 4 minutes, panels were trimmed to final size, density was calculated, and panels were allowed to hot stack over night prior to OSB panel testing at a private testing lab.

DATA ANALYSIS

All log and full panel data analysis was performed using Minitab Statistical Software version 15 (Student edition). Dynamic stiffness (MOE) was calculated from the measured log velocities. Variables considered from the raw tree data were site location (Site), inside bark butt diameter in inches (IBD), green and basic specific gravity (GSG and BSG respectively), and tree age (age). All data was analyzed for relationships with either log velocity (V) or dynamic stiffness (DMOE). All data was analyzed using naturally and plantation grown trees as separate groups.

All NIR calibrations were created using the Unscrambler® (version 9.2) software package (Camo AS, Norway) and Standard Normal Variate (SNV) treated spectra that had been truncated to 1000-2200 nm to remove excessive noise. Partial Least Squares (PLS) regression was used for the calibrations with four cross-validation segments and a maximum of ten factors. The Unscrambler® software recommended the final number of factors to use for each calibration.

The Standard Error of Calibration (SEC) (determined from the residuals of the final calibration), the Standard Error of Cross Validation (SECV) (determined from the residuals of each cross validation phase), and the coefficient of determination (R^2) were used to assess calibration performance. Three samples were removed as outliers prior to development of the final calibrations. The samples were omitted as each failed prematurely owing to the presence of knots. Once calibrations for MOE and MOR were developed they were used to predict the MOE and MOR of the cross section samples.

Variables considered from measured panel properties were full panel stiffness, planar shear, fastener holding capability, small sample strength, small sample stiffness, dimensional stability, internal bond, water absorption and edge thickness swell, vertical density profiles, and axial compression. All property data was analyzed for relationships with the log velocity groups and differences in properties by group.

FIGURES AND TABLES FOR CHAPTER 2

Table 2.1. Origin of logs sampled for this study.

	County	State
Natural	Arkansas	Arkansas
	Bowie	Texas
	Caddo	Louisianna
	Cass	Texas
	Clark	Arkansas
	Columbia	Arkansas
	Hot Springs	Arkansas
	Howard	Arkansas
	Lafayette	Arkansas
	Leflore	Oklahoma
	McCurtain	Oklahoma
	Montgomery	Arkansas
	Nevada	Arkansas
	Ouachita	Arkansas
	Pushmataha	Oklahoma
	Scott	Arkansas
	Stevens	Arkansas
	Washita	Arkansas
Plantation	Clark	Arkansas
	Hempstead	Arkansas
	Howard	Arkansas
	Leflore	Oklahoma
	McCurtain	Oklahoma
	Okolona	Arkansas
	Ouachita	Arkansas
	Polk	Arkansas
	Pushmataha	Oklahoma
	Washita	Arkansas

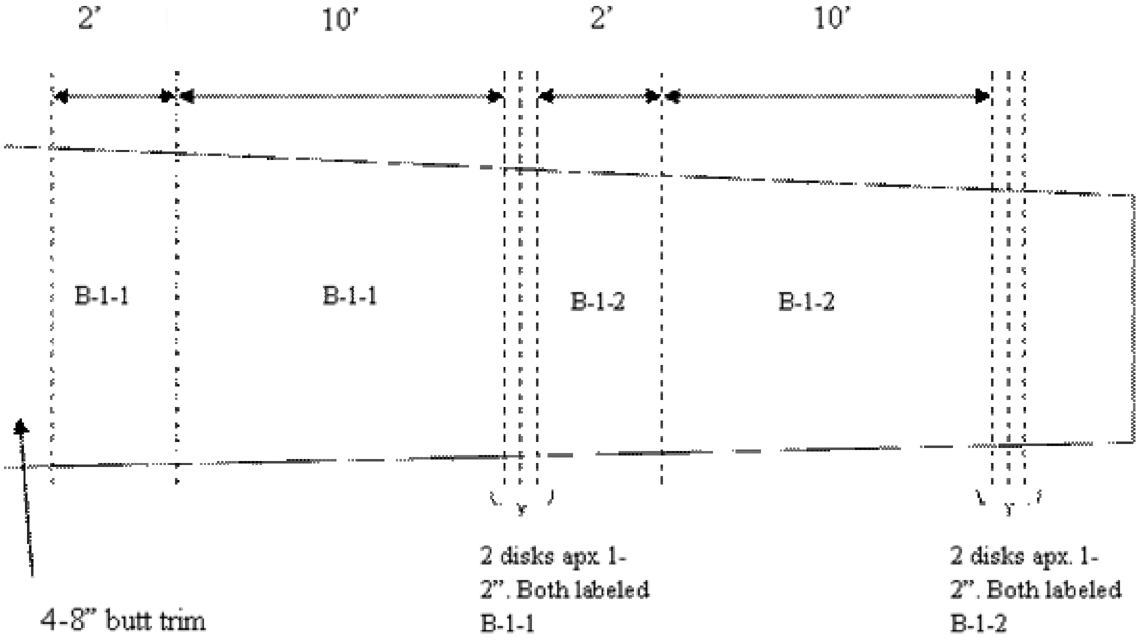


Figure 2.1. Sampling locations for each log.

CHAPTER 3

LOG DATA RESULTS

OBJECTIVE

Initial log velocity was analyzed (excluding moisture content effects) to determine if there was a correlation between log velocity and site location. The raw tree data was collected to give an indication of log quality by means of specific gravity and green density. The data was further analyzed to investigate relationships between velocity and other physical log properties that could be easier to measure in a manufacturing setting. Variables considered from the raw tree data were site location (Site), inside bark butt diameter in inches (IBD), green and basic specific gravity (GSG and BSG respectively), tree age (age), and velocity in feet/second (V). Dynamic stiffness in psi (DMOE) was calculated from the velocity measurements, where:

$$\mathrm{DMOE} = V^2 * \rho \ (\mathrm{lb/ft.}^3) \qquad [3.1]$$

V – log velocity (ft./sec)

ρ – disk green density (lb/ft.^{3})

$$\rho = \mathrm{MC} * \mathrm{BSG} \qquad [3.2]$$

MC – moisture content

$$\mathrm{MC} = (\text{green weight-oven dry weight})/\text{oven dry weight} \qquad [3.3]$$

BSG - basic specific gravity

$$\mathrm{BSG} = \text{Oven-dry weight} / \text{green volume} \qquad [3.4]$$

The 2’ bolts were collected to provide clear specimens for static bending tests, but owing to financial and time constraints, along with equipment malfunction, only a small sub-sample from each velocity group could be tested. To obtain test data for all samples NIR analysis was conducted on the static bending samples to get a prediction equation for static MOE and MOR, then the rest of the bolts from each velocity group were scanned using NIR and the prediction equations were used to predict MOE and MOR.

METHODS

Log Velocity Methods

Log length was measured and then the acoustic velocity of the logs was determined using the Director HM 200 (refer to Figure 3.1). Approximately 30 random logs were used to check the repeatability of the HM 200 throughout the sampling period. Results determined the tool was more than adequate for the ranges of velocities being sampled. Specimens were selected based on pre-set velocity groups (established from baseline data), then cut according to our sampling plan. Discs taken from the base of the log were used to estimate tree age (based on a ring count). For each disc inside bark diameter, green volume and green weight were also measured. Disks were oven dried at 120 °F for 72 hours and their oven dry volume and weights determined. Specific gravity, moisture content, and green density were calculated from each disk according to formulas 3.2-3.4. For each property whole-tree averages were calculated and used for all data analysis. Groups were assigned based on velocity ranges according to Table 3.1.

NIR Methods

From the trees that were sampled a total of 85 bolts were available for static bending analysis. From these 85 bolts 20 were selected for processing. From each a 2” thick slab was cut from bark-to-bark through the pith for processing into short-clear samples. The slabs were dried to 12 percent equilibrium moisture content (EMC) and as many short-clear samples as possible, sized 1” x 1” x 16”, were cut from the slabs. The short-clear samples were conditioned to 12 percent EMC before testing. A total of 49 short-clear samples were obtained.

An additional 65 slabs remained and from these pith to bark samples, approximately 2” tangentially x 2” longitudinally (radial dimension depended on the radius of the bolt the slab was cut from), were cut. These samples were used for NIR analysis and the prediction of MOE and MOR.

Determination of wood properties

The 1” x 1” x 16” short-clear samples were tested at 12 percent EMC over a 14” span with center loading and pith up on a Tinius Olsen static bending machine following the procedures for alternate sample size under ASTM D-143 (ASTM 1980). A continuous load was applied at a head speed of 0.07” per minute, rather than 0.05” per minute to reduce test time. After testing, each sample was oven dried at 217 ˚F, and specific gravity was calculated based on specimen dimensions at 12 percent EMC and oven-dry weight. Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated using procedures outlined in ASTM D-143 (ASTM 1980).

Near infrared spectroscopy

After the static bending tests were completed a single diffuse reflectance NIR spectrum was collected from one end, i.e. the cross-sectional surface, of each short-clear sample using an Analytical Spectral Devices (ASD) AgriSpec® spectrometer fitted with a fiber optic probe system (the aperture of the window was 0.8”). Care was taken to ensure that the end of the sample used was clear of defects. The spectra were collected at 1 nm intervals over the wavelength range 350-2500 nm.

Using the same spectrometer NIR spectra were collected from the cross-sectional surface of the 65 samples cut from the ends of the remaining slabs. Adjacent spectra were collected from these samples starting from the bark side of the sample and moving toward the pith. As many spectra as possible were collected from each individual sample, giving 177 in total.

PLS calibrations for the prediction of MOE and MOR

All calibrations were created using the Unscrambler® (version 9.2) software package (Camo AS, Norway) and Standard Normal Variate (SNV) treated spectra that had been truncated to 1000-2200 nm to remove excessive noise. Partial Least Squares (PLS) regression was used for the calibrations with four cross-validation segments and a maximum of ten factors. The Unscrambler® software recommended the final number of factors to use for each calibration.

The Standard Error of Calibration (SEC) (determined from the residuals of the final calibration), the Standard Error of Cross Validation (SECV) (determined from the residuals of each cross validation phase), and the coefficient of determination (R^2) were used to assess calibration performance. Three samples were removed as outliers prior to development of the final calibrations. The samples were omitted as each failed prematurely owing to the presence of knots. Once calibrations for MOE and MOR were developed they were used to predict the MOE and MOR of the cross section samples.

RESULTS

Log Velocity Results

Trees from ten plantation sites were assessed with the number of logs measured varying among sites and dependent on how many trucks were sampled from each location. Sampling was random with trucks sampled as they arrived at the plant. Most sites exhibited the full range of log velocities for plantation trees. Figure 3.2 gives a summary of velocities for the measured plantation trees. The minimum velocity measured was 6,562 ft./sec. with a maximum of 14,731 ft./sec. and an average of 9,403 ft./sec. Plotting the log velocity data against the sites showed that location did not appear to affect log velocity (Figure 3.3).

The natural sites showed similar results (Figure 3.4). The minimum velocity measured was 6,411 ft./sec. with a maximum of 14,961 ft./sec. and an average of 9,994 ft./sec. Of the 17 locations measured, almost all showed the full range of log velocities (Figure 3.5).

The log property data was very similar for plantation and natural grown trees (Table 3.2). Plantation grown trees gave average green moisture contents from 80 to 152% with average specific gravities of 0.365 to 0.526 (average 0.447). The average plantation tree age was 20 years (ranging from 13 to 28) with an average butt diameter of 8.39" The average moisture content for natural logs ranged from 62 to 157% with specific gravities of 0.381 to 0.587 (average of 0.460). The average age of the natural trees was 28 years, with the youngest being 12 and the oldest 45 years. Butt diameters ranged from 5.9 to 13.9 inches with an average of 8.5 inches.

NIR Results

MOE and MOR calibration

MOE and MOR calibrations were created using PLS regression and NIR spectra obtained from the cross-sectional surface of the 46 short-clear samples. The calibrations were then applied to a separate set of 177 NIR spectra (collected from the cross-sectional surface of the radial samples cut from the ends of prepared slabs).

The MOE and MOR calibrations are shown in Figure 3.6. Both wood properties gave strong relationships with coefficients of determination (R^2) of 0.84.

ANALYSIS

Log Velocity Analysis

Green moisture content, specific gravity, age, inside bark butt diameter, and log length were all analyzed by group for each growth type to determine physical differences between each group (Table 3.3 and 3.4). Green moisture content data had a lot of variability, but no statistical differences were detected between groups (Figure 3.7). Differences were detected between all plantation groups for specific gravity (Figure 3.8); and between group 1 and the other two plantation groups for butt diameter (Figure 3.9). Differences were seen between group 6 and groups 4 and 5 in the natural stands for average moisture content (Figure 3.10) and basic specific gravity (Figure 3.11).

The relationships between physical properties and velocity were analyzed (Table 3.5). The plantation grown trees had a negative relationship between velocity and IBD, while velocity was correlated to the average BSG and the average MC in trees from the natural stands.

Regression analysis was conducted to determine if the correlations between velocity and the various variables were significant. A step-wise regression was conducted using velocity as a response and all the variables as predictors to ensure no relationships were missed. Regression analysis of the plantation grown trees gave the same results as the correlation analysis, with IBD being the only significant variable, but the fit was poor when only IBD was used with an R^2 of 18.6%. Figure 3.12 shows the plot of IBD against velocity with the regression line fit of velocity = 12563 - 302 * IBD. The stepwise regression of the natural data showed no significant variables, so a regression was run again using only the variables deemed significant by the correlation analysis, BSG and MC. Using both variables in a regression neither had significant p-values, so a third regression was performed using each of the two variables separately. Natural growth BSG was shown to have a 21.3% fit to the line velocity = 1017 + 18229 Avg. BSG

(Figure 3.13). Moisture content resulted in a regression fit of 26.5% to the line velocity = 14599 - 4646 Avg. MC, shown in Figure 3.14.

All of the analysis described in this section was repeated using stiffness (DMOE) as the response instead of velocity to ensure no additional relationships were present due to the addition of moisture content to the basic velocity data. Analysis resulted in the same relationships, so it was not presented. The regression equations are listed in Table 3.6.

NIR Analysis

The NIR calibration was used to predict static MOE for the remaining 2' bolts. Multiple scans were taken from bark to pith, MOE was calculated using the calibration, then the MOE's were weighted by location from the bark to give bolt MOE averages. Some of the 2' bolts were missing due to small top diameter, so not all bolts were read. Most of the missing bolts were tops from trees sampled, so calculating a total tree average MOE would be skewed to favor those that only contained one sample bolt, so all analysis was conducted using bolt averages instead of tree averages. Figure 3.15 shows the weighted NIR MOE predictions by stiffness group. A positive trend can be seen between MOE and stiffness group in both the natural and plantation groups, but ANOVA gave a high p-value indicating no significant difference between the groups. Both the plantation and naturally grown groups had a few data points that could potentially be outliers, but more sampling would be necessary to determine if that was the case. No trend was detected between predicted MOR and stiffness group (Figure 3.16).

DISCUSSION

Velocity differences were not detected between plantation and naturally grown trees. In addition the velocity groups had very similar low, medium, and high ranges, and statistical analysis showed no significant differences. However, in order to decrease as much variability as possible, the groups were kept separate for all analysis conducted. A correlation analysis was conducted on log velocity and site location to determine if certain sites had low quality logs, but no trends were detected. No trends were seen in the plantation or the naturally grown trees, so site could not be used as an indicator for log quality in any way. Relationships between basic log properties such as moisture content, specific gravity, diameter inside bark, age, and log length with log velocity were examined with the aim of using these properties as possible indicators of log quality. A few correlations were seen, but all had poor R^2, so could not potentially be used as quality indicators.

When determining the quality of logs entering a manufacturing site, velocity groups can be used for simplicity and to save labor. Studies should be conducted to determine the range of velocities entering the facility and what the ranges for high, medium, and low need to be for quality purposes. Seasonal variation is going to show an effect on velocity due to significantly different moisture contents of incoming material, so studies should also be done under different seasonal conditions to determine what effects exist. Studies could probably be limited to two seasonal settings based on temperature and rainfall and depending on the location of the facility. One problem using velocity groups instead of determining green moisture content and calculating stiffness is that if logs are not delivered to the manufacturing facility soon after harvest, velocity is not going to be a good indicator in comparison to logs that have been felled and delivered in a timely fashion.

In a manufacturing setting, a sampling frequency must be determined based on site location, variability of incoming material, seasonal variation effects on incoming material, and material turnover rates. If there incoming material variability is low, it might not be financially viable to invest in the additional labor associated with periodically sampling material for quality.

However, if some of the material is extremely low quality, even if it is only a small portion of the raw material, it could cause a significant amount of downgrade to the final product and a small investment to identify the low quality material could be beneficial. If there is a large amount of variation in the raw material, it would be advisable to complete a few studies on what the incoming variation actually is, if there is a relationship between site and the low or high quality material, and what an adequate sampling plan would be to identify and reject or separate the low quality material. Each manufacturing facility is going to be different, but the cost associated with using a tool such as the HM 200 for determining log quality is very small. Current forestry trends are to grow trees faster on short rotations (Fox et al. 2004), so any indicator of raw material quality is going to be a benefit to those facilities receiving low quality, fast grown trees.

A lot of variation was seen in the basic log properties such as moisture content and specific gravity, but none of the variables evaluated correlated very well with velocity. This could be due to the location and size of the wood basket. The area is known for low quality material (Jordan et al. 2008). For a plant that is operating in a region of higher quality wood, e.g. the coastal plain (see Figure 3.17), residual material available to an OSB facility could show quite different trends in velocities and basic log properties. In addition, studies need to be conducted at several mills across the south, or other regions, to provide comparative velocity data to accompany the small area sampled in this study.

The NIR analysis appeared to be a good predictor of static MOE and MOR but did not work as well for the dynamic MOE. Dynamic MOE was calculated on a whole log basis whereas the NIR was using 2' bolts to predict static MOE. Whole tree NIR MOE and MOR averages were not calculated because some bolts were missing. A further investigation using NIR would be beneficial to simply and quickly determine dynamic MOE dynamic MOE.

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FIGURES AND TABLES FOR CHAPTER 3

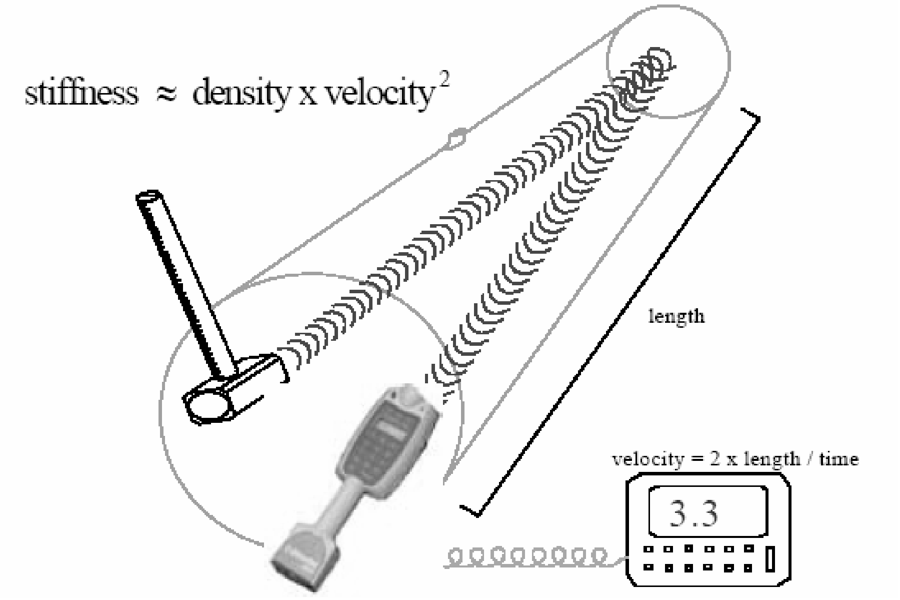
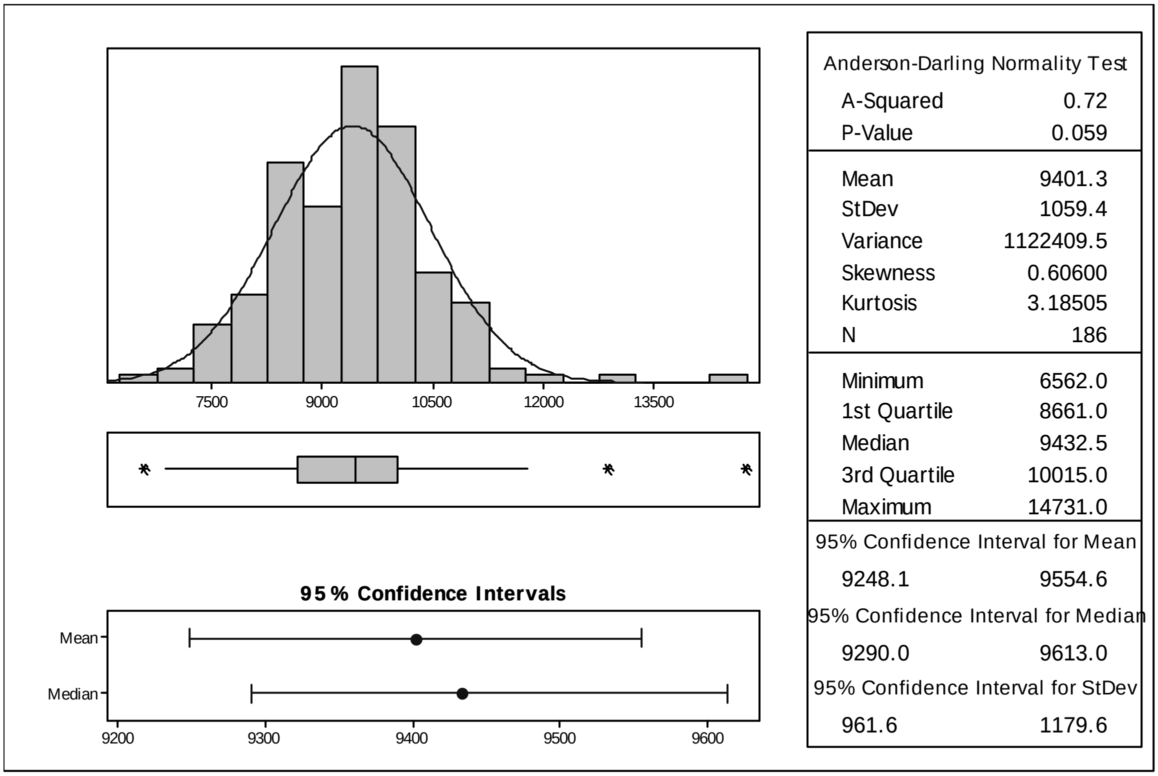


Figure 3.1 Acoustic tool and method. (Carter, P., 2007).

Table 3.1. Summary of measured velocities.

growth	color code	Stiffness group	velocity min (ft/sec)	velocity max (ft/sec)	# trees
plantation	red	1	7480	8957	7
	green	2	9416	11089	11
	purple	3	11122	14731	9
natural	orange	4	7054	8432	13
	NA	5	8530	10827	3
	blue	6	11089	14961	7



Anderson-Darling Normality Test	
A-Squared	0.72
P-Value	0.059
Mean	9401.3
StDev	1059.4
Variance	1122409.5
Skewness	0.60600
Kurtosis	3.18505
N	186
Minimum	6562.0
1st Quartile	8661.0
Median	9432.5
3rd Quartile	10015.0
Maximum	14731.0
95% Confidence Interval for Mean	
9248.1	9554.6
95% Confidence Interval for Median	
9290.0	9613.0
95% Confidence Interval for StDev	
961.6	1179.6

Figure 3.2. Plantation log velocity summary.

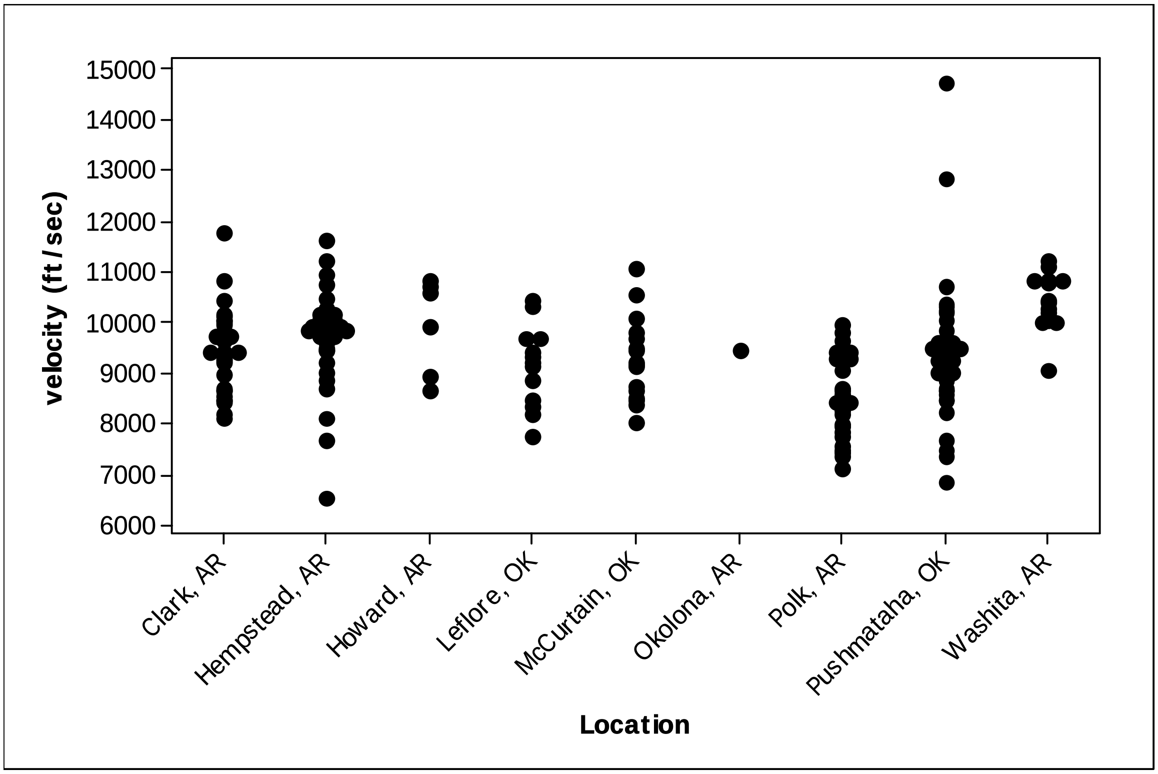
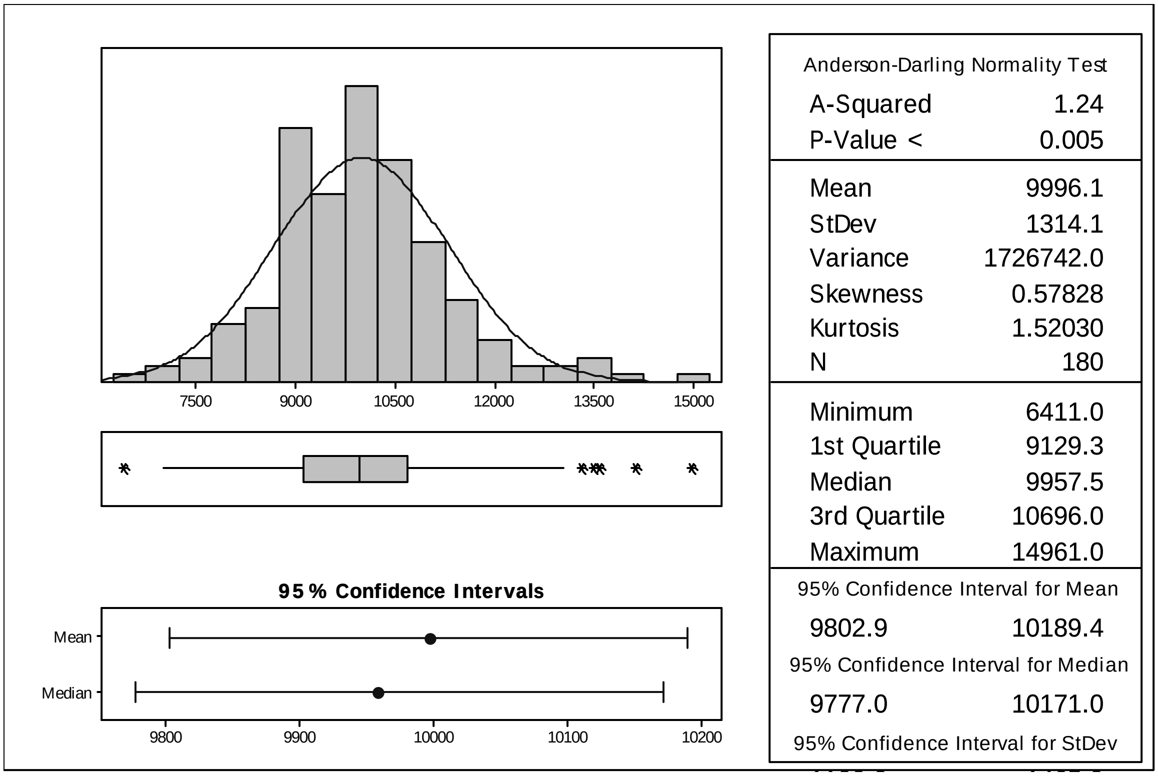


Figure 3.3. Plantation grown log velocities versus site location.



Anderson-Darling Normality Test	
A-Squared	1.24
P-Value <	0.005
Mean	9996.1
StDev	1314.1
Variance	1726742.0
Skewness	0.57828
Kurtosis	1.52030
N	180
Minimum	6411.0
1st Quartile	9129.3
Median	9957.5
3rd Quartile	10696.0
Maximum	14961.0
95% Confidence Interval for Mean	
9802.9	10189.4
95% Confidence Interval for Median	
9777.0	10171.0
95% Confidence Interval for StDev	

Figure 3.4. Natural log velocity summary.

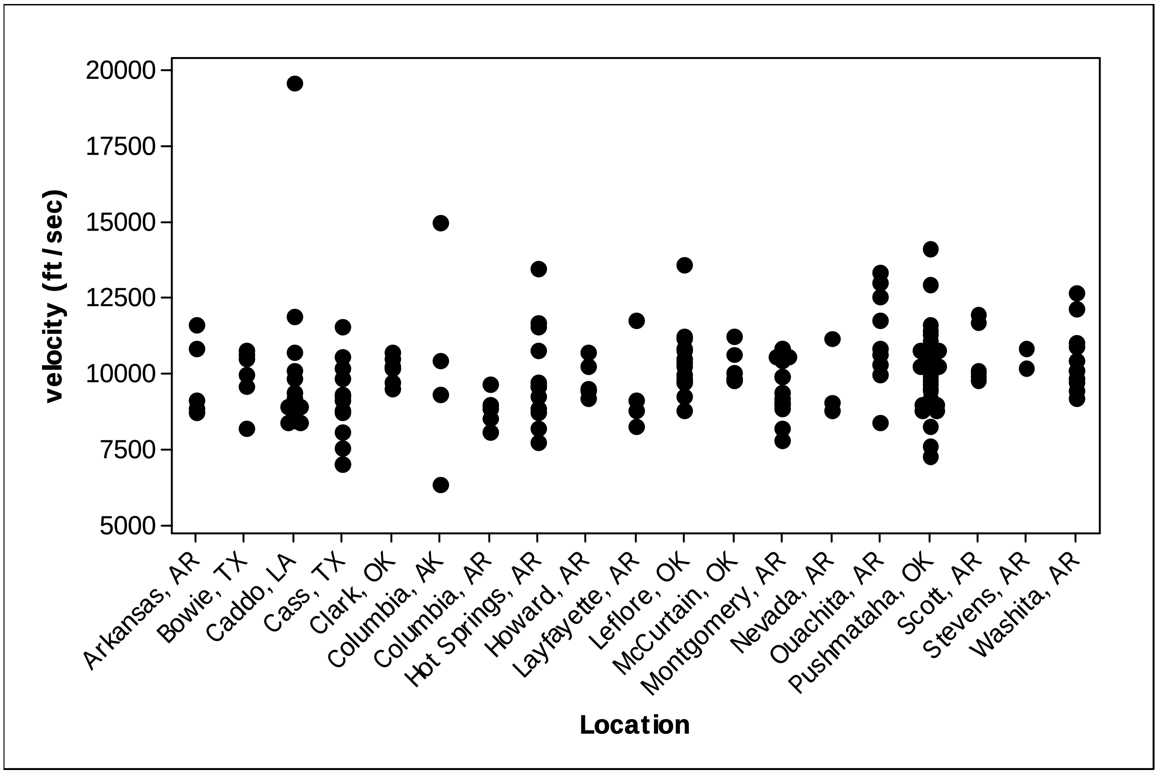
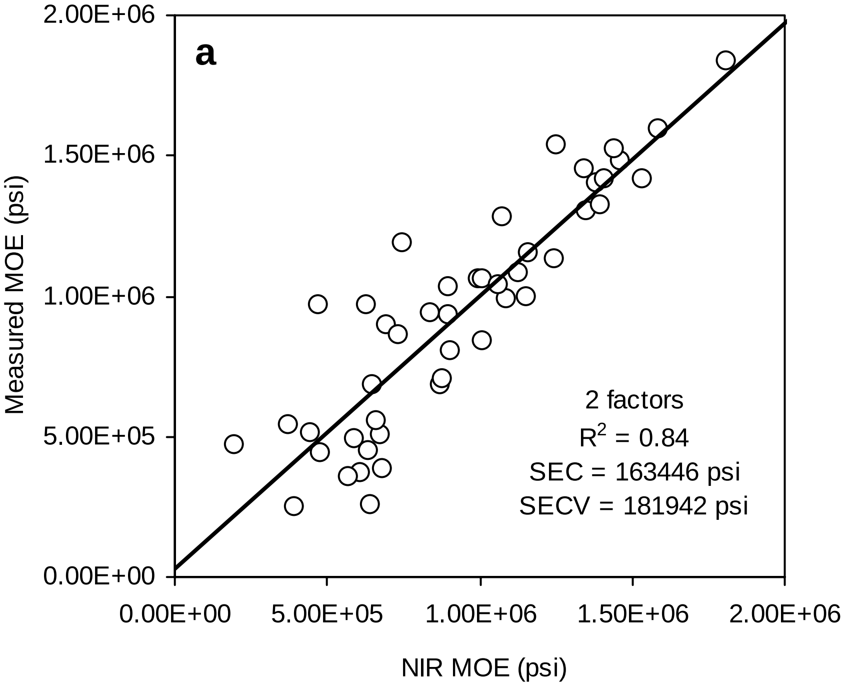


Figure 3.5. Naturally grown log velocities versus site location.

Table 3.2. Summary of physical properties.

Growth Type	Variable	Avg.	Min	Max
Plantation	Tree MC	------	80%	152%
	BSG	0.447	0.365	0.526
	Tree Age	20	13	28
	IBD	8.39	4.7	13.7
	Length	38.8	17.1	52.7
Natural	Tree MC	------	62%	157%
	BSG	0.460	0.381	0.587
	Tree Age	28	12	45
	IBD	8.58	5.9	13.5
	Length	31.4	15.9	52.1



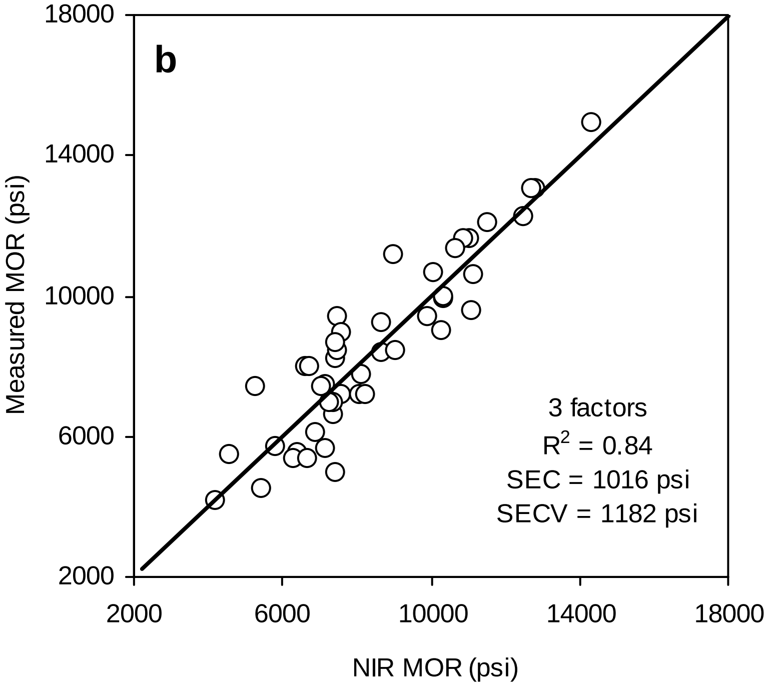


Figure 3.6. Relationships between measured values and NIR-estimated values for (a) modulus of elasticity (MOE) and (b) modulus of rupture (MOR). Calibrations were developed using 46 NIR spectra collected from the ends of short clear samples.

Table 3.3. Descriptive statistics for average moisture content (Avg. MC), average basic specific gravity (Avg. BSG), age, butt diameter (IBD (in.)), and length for plantation grown groups.

Variable	Velocity Group	Mean	StDev	Min	Median	Max	p-value
Avg. MC	1	1.2106	0.2031	0.8772	1.1660	1.5188	0.055
	2	1.0175	0.1470	0.8029	1.0259	1.2180	
	3	1.0415	0.1710	0.8532	1.0213	1.3801	
Avg. BSG	1	0.4204	0.0341	0.3864	0.4122	0.4676	0.013
	2	0.4441	0.0325	0.3645	0.4531	0.4764	
	3	0.4767	0.0421	0.3985	0.4874	0.5262	
Age	1	20.25	1.669	17.000	20.500	22.000	0.162
	2	19.00	2.757	13.000	19.000	23.000	
	3	22.11	5.130	14.000	22.000	28.000	
IBD	1	10.349	2.521	6.811	10.197	13.740	0.020
	2	7.777	1.784	5.591	7.795	11.772	
	3	7.419	2.270	4.724	7.598	11.220	
Length	1	40.57	6.80	30.50	40.75	52.67	0.781
	2	38.57	7.32	29.42	36.92	49.17	
	3	37.56	11.88	17.08	35.75	49.17	

Table 3.4. Descriptive statistics for average moisture content (Avg. MC), average basic specific gravity (Avg. BSG), age, butt diameter (IBD (in.)), and length for natural stand groups.

Variable	Velocity Group	Mean	StDev	Min	Median	Max	p-value
Avg. MC	4	1.2363	0.1541	1.0282	1.2673	1.4540	0.010
	5	1.1190	0.3890	0.8880	0.9010	1.5680	
	6	0.8992	0.2231	0.6187	0.8827	1.2525	
Avg. BSG	4	0.4333	0.0469	0.3807	0.4153	0.5325	0.010
	5	0.4554	0.0455	0.4075	0.4606	0.4980	
	6	0.5117	0.0541	0.4410	0.5050	0.5872	
Age	4	24.15	11.49	12.00	17.00	42.00	0.141
	5	33.00	12.49	19.00	37.00	43.00	
	6	34.00	9.04	21.00	36.00	45.00	
IBD	4	8.455	2.271	5.906	8.268	13.504	0.228
	5	10.59	2.210	8.11	11.30	12.360	
	6	7.964	1.936	6.220	6.890	11.811	
Length	4	27.45	7.35	15.92	25.50	38.50	0.106
	5	42.28	9.27	33.67	41.08	52.08	
	6	30.87	14.84	0.00	36.42	44.33	

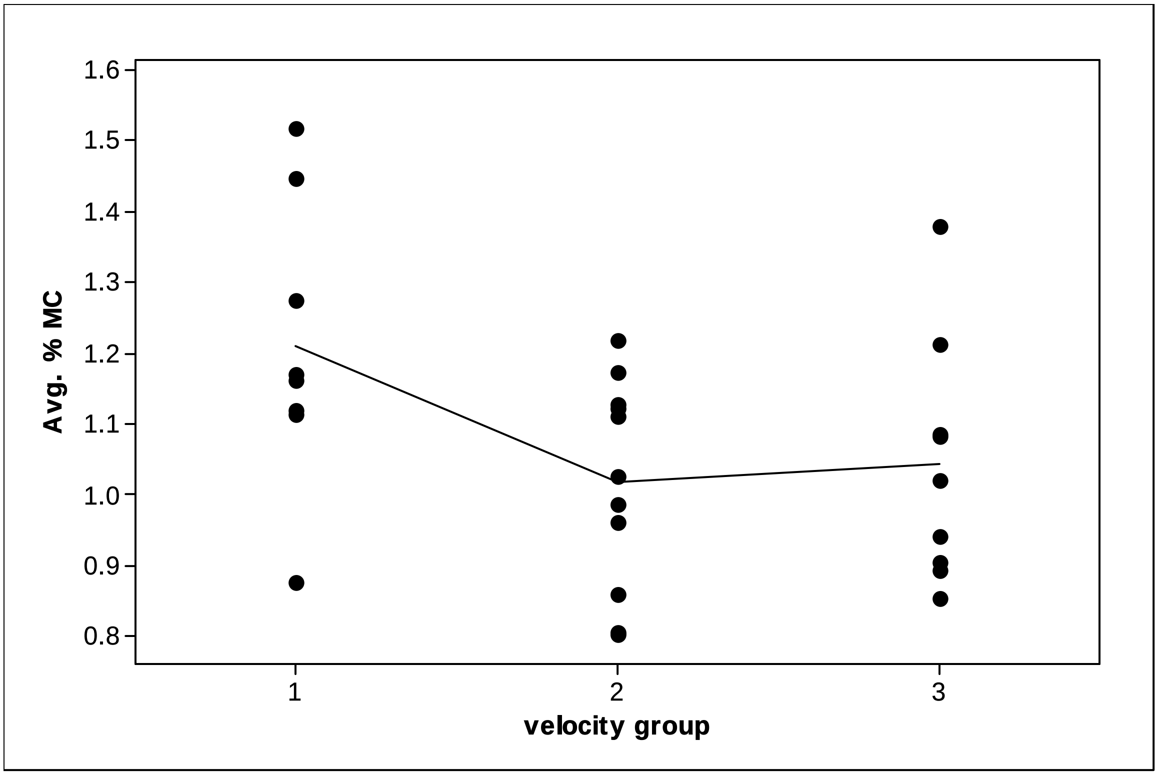


Figure 3.7. Plot of average green moisture content by group for plantation grown trees.

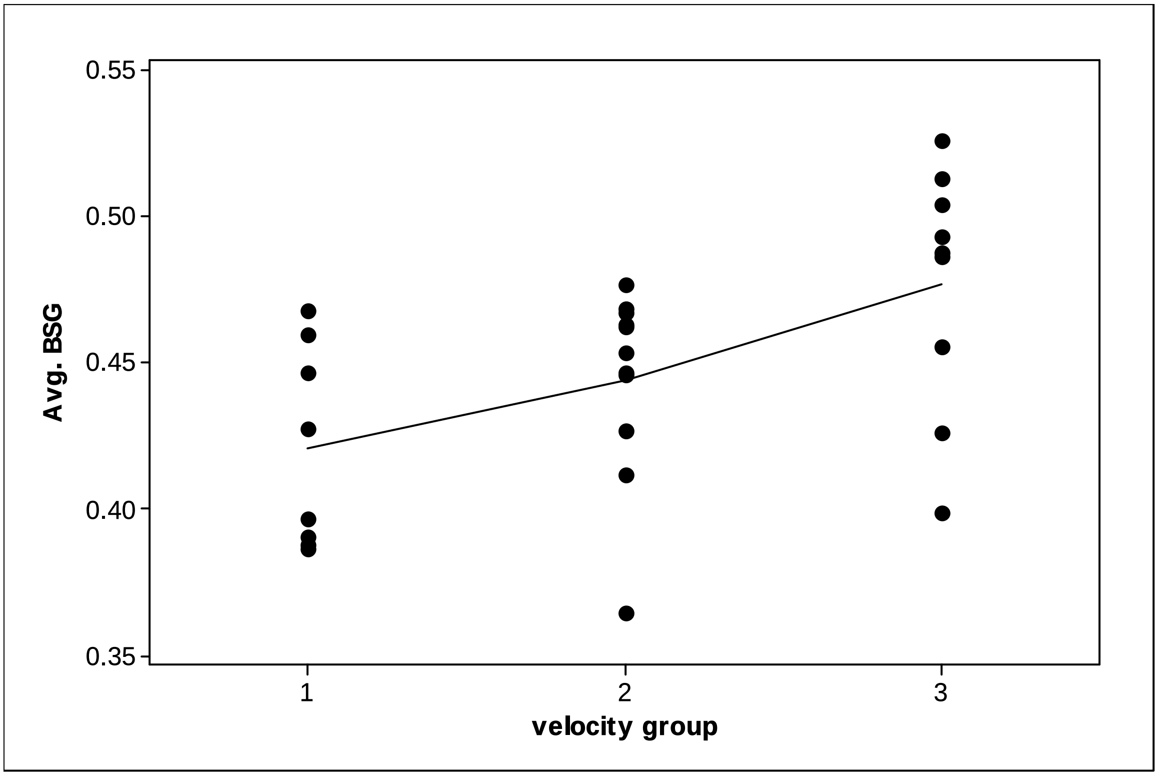


Figure 3.8. Plot of average basic specific gravity by group for plantation grown trees.

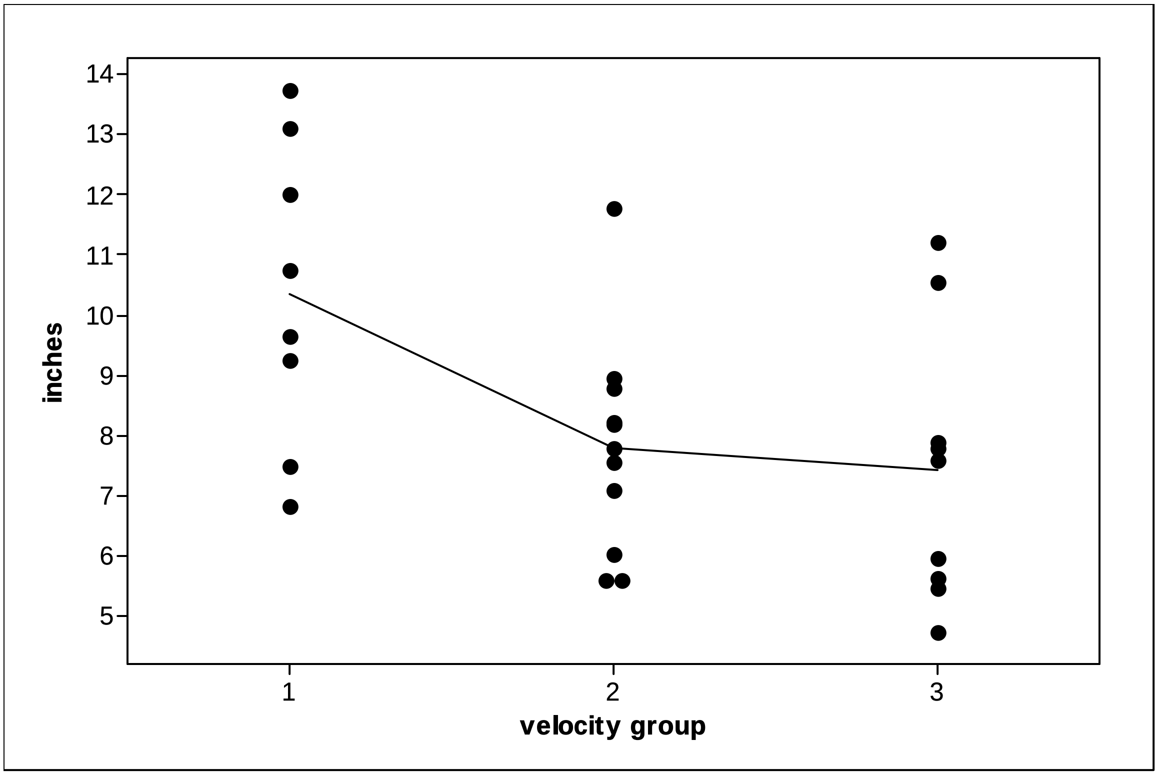


Figure 3.9. Plot of average butt diameter (inches) by group for plantation grown trees.

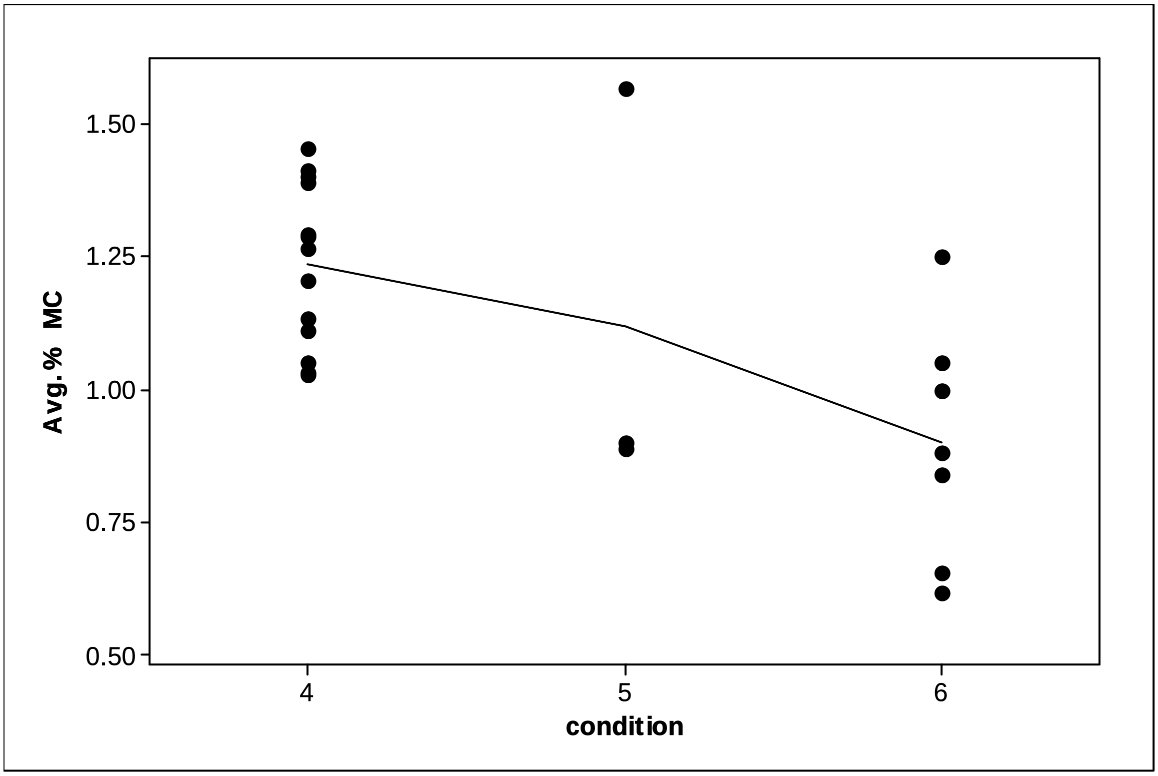


Figure 3.10. Plot of average green moisture content by group for natural grown trees.

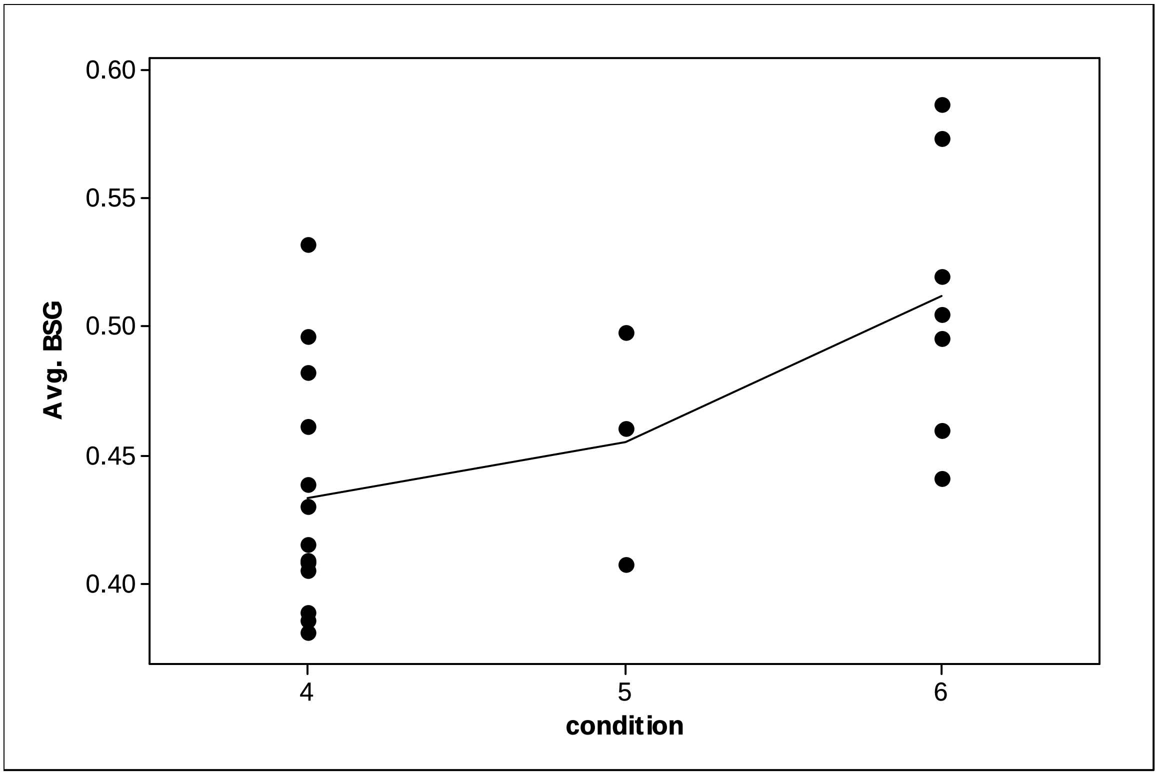


Figure 3.11. Plot of average basic specific gravity by group for natural grown trees.

Table 3.5. Correlations between length, age, avgerage basic specific gravity (Avg. BS), average moisture content (Avg. MC), diameter inside bark (IBD (in.)), and velocity for, A) plantation grown trees and B) trees grown in natural stands.

A) Results for: plantation grown trees

	Length	Age	Avg. BSG	avg. MC	IBD (in)
Age	0.423				
	0.025				
Avg. BS	0.116	0.551			
	0.557	0.002			
Avg. MC	0.253	-0.040	-0.528		
	0.193	0.839	0.004		
IBD (in)	0.246	-0.013	-0.456	0.639	
	0.207	0.950	0.015	0.000	
Velocity	-0.325	-0.123	0.293	-0.347	**-0.465**
	0.092	0.532	0.130	0.070	**0.013**

B) Results for: naturally grown trees

	Length	Age	Avg. BSG	avg. MC	IBD (in)
Age	0.407				
	0.054				
Avg. BS	0.343	0.423			
	0.109	0.044			
Avg. MC	-0.363	-0.293	-0.893		
	0.089	0.175	0.000		
IBD (in)	-0.166	0.085	-0.240	0.395	
	0.448	0.701	0.269	0.062	
Velocity	0.181	0.348	**0.499**	**-0.546**	0.025
	0.407	0.104	**0.015**	**0.007**	0.911

*note: Cell Contents: Pearson correlation
P-Value

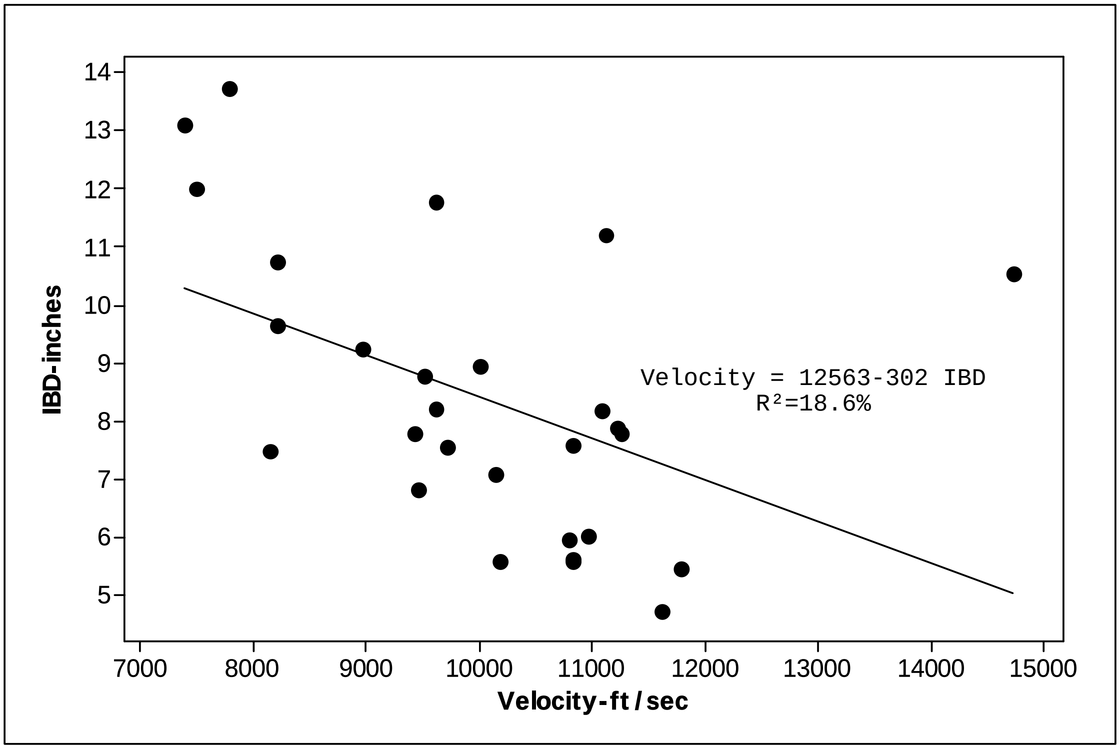


Figure 3.12. Plot of inner bark diameter versus velocity with regression fit- Plantation grown trees.

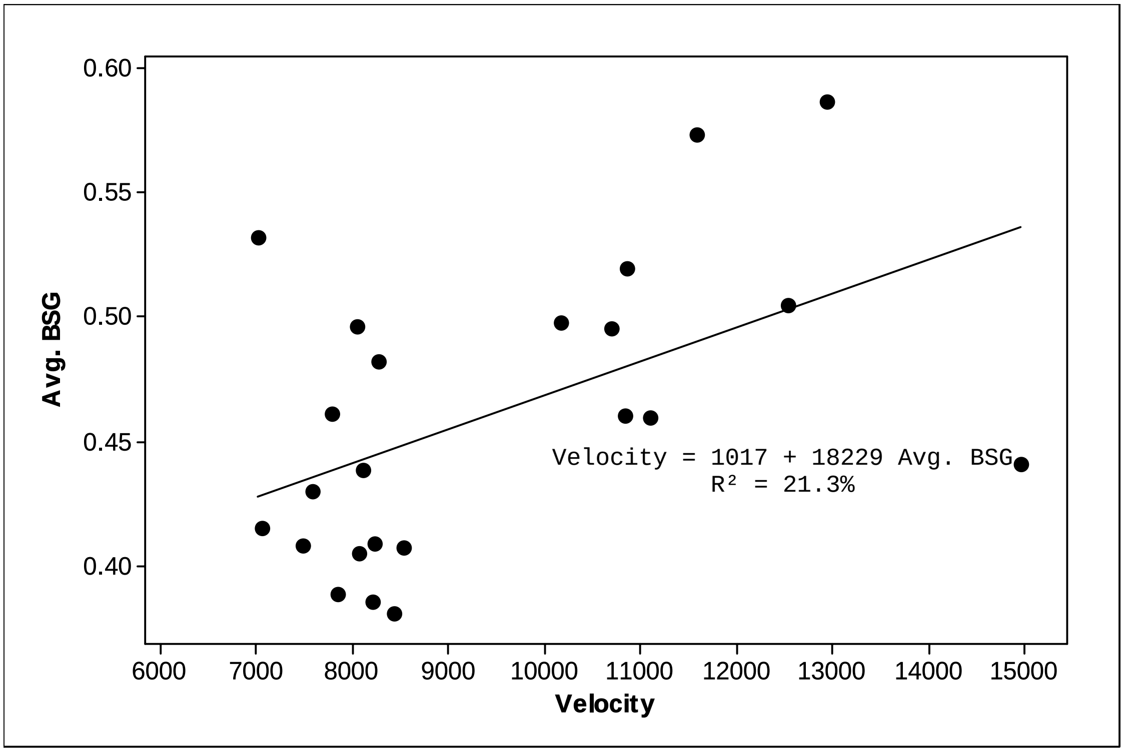


Figure 3.13. Plot of basic specific gravity versus velocity with regression fit – Naturally grown trees.

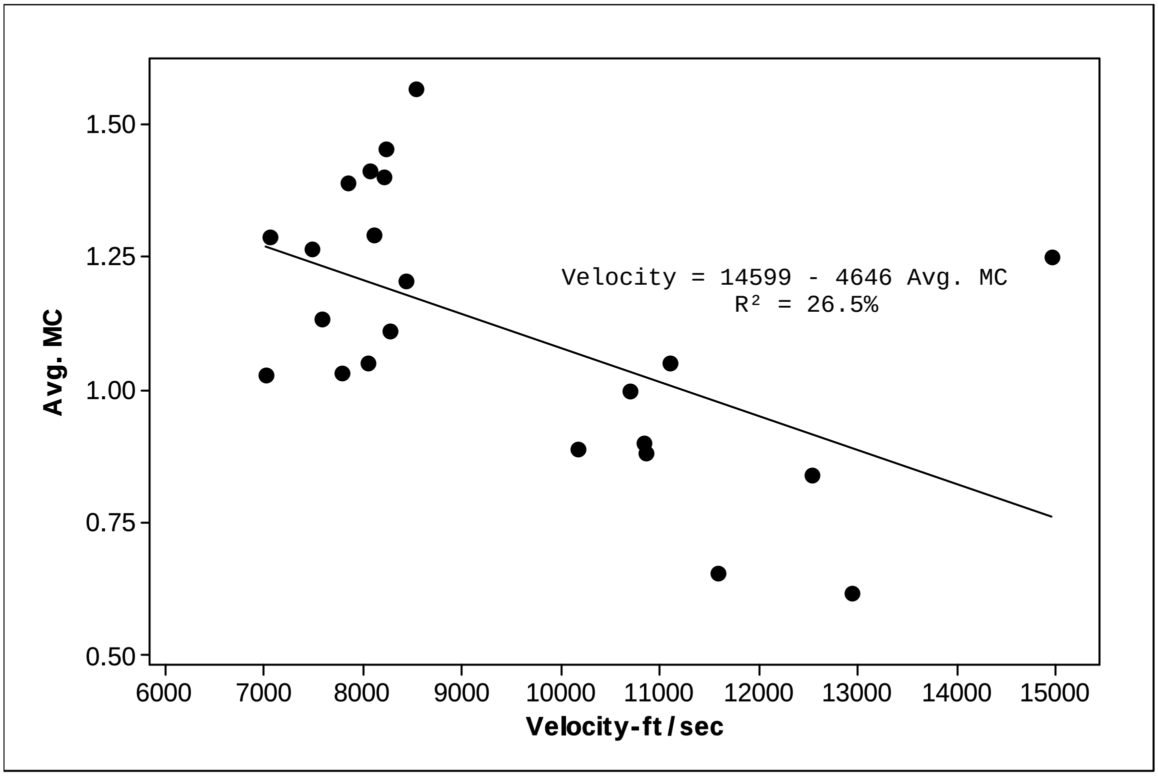


Figure 3.14. Plot of avg. moisture content vs. velocity with regression fit – Naturally grown trees.

Table 3.6. Regression results for log stiffness.

Growth Type	Regression Equation
Plantation	Stiffness = 1779006 - 59193 Butt D (in) R^2 = 7.7%
Natural	Stiffness = - 1097397 + 5016747 Avg. Basic Sp Gr-N R^2 = 20.6%
	Stiffness = 2505959 - 1158223 Avg. MC-N R^2 = 20.1%

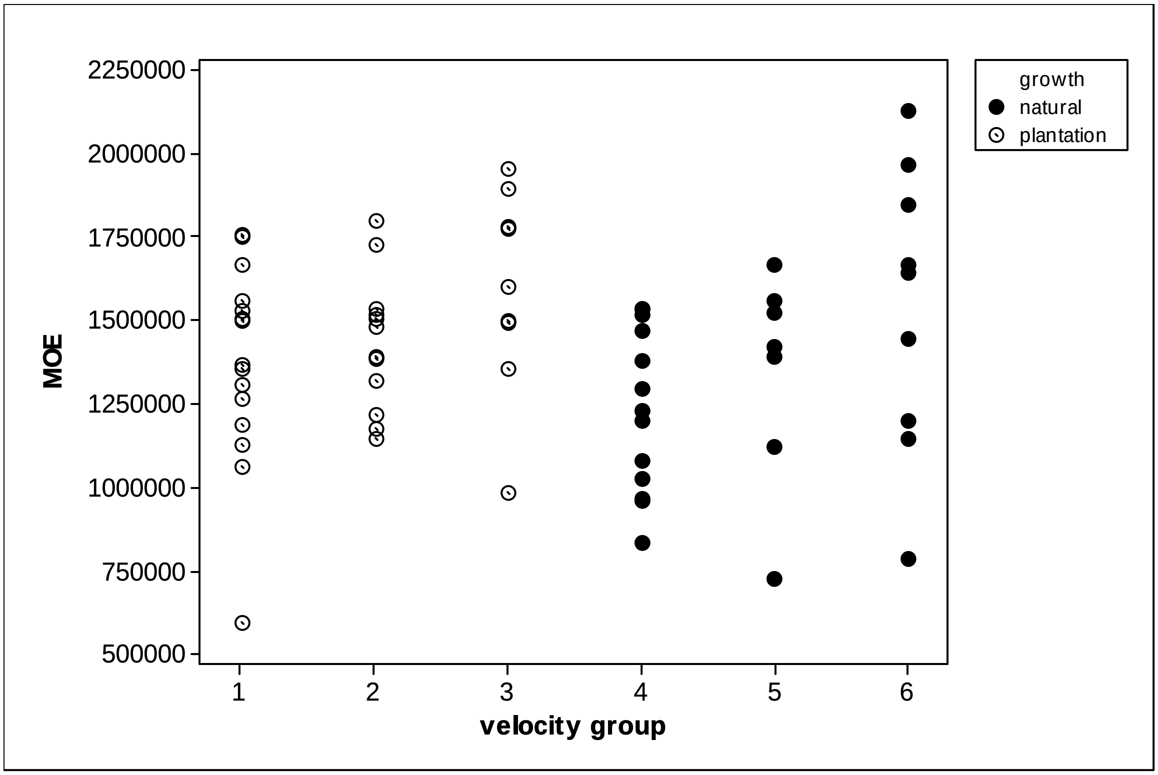


Figure 3.15. Weighted NIR MOE predictions by velocity group.

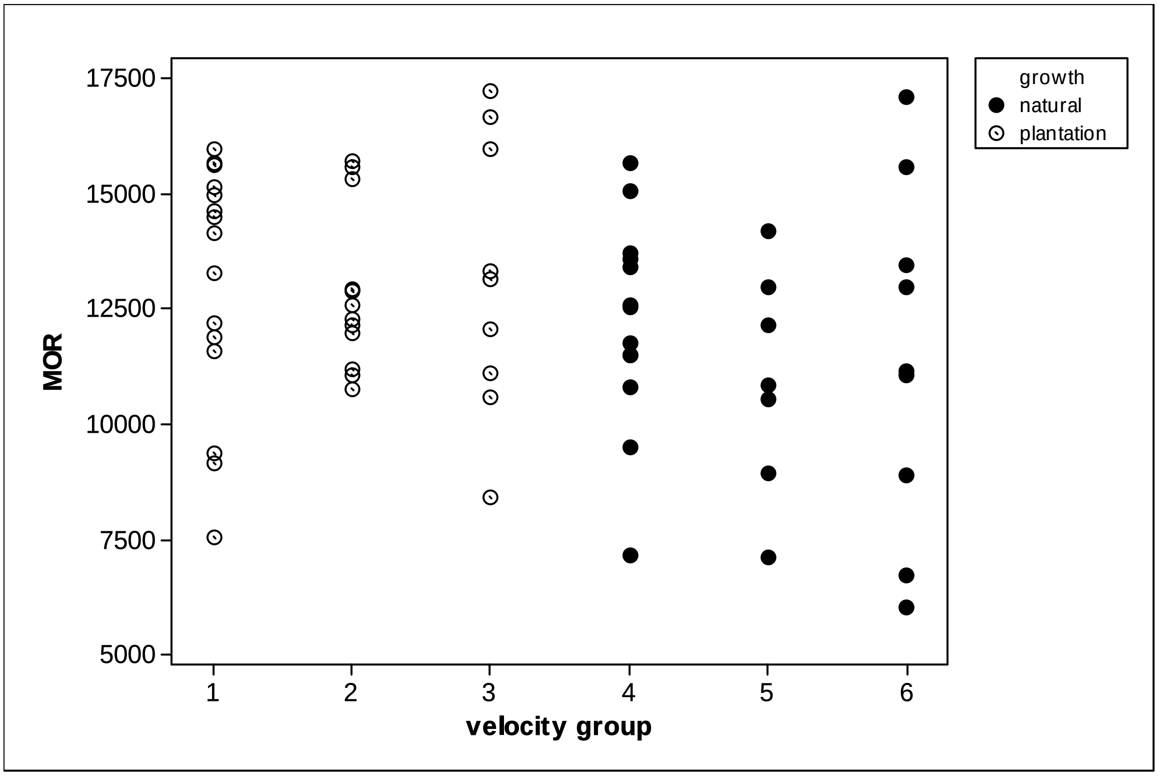


Figure 3.16. Weighted NIR MOR predictions by velocity group.

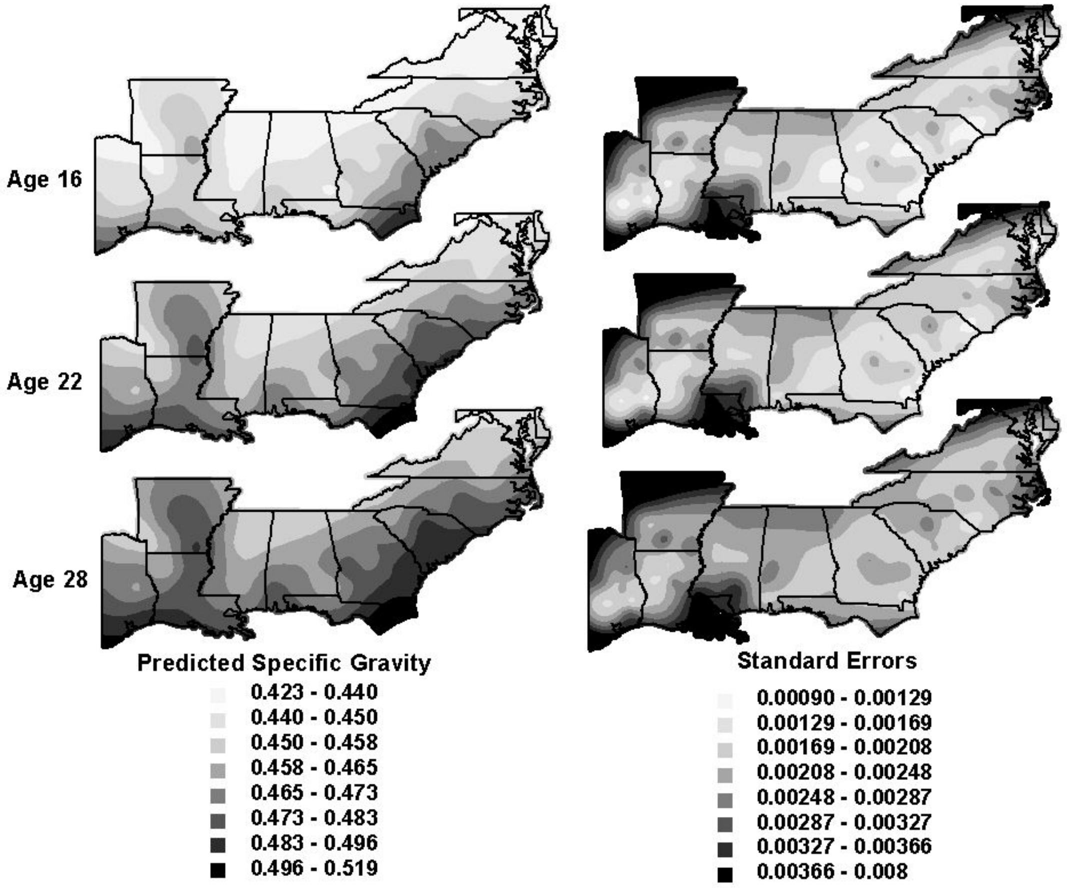


Figure 3.17. Plot of whole stand specific gravity and corresponding standard errors of trees at age 16, 22, and 28 for the southeast region (Jordan et al. 2008).

CHAPTER 4

OSB PANEL RESULTS

OBJECTIVE

The major objective of this study was to determine if acoustic technology could be used to pre-sort logs for manufacturing high stiffness OSB products. In order to fulfill this objective, it was necessary to first verify that log stiffness contributed to OSB panel stiffness (EI). We also investigated the effects of log stiffness on other OSB properties such as dimensional stability (LE), water absorption (WA and ES), planar shear (INSC), fastener holding ability (NW), internal resin bonding (IB), compression (EA), and small sample strength and stiffness (MOR and MOE) respectively.

METHODS

As described in Chapter 3 logs were shipped to the University of Maine in Bangor, ME for debarking, flaking, and drying. Acoustic log velocities and green log data were used to determine stiffness groups and these were used instead of the original velocity groups. Each stiffness group was flaked, screened, and then dried at the same time to keep the different groups separate and labeled correctly.

The flakes were then shipped to Alberta Research Council in Edmonton, Canada for OSB panel manufacture. Upon arrival at ARC, the flakes were re-dried to appropriate moisture contents prior to panel manufacture. Manufacturing parameters are shown in Table 4.1. A stiffness group was dried overnight, then blended in multiple batches so it was not possible to keep track of which panels came from which logs.

Panels were testing according to Table 4.2. Properties evaluated were full panel stiffness in both the parallel and perpendicular strength directions (Panel flexure-QL-3), planar shear in both the parallel and perpendicular strength directions (induced nominal shear capacity-INSC or Fs), fastener holding capability (nail withdrawal-NW), small sample bending for strength and stiffness (MOE and MOR respectively along with FbS), dimensional stability parallel and perpendicular (linear expansion-LE), resin holding/internal bond (IB), water absorption and thickness swell on edge (ABS and TS respectively), vertical density profile, and parallel and perpendicular axial compression (FcA).

FULL PANEL RESULTS

Full panel bending, panel flexure, was tested according to ASTM D 3043 method C (2000). A summary of the results by stiffness group is shown in Table 4.3. Group 1, the low stiffness plantation growth group, gave parallel EI values from 423,683 to 507,755 with an average of 468,460 lb-in²/ft. In comparison, group 4, the low stiffness natural growth group gave parallel EI values from 353,406 to 476,419 with an average of 437,345 lb-in²/ft. The high stiffness groups had similar performance with an average of 511,802 lb-in²/ft. (range of 454,787 to 558,726) for plantation grown trees and an average of 519,783 lb-in²/ft (range from 400,182 to 596,165) for naturally grown trees. Perpendicular EI results were similar for the plantation and natural growth groups. The middle stiffness groups of the parallel and perpendicular EI groups of both growth types had slightly higher averages than the other groups with higher minimum and maximum values. Figure 4.1 shows a scatter plot of the parallel data by stiffness group and perpendicular results are shown in Figure 4.2.

SMALL SAMPLE RESULTS

Small sample test averages are shown in Table 4.4.

Planar shear was tested using the five point bending method according to ASTM 2718 (2000). A summary of the results by stiffness group is shown in Table 4.5. Plantation grown group averages in the parallel machine direction ranged from 1,585 to 1,701 to 1,534 lbf for low, medium, and high stiffness groups respectively (Figure 4.3). Test results for the naturally grown stiffness groups were slightly higher with parallel averages from 1,671 to 1,625 to 1,591 lbf for low, medium, and high stiffness groups (Figure 4.3). Perpendicular results were similar with averages for plantation grown trees ranging from 1,781 to 1,805 to 1,847 lbf and the naturally grown trees from 1,688 to 1,797 to 1,698 lbf for the low, medium, and high stiffness groups respectively (Figure 4.4).

Fastener holding capability was tested using the nail withdrawal method with 8d bright common nails from ASTM D 1037 (1999). A summary of test results is given in Table 4.6 and the corresponding scatterplot is shown in Figure 4.5. Testing resulted in similar averages and large standard deviations for all groups in both the plantation and the naturally grown groups. Results ranged from 150.5 to 102.5 lbf/in. (low stiffness plantation and middle stiffness natural respectively) with standard deviations of up to 40.2 lbf/in (medium plantation).

Small sample bending was tested according to ASTM D 3043 (2000) method D: three-point bending using an MTS universal test machine. Refer to Table 4.7 for the summary of results and Figures 4.6 to 4.13 for scatterplots of parallel and perpendicular strength and stiffness results.

Plantation grown trees resulted in parallel small sample stiffness of 1.045 x 10^6 psi, with 441,042 in*lbf EI for the low log stiffness group, a MOE of 1.193 x 10^6 psi, with an EI of 503,311 in*lbf for the middle group, and a MOE of 1.224 x 10^6 psi with a EI of 516,767 in*lbf for the high log stiffness group. Naturally grown trees had similar parallel small sample stiffness with 1.023 x 10^6 psi, with 431,950 in*lbf EI for the low log stiffness group, a MOE of 1.208 x 10^6 psi, with 509,773 in*lbf EI for the middle group, and 1.278 x 10^6 psi MOE with an EI of 539,283 in*lbf for the high log stiffness group.

Perpendicular small sample stiffness ranged from 396,382 psi (167,224 in*lbf EI) to 355,637 psi (150,035 in*lbf EI) for plantation grown trees, and 360,575 (152,118 in*lbf EI) to 341,855 psi (144,221 in*lbf EI) for the low and high log stiffness groups respectively. Strength results were similar for all groups with high standard deviations for both the naturally grown and the plantation grown trees.

The low stiffness plantation group resulted in a parallel MOR of 7,657 psi with an FbS of 8,614 lbf*in; the high stiffness group resulted in a MOR of 8,196 psi (9,221 lbf*in FbS) with the middle group resulting in a MOR of 8,444 psi and a FbS of 9500 lbf*in and standard deviations ranging from 1,543 to 887 psi and 1,736 psi to 997 lbf*in FbS for the low and high groups respectively. The low stiffness naturally grown trees showed a parallel MOR of 7,535 psi with an FbS of 8,477 lbf*in. The middle log stiffness group resulted in a MOR of 7,734 psi (8,477 lbf*in FbS) with the high stiffness group resulting in a MOR of 8,031 psi (9,035 lbf*in FbS) with similarly high standard deviations (980 1,427 psi for low and high groups).

Dimensional stability was tested in the parallel and perpendicular strength axis using the linear expansion wet/redry method of PSII (2004). None of the samples in either machine direction were above the expansion limit of 0.5%. The parallel direction resulted in 0.174% to 0.190% expansion for the plantation groups and 0.190 to 0.195% in the natural growth groups (low to high stiffness groups). The results are shown in Table 4.8 with scatterplots given in Figure 4.14 and 4.15 for the parallel and perpendicular axis respectively.

Resin bond was tested using the internal bond method from ASTM D 1037 (1999). Plantation groups showed results from 80.4 psi in the low stiffness group to 98.2 psi in the middle group to 91.8 psi in the high stiffness group. The naturally grown trees resulted in IB's ranging from 89.5 psi to 87.5 psi to 87.9 psi for low, middle, and high stiffness groups respectively. The results are shown in Table 4.9 with a scatterplot given in Figure 4.16.

Water properties were evaluated using the 24 hour water soak/oven dry method in ASTM D 1037 (1999). Results are shown as water absorption and thickness swell. All groups and growth types were very similar. The summary is shown in Table 4.10 with scatterplots in Figures 4.17 and 4.18 for WA and TS respectively.

The vertical density profile was evaluated to determine density variations throughout the panels. Each panel was tested in 6 locations, then each panel in a stiffness group was averaged, and finally each stiffness group was plotted to look for visual differences in vertical panel densities. Figure 4.19 shows the graph of plantation grown stiffness groups and Figure 4.20 shows the naturally grown groups.

Axial compression was tested according to ASTM D 1037 (2000). All groups, tested in both parallel and perpendicular directions, had very similar and very high results. Parallel compression results ranged from 29,432 to 32,170 lbf/in for low and high stiffness plantation grown trees and 30,415 to 31,022 lbf/in for the naturally grown low and high stiffness groups while compression in the perpendicular direction resulted in 23,071 to 20,772 lbf/in and 21,892 to 19,949 lbf/in. See Table 4.11 for a summary of test results and Figures 4.21 and 4.22 for parallel and perpendicular scatterplots.

ANALYSIS

The log stiffness groups were used for all analysis to give indications of the relationships between high, medium, and low log stiffness effects on panel properties. Relationships were observed between the stiffness groups of plantation grown trees and full panel stiffness (EI) in both machine directions, small sample bending stiffness parallel and perpendicular (MOE/EI), dimensional stability parallel and perpendicular (LE), internal bond (IB), edge swell, and perpendicular axial compression. For naturally grown trees relationships were observed between the stiffness groups and parallel full panel stiffness (EI), small sample bending stiffness parallel and perpendicular (MOE/EI), perpendicular dimensional stability, and perpendicular axial compression. Table 4.12 gives the correlation results with differences denoted by bold print.

ANOVA was conducted to determine which stiffness groups were significantly different for each of the tests that showed correlations with the log stiffness groups. Analysis of parallel EI showed that the low stiffness plantation and natural groups performed poorly compared to the middle and high stiffness groups (Figure 4.23). Perpendicular EI only showed a significant difference in the plantation grown trees with the high stiffness group performing poorly compared to the middle and low groups (Figure 4.24).

ANOVA of small sample bending results showed the low stiffness groups for both growth types did not perform as well as the middle and high groups for parallel stiffness while the high stiffness groups did not performing as well in the perpendicular panel directions. See Figures 4.25 and 4.26 for boxplots of the parallel and perpendicular results respectively.

An ANOVA of dimensional stability showed the high stiffness group in the plantation growth type did not perform as well as the other stiffness groups in the parallel and perpendicular directions (Figures 4.27 and 4.28). However, in the natural growth condition for perpendicular dimensional stability, the performance of each group was significantly different from each other, with the low stiffness group showing the best results, followed by the high stiffness and middle stiffness groups.

Internal bond showed the low stiffness group in the plantation grown trees performed significantly better then the high and middle stiffness groups, while no differences were detected in the natural growth type (Figure 4.29).

No significant differences were seen in water absorption, but for the plantation grown trees the low stiffness group performed better than the middle and high groups. No differences were seen in the naturally grown trees (Figure 4.30).

An ANOVA of axial compression showed that the high stiffness group of the plantation grown trees was lower than the low stiffness group with the middle stiffness group statistically equivalent to both (Figure 4.31). Again, no differences were seen in the naturally grown groups.

DISCUSSION

Correlations were seen between log stiffness groups and full panel stiffness, small sample bending stiffness, dimensional stability, internal bond, edge swell, and axial compression. Analysis showed that in general, the low log stiffness groups had poor full panel and small sample stiffness in the parallel machine direction, low internal bonding, better dimensional stability and edge swell, and higher axial compression. The middle and high log stiffness groups rarely performed differently from each other, while the low groups negatively influenced OSB panel stiffness. The high log stiffness groups showed the poorest results in perpendicular panel stiffness and dimensional stability. Typically the perpendicular panel properties are controlled more by manufacturing operations than by raw material quality, so poor performance along the perpendicular strength axis is not a concern for quality.

Plantation and naturally grown trees from the area sampled do not need to be segregated; log quality indicated no difference between growth types. The most important factor for segregation in the region analyzed was log velocity. The lowest velocity groups negatively impacted panel stiffness which is the most important and the most difficult panel property to control by manipulating manufacturing parameters. If the low stiffness logs can be rejected prior to processing, panel stiffness should go up and ideally the amount of rejected material due to low quality would go down. Similar results have been seen in the lumber, plywood, and veneer industries using techniques similar to these (Carter and Lausberg 2002, Dickson et at 2004, Ross et al 2005).

Dickson et al. (2004) found that plywood panel stiffness was closely related to the average log velocity of each stiffness group: low, medium, and high. This method was used to quantify the relationship between machine stress graded panel stiffness and log velocity when one panel was produced from more than one log. However, in this study, an attempt was made to use the same method of averaging by stiffness group both machine directions for panel stiffness were investigated and neither gave a strong relationship with the averaged log stiffness for each stiffness group. This is probably due to the lack of differentiation between the medium and high log stiffness groups in regard to panel stiffness.

OSB panels manufactured from logs having the lowest stiffness showed significantly higher axial compression with trends toward better perpendicular strength and stiffness. It was noted during processing that larger logs produced wider flakes due to the limitations of the laboratory flaker used. More of the lower stiffness material came from logs of larger diameter, which in turn had wider flakes. It was hoped that flake width would adjust itself by breaking the flakes during the drying and blending processes, but the laboratory equipment was extremely gentle with material in order to produce the best material possible, however, this is not true for manufacturing facilities. Materials produced by pilot plants are typically a much higher quality in regards to flake dimensions which is probably the cause of the extremely high axial compression data. Perpendicular strength and stiffness are also significantly affected by wider flakes.

The low log stiffness groups showed significantly better dimensional stability and edge swell as well. Again, the wider flakes in the low stiffness groups will have an affect on any water property evaluated. In terms of this study, there was a lot of variation in the test results for edge swell and linear expansion, so the difference detected might have been related to the relatively small sample size.

No differences between stiffness groups were detected between fastener holding capability or internal bond. Both tests are performed to indicate other major problems such as resin failures or manufacturing malfunction which will typically be detected prior to testing panels. The tests are run on a very small sample so there is a lot of variability inherent to the methods, and differences between conditions are rarely detected. No literature was found in regards to attempting to correlate velocity data with fastener holding or any type of resin bonding capability.

Overall, differences in log stiffness calculated from velocity had little or no effect on OSB panel properties other than stiffness. One explanation is that the logs were generally young and probably had a high proportion of juvenile wood which will lower the OSB panel performance (Pugel et al. 1990 and Cloutier et al. 2007). This theory would be supported by the negative trend in the plantation grown group between IBD and velocity as smaller, younger trees have a higher proportion of juvenile wood (Huang et al. 2003, Peters et al. 2002). However, the positive trend in BSG with log velocity seen in the naturally grown group shows that in general, acoustic velocity is an indicator of log quality.

If low velocity logs are segregated from the higher quality material, a stiffer panel can be made under normal operations. If producing a stiffer panel is not a problem for the manufacturing facility, using only the higher quality material could result in the ability to lower panel densities, lower resin, and overall reduce raw material costs. If a plant does not make lower stiffness products, the purchase of low stiffness material could be avoided by eliminating it at procurement sites. This approach would require some additional studies and would require the manufacturing facility to buy mostly procured logs, not gatewood.

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FIGURES AND TABLES FOR CHAPTER 4

Table 4.1. OSB manufacturing parameters.

Stiffness Group	1	2	3	4	5	6
# of Panels	7	7	6	7	4	6
Strand Screening	pre-screened	pre-screened	pre-screened	pre-screened	pre-screened	pre-screened
Panel Thickness (in)	0.75	0.75	0.75	0.75	0.75	0.75
Panel Density (pcf)	41.5	41.5	41.5	41.5	41.5	41.5
Panel Size (ft)	4' x 8'	4' x 8'	4' x 8'	4' x 8'	4' x 8'	4' x 8'
Oriented	yes	yes	yes	yes	yes	yes
Mat Split						
Face/Core	60/40	60/40	60/40	60/40	60/40	60/40
Resin						
Face type	MDI	MDI	MDI	MDI	MDI	MDI
% solids	5	5	5	5	5	5
Core type	MDI	MDI	MDI	MDI	MDI	MDI
% solids	5	5	5	5	5	5
Wax Type						
Face/Core	E-wax	E-wax	E-wax	E-wax	E-wax	E-wax
% solids	2.00	2.00	2.00	2.00	2.00	2.00
Mat MC						
Face	6-8	6-8	6-8	6-8	6-8	6-8
Core	3-5	3-5	3-5	3-5	3-5	3-5
Press Temp. (F)	410	410	410	410	410	410
Caul	caul	caul	caul	caul	caul	caul
Plate/screen	plate	plate	plate	plate	plate	plate
Press Cycle						
Close (sec)	35	35	35	35	35	35
Cook Time (sec)	210	210	210	210	210	210
Degas (sec)	25	25	25	25	25	25

Table 4.2 OSB Panel testing matrix.

Test	Method	Conditions	Panels per Condition	Specimens per Panel	Total Specimens
Panel Flexure (QL-3)	ASTM D3043C	6	7		
EI 1				2	84
EI 2				2	84
FbS 1				0	0
FbS 2				0	0
Planar Shear	ASTM D2718	6	7		
parallel				2	84
perpendicular				2	84
Nail Withdrawal	ASTM D1037 8d	6	7	2	84
Small Specimen Bending	ASTM D3043D	6	7		
Dry Parallel				4	168
Dry Perpendicular				4	168
Linear Expansion	PS2	6	7		
parallel				4	168
perpendicular				4	168
Internal Bond	ASTM D1037	6	7	4	168
Thickness Swell	PS2, ASTM D1037	6	7		
edge				4	168
1"				4	168
VDP	Huber internal	6	7	4	168

Table 4.3. Summary of full panel bending test results.

Stiffness group	Avg. Para EI	Avg. Perp EI	StDev Para EI	StDev Perp EI	Min Para EI	Min Perp EI	Max Para EI	Max Perp EI	N
1	468,460	200,382	27,506	14,131	423,683	181,587	507,755	228,351	10
2	519,123	191,164	29,340	8,928	476,882	177,956	570,536	208,963	14
3	511,802	183,089	35,237	8,276	454,787	169,557	558,726	193,269	12
4	437,345	177,304	38,018	11,185	353,406	161,751	476,419	197,359	14
5	531,667	196,799	30,269	11,096	491,763	180,342	577,644	207,987	8
6	519,738	180,973	59,678	13,099	400,182	160,865	596,165	206,298	12

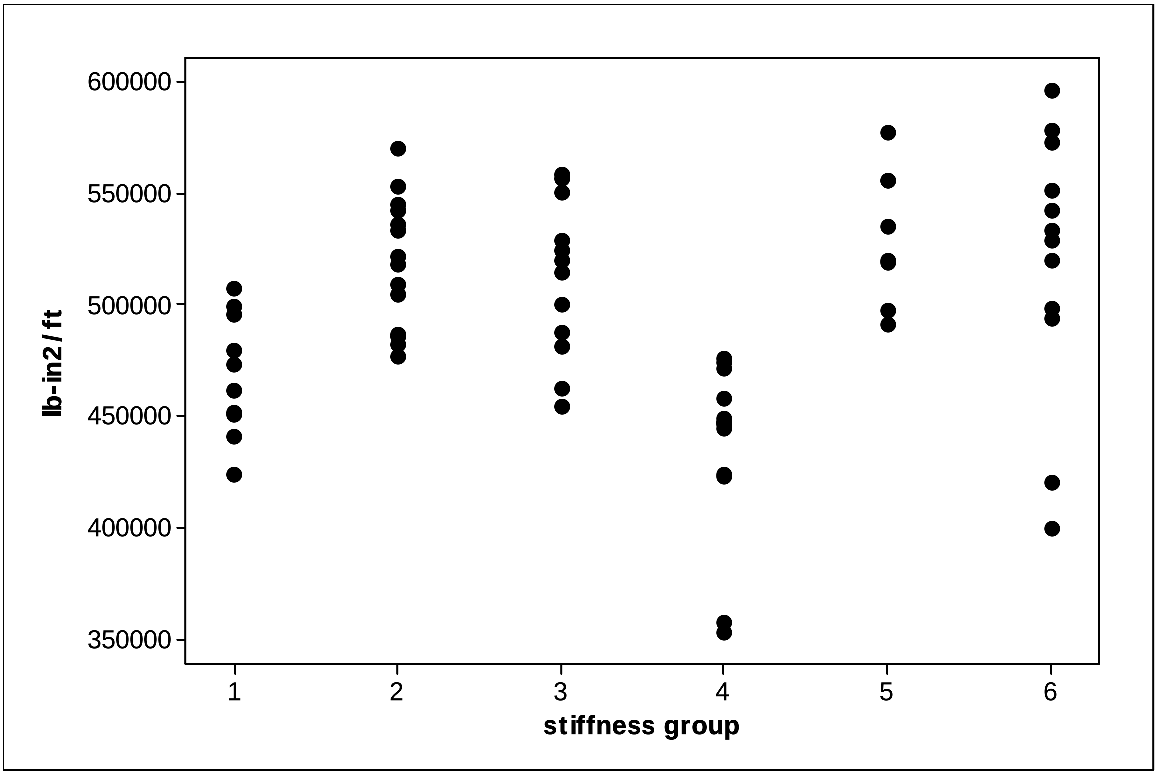

Figure 4.1. Plot of parallel full panel EI by stiffness group.

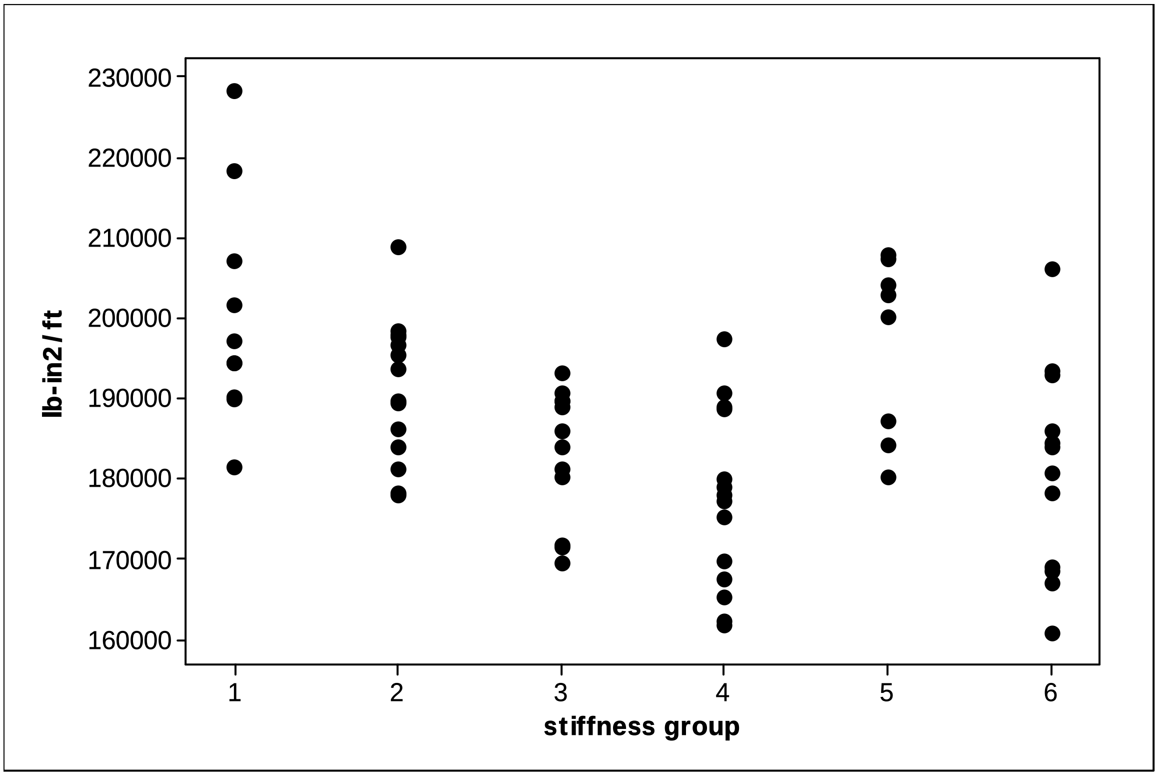

Figure 4.2. Plot of perpendicular full panel EI by stiffness group.

Table 4.4. Summary of small sample test results.

Stiffness group	Avg. Para Fs	Avg. Perp Fs	Avg. NW
1	1,585	1,781	150.5
2	1,701	1,805	132.9
3	1,534	1,847	145.0
4	1,671	1,688	141.2
5	1,625	1,797	102.5
6	1,591	1,698	128.8

Stiffness group	Para Avg. MOE	Para Avg. MOR	Para Avg. FbS	Perp Avg. MOE	Perp Avg. MOR	Perp Avg. FbS
1	1,045,430	7,657	8614	396,382	3,158	3,552
2	1,193,030	8,444	9500	396,392	3,261	3,668
3	1,224,925	8,196	9221	355,637	3,098	3,485
4	1,023,879	7,535	8477	360,575	2,936	3,303
5	1,208,349	7,734	8701	377,605	3,112	3,501
6	1,278,298	8,031	9035	341,855	2,936	3,304

Stiffness group	Avg. Para LE	Avg. Perp LE	Avg. IB	Avg. ABS	Avg. TS	Avg. Para FcA	Avg. Perp FcA
1	0.174	0.352	80.4	17.3	10.7	32170	23071
2	0.178	0.351	98.2	17.9	11.5	35345	21866
3	0.190	0.368	91.8	18.5	11.5	29432	20772
4	0.190	0.375	89.5	17.8	11.3	30415	21892
5	0.210	0.438	87.5	20.9	12.4	30536	20468
6	0.195	0.400	87.9	18.9	12.0	31022	19949

Table 4.5. Summary of planar shear test results by stiffness group.

Stiffness group	Avg. Para Fs	Avg. Perp Fs	StDev Para Fs	StDev Perp Fs	Min Para Fs	Min Perp Fs	Max Para Fs	Max Perp Fs	N
1	1,585	1,781	197	123	1,128	1,581	1,859	1,986	12
2	1,701	1,805	200	108	1,265	1,708	1,934	2,057	14
3	1,534	1,847	164	161	1,288	1,548	1,941	2,057	12
4	1,671	1,688	108	93	1,458	1,538	1,854	1,824	14
5	1,625	1,797	217	189	1,317	1,583	1,990	2,069	8
6	1,591	1,698	160	114	1,242	1,527	1,844	1,924	12

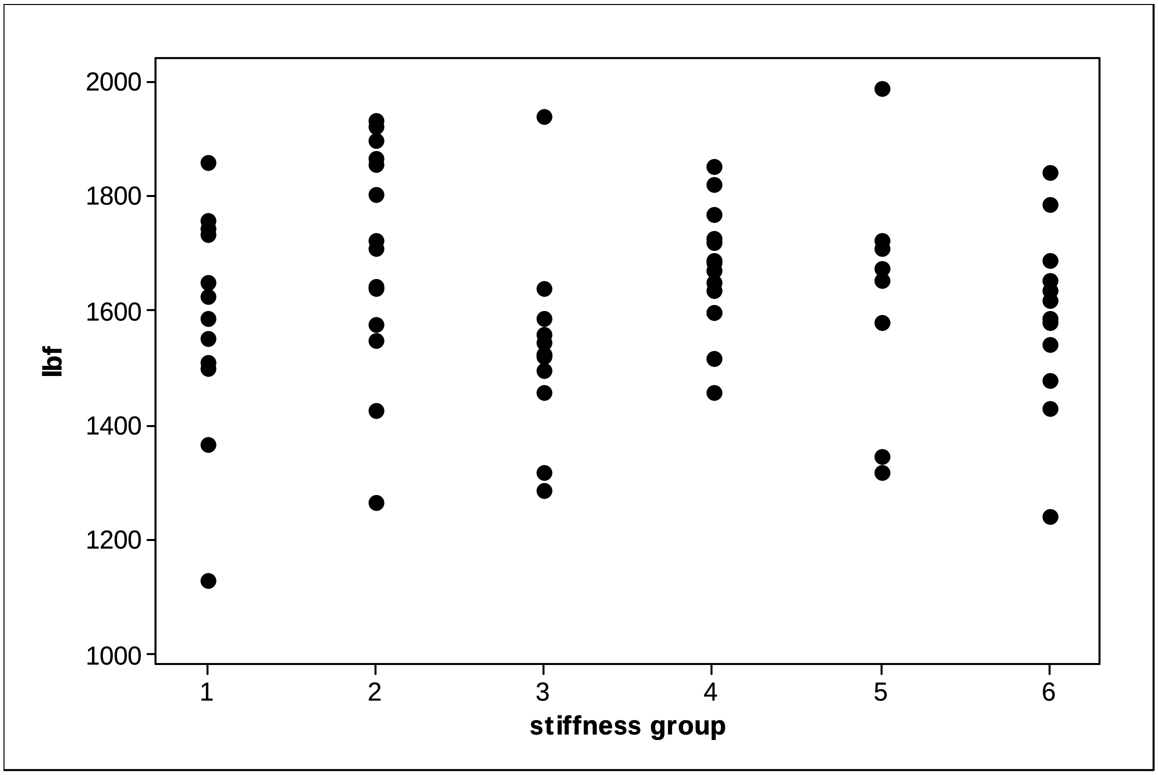

Figure 4.3. Plot of parallel planar shear by stiffness group.

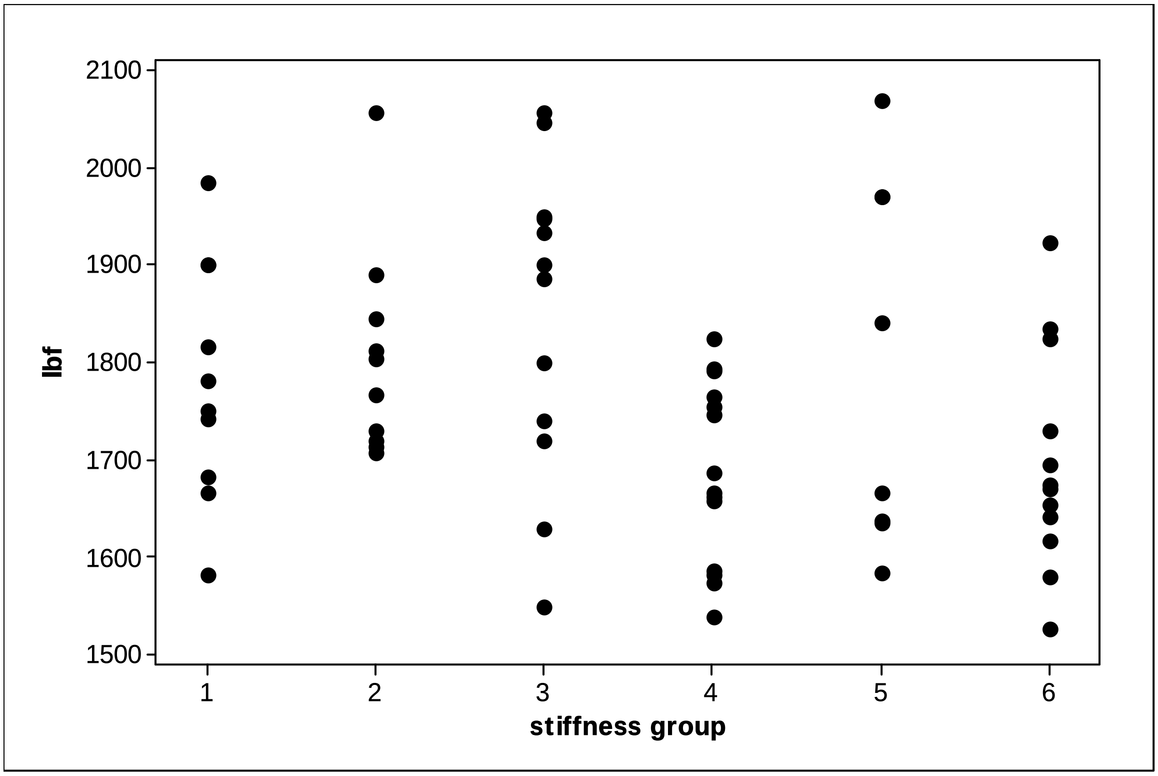

Figure 4.4. Plot of perpendicular planar shear by stiffness group.

Table 4.6. Summary of fastener holding (NW) test results by stiffness group.

Stiffness group	Avg. NW	StDev NW	Min NW	Max NW	N
1	150.5	39.5	102.3	251.1	12
2	132.9	40.2	94.1	242.3	14
3	145.0	31.2	97.8	190.9	12
4	141.2	32.1	94.4	208.4	14
5	102.5	21.3	67.0	138.4	8
6	128.8	24.5	94.1	171.9	12

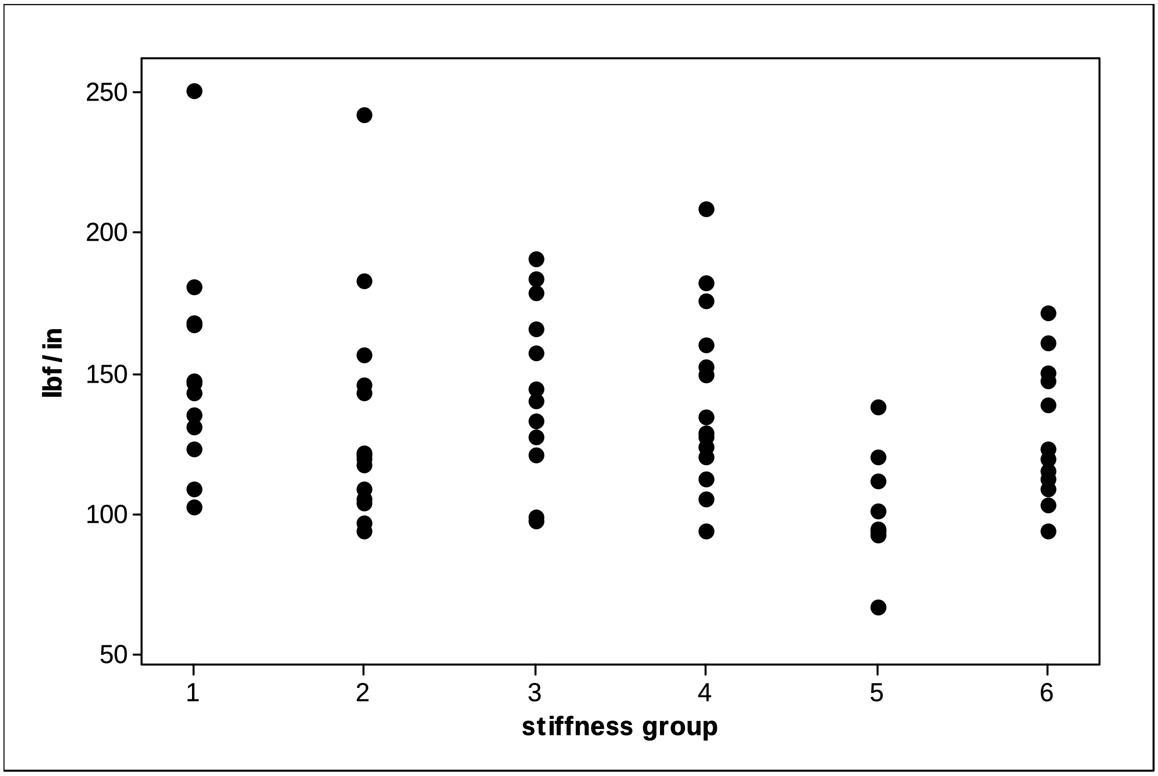

Figure 4.5. Plot of nail withdrawal by stiffness group.

Table 4.7. Summary of small sample bending strength and stiffness results by stiffness group.

PARALLEL MACHINE DIRECTION (along strength axis)

Stiffness group	Avg. MOE	Avg. EI	StDev MOE	StDev EI	Min MOE	Min EI	Max MOE	Max EI	N
1	1,045,430	441,042	69,132	29,165	915,093	386,056	1,187,166	500,837	23
2	1,193,030	503,311	115,118	48,565	857,272	361,662	1,400,709	590,925	28
3	1,224,925	516,767	77,564	32,723	1,093,826	461,459	1,378,526	581,567	24
4	1,023,879	431,950	79,338	33,471	839,014	353,960	1,146,938	483,865	28
5	1,208,349	509,773	129,078	54,455	1,011,338	426,659	1,473,401	621,593	16
6	1,278,298	539,283	110,133	46,463	1,060,830	447,539	1,477,615	623,370	24

PERPENDICULAR MACHINE DIRECTION (90 deg to strength axis)

Stiffness group	Avg. MOE	Avg. EI	StDev MOE	StDev EI	Min MOE	Min EI	Max MOE	Max EI	N
1	396,382	167,224	40,691	17,167	331,123	139,693	474,249	200,074	23
2	396,392	167,228	31,596	13,330	334,412	141,080	445,265	187,847	28
3	355,637	150,035	33,176	13,996	304,456	128,443	409,228	172,644	24
4	360,575	152,118	27,932	11,784	315,053	132,913	426,293	179,843	28
5	377,605	159,303	26,634	11,236	331,308	139,771	425,811	179,639	16
6	341,855	144,221	26,630	11,234	292,287	123,309	398,972	168,317	24

PARALLEL MACHINE DIRECTION (along strength axis)

Stiffness group	Avg. MOR	Avg. FbS	StDev MOR	StDev FbS	Min MOR	Min FbS	Max MOR	Max FbS	N
1	7,657	8614	1,543	1736	1,401	1576	9,657	10864	23
2	8,444	9500	1,185	1333	5,399	6073	10,573	11895	28
3	8,196	9221	887	997	6,544	7362	10,473	11783	24
4	7,535	8477	980	1103	5,318	5982	9,201	10351	28
5	7,734	8701	1,187	1335	6,014	6766	10,954	12323	16
6	8,031	9035	1,427	1606	5,985	6733	10,912	12277	24

PERPENDICULAR MACHINE DIRECTION (90 deg to strength axis)

Stiffness group	Avg. MOR	Avg. FbS	StDev MOR	StDev FbS	Min MOR	Min FbS	Max MOR	Max FbS	N
1	3,158	3,552	368	414	2,398	2,698	4,003	4,503	23
2	3,261	3,668	406	457	2,045	2,300	3,948	4,441	28
3	3,098	3,485	459	516	2,305	2,594	4,044	4,549	24
4	2,936	3,303	408	459	1,952	2,196	3,818	4,295	28
5	3,112	3,501	336	379	2,432	2,736	3,696	4,158	16
6	2,936	3,304	306	344	2,145	2,414	3,456	3,888	24

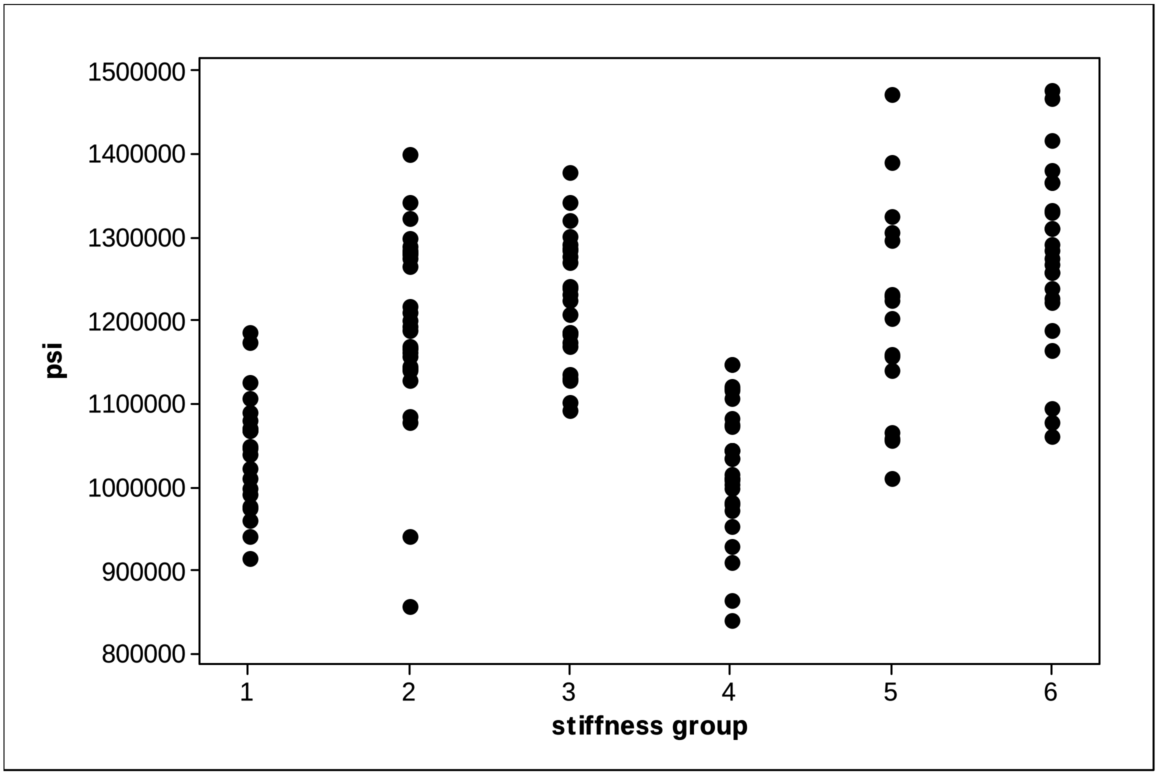

Figure 4.6. Plot of small sample bending parallel Modulus of Elasticity by stiffness group.

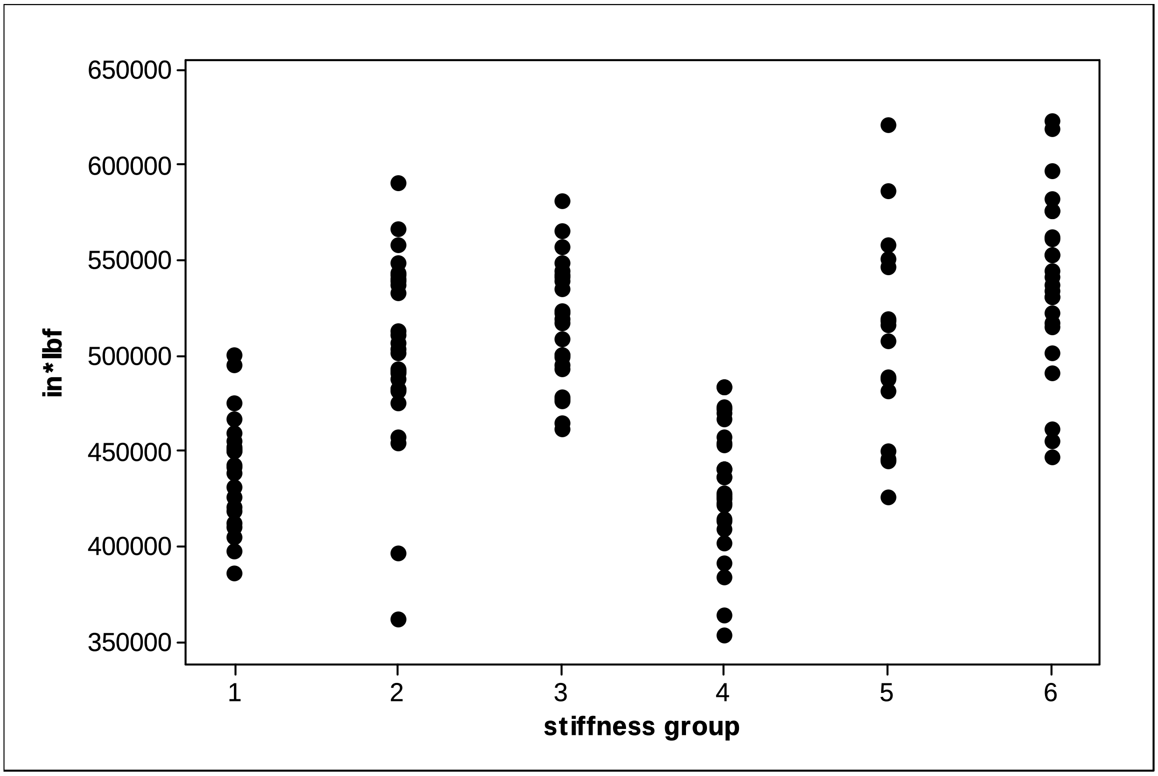

Figure 4.7. Plot of small sample bending parallel stiffness (EI) by stiffness group.

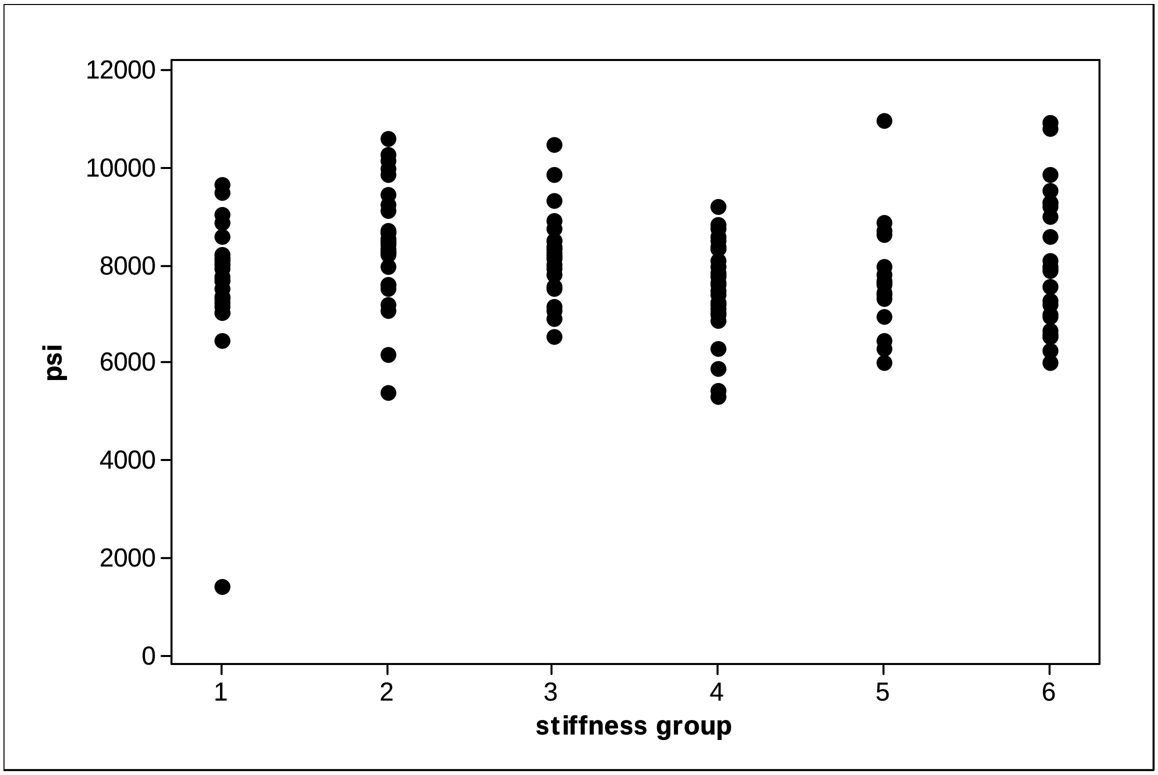

Figure 4.8. Plot of small sample bending parallel Modulus of Rupture by stiffness group.

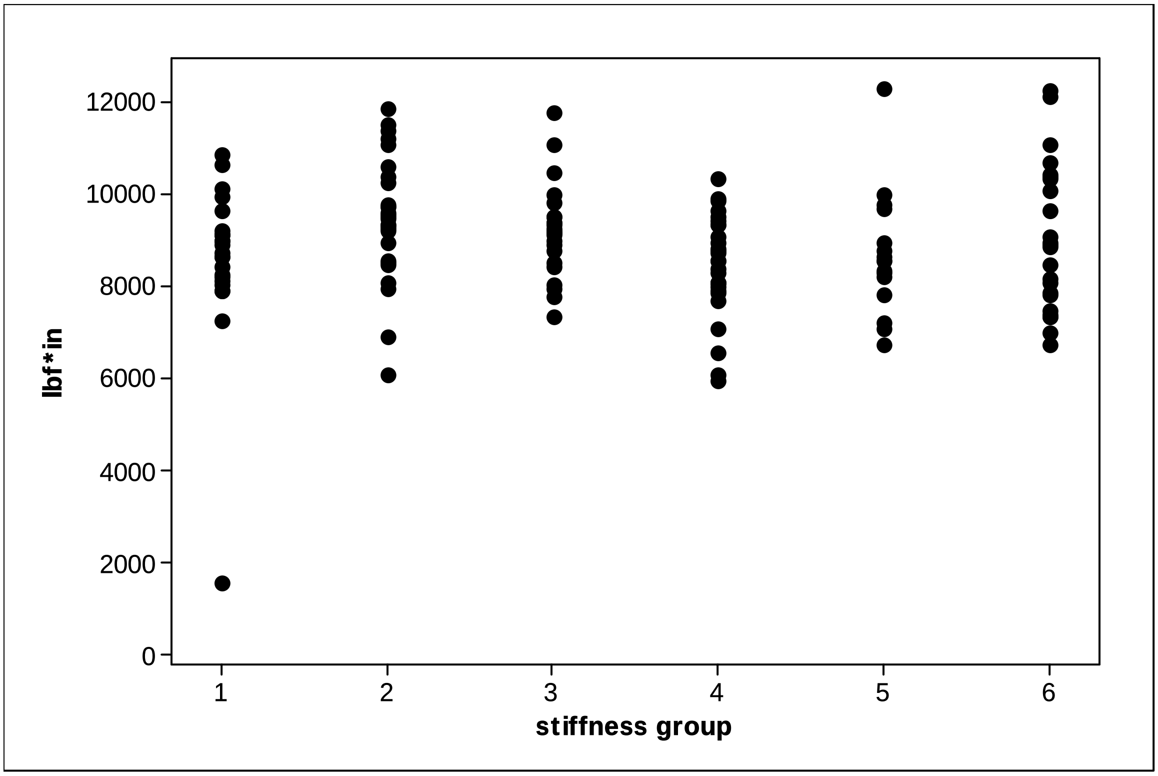

Figure 4.9. Plot of small sample bending parallel bending strength (FbS) by stiffness group.

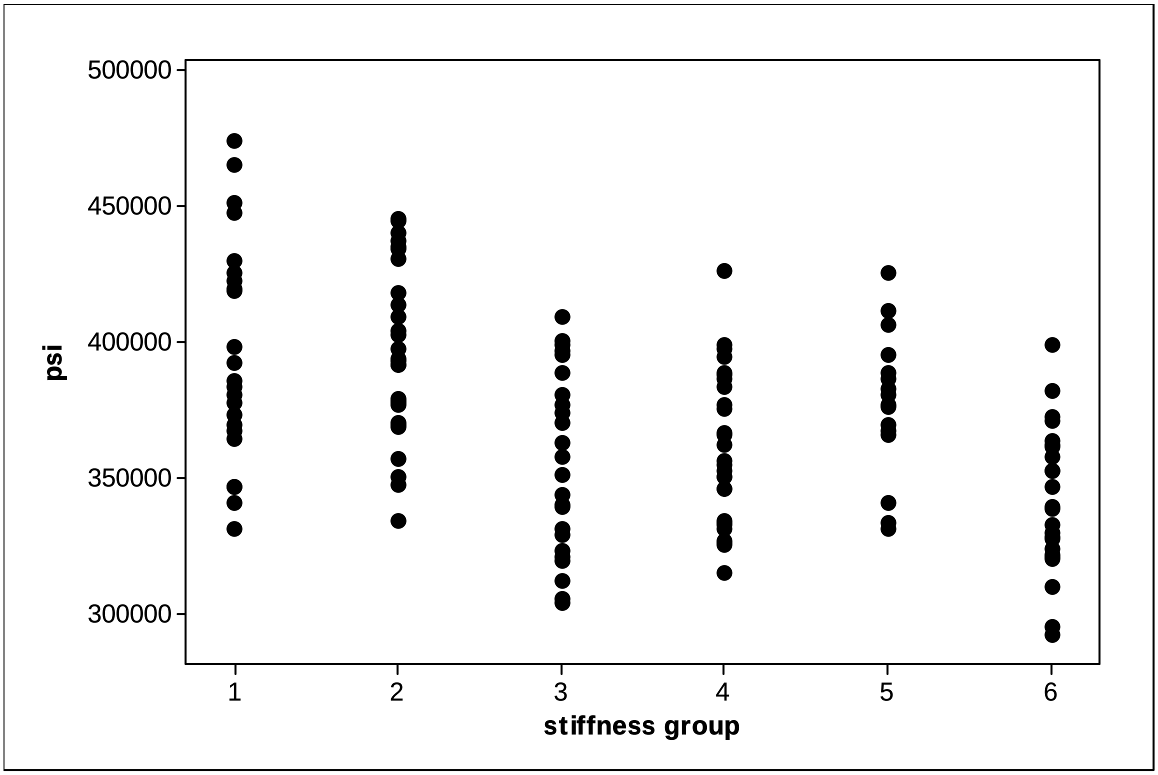

Figure 4.10. Plot of small sample bending perpendicular Modulus of Elasticity by stiffness group.

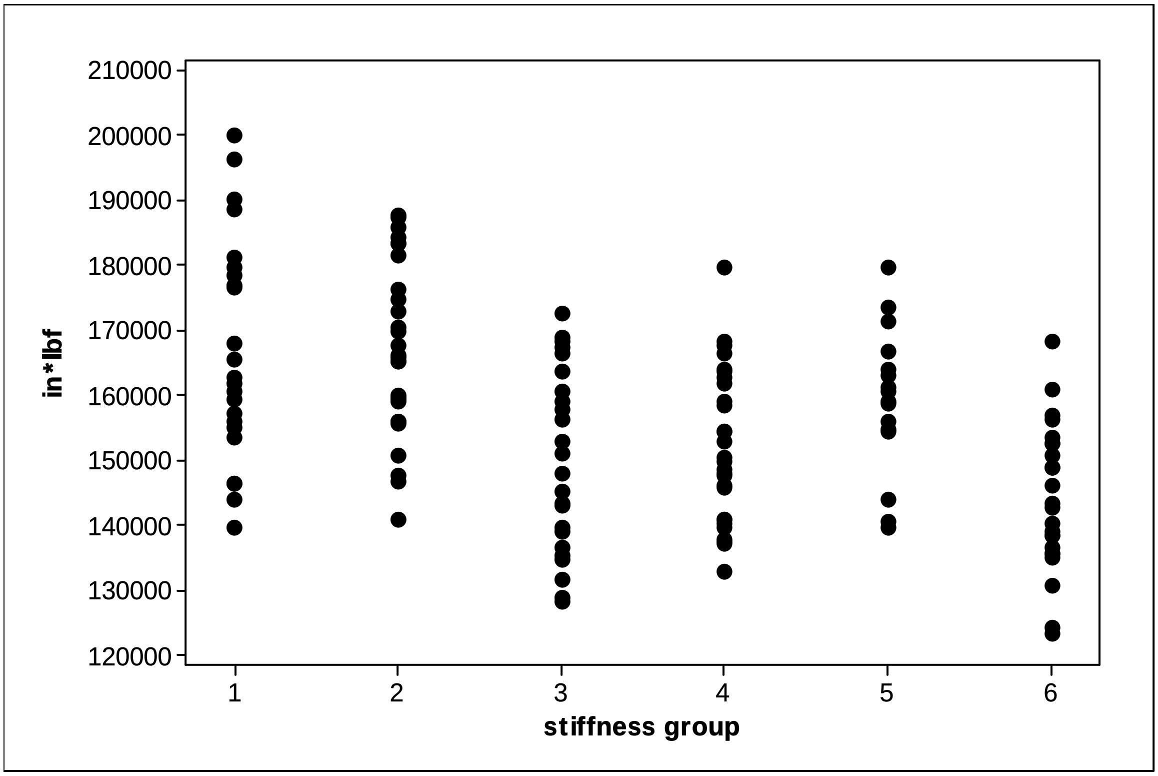

Figure 4.11. Plot of small sample bending perpendicular stiffness (EI) by stiffness group.

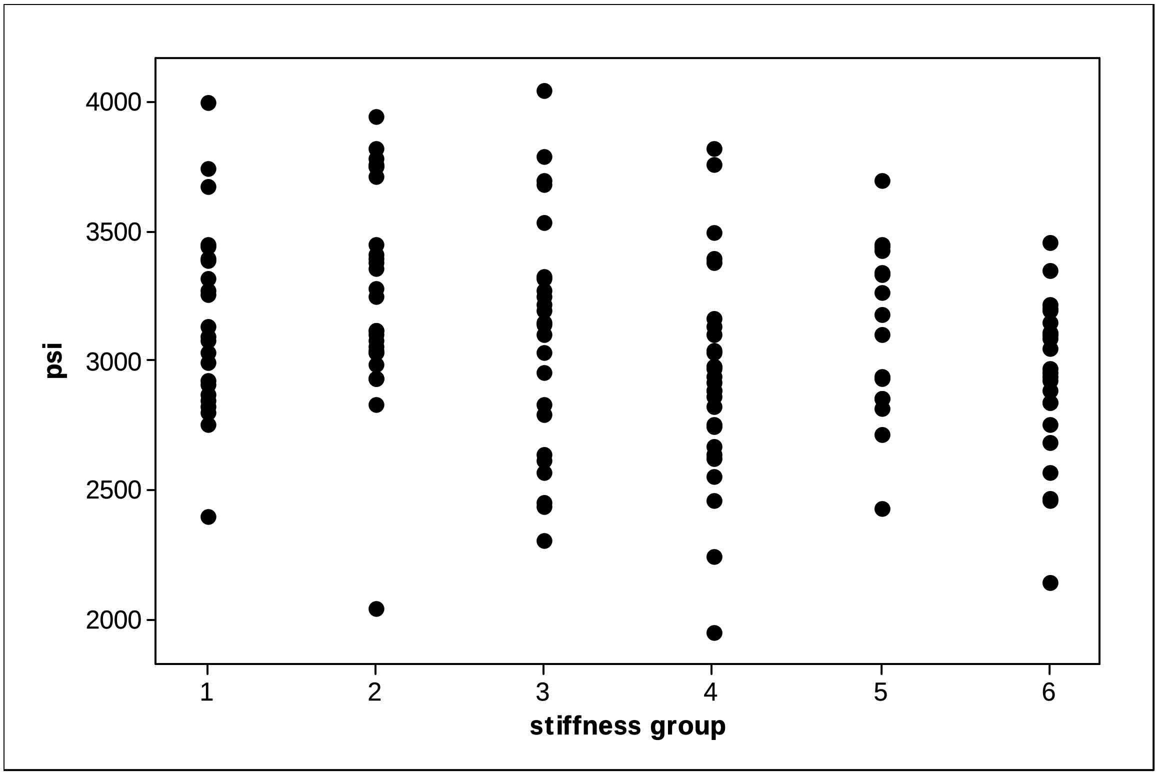

Figure 4.12. Plot of small sample bending perpendicular Modulus of Rupture by stiffness group.

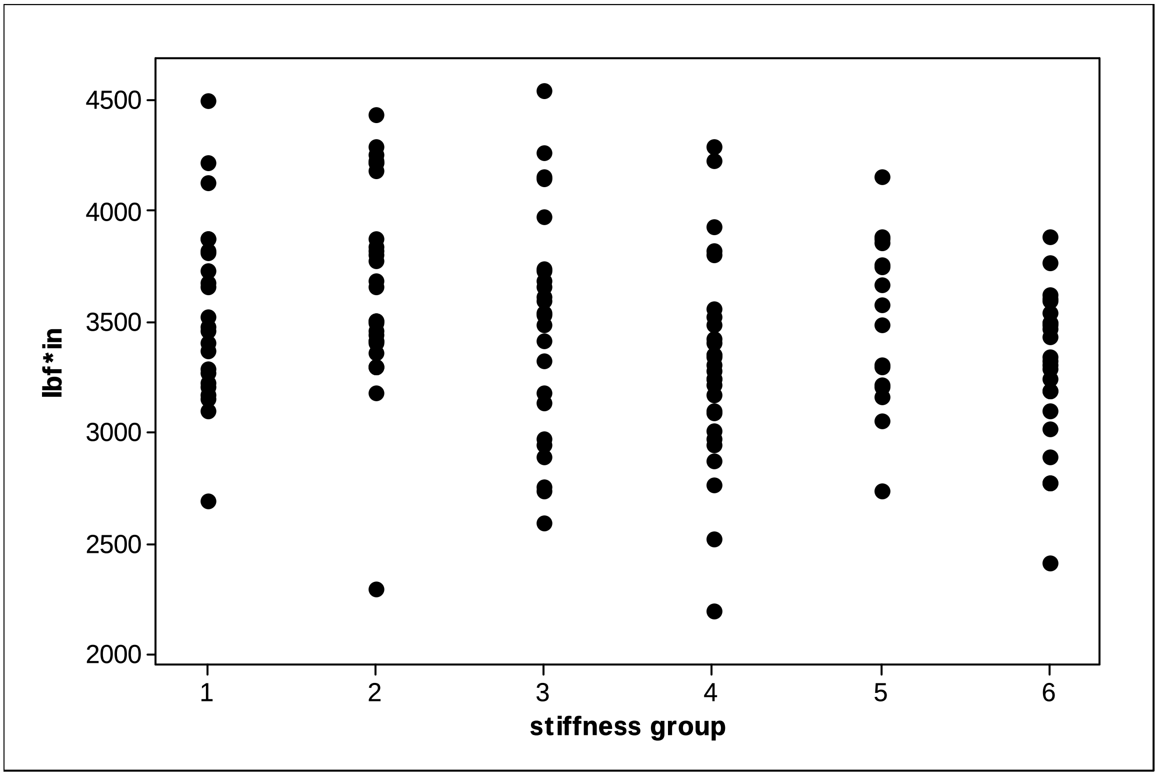

Figure 4.13. Plot of small sample bending perpendicular strength (FbS) by stiffness group.

Table 4.8. Summary of dimensional stability (LE) test results.

Stiffness group	Avg. Para LE	Avg. Perp LE	StDev Para LE	StDev Perp LE	Min Para LE	Min Perp LE	Max Para LE	Max Perp LE	N
1	0.174	0.352	0.013	0.016	0.15	0.32	0.19	0.38	24
2	0.178	0.351	0.014	0.015	0.15	0.31	0.2	0.38	28
3	0.190	0.368	0.012	0.022	0.16	0.33	0.22	0.4	24
4	0.190	0.375	0.010	0.018	0.17	0.34	0.21	0.41	28
5	0.210	0.438	0.013	0.015	0.19	0.41	0.23	0.47	16
6	0.195	0.400	0.010	0.015	0.18	0.37	0.21	0.43	24

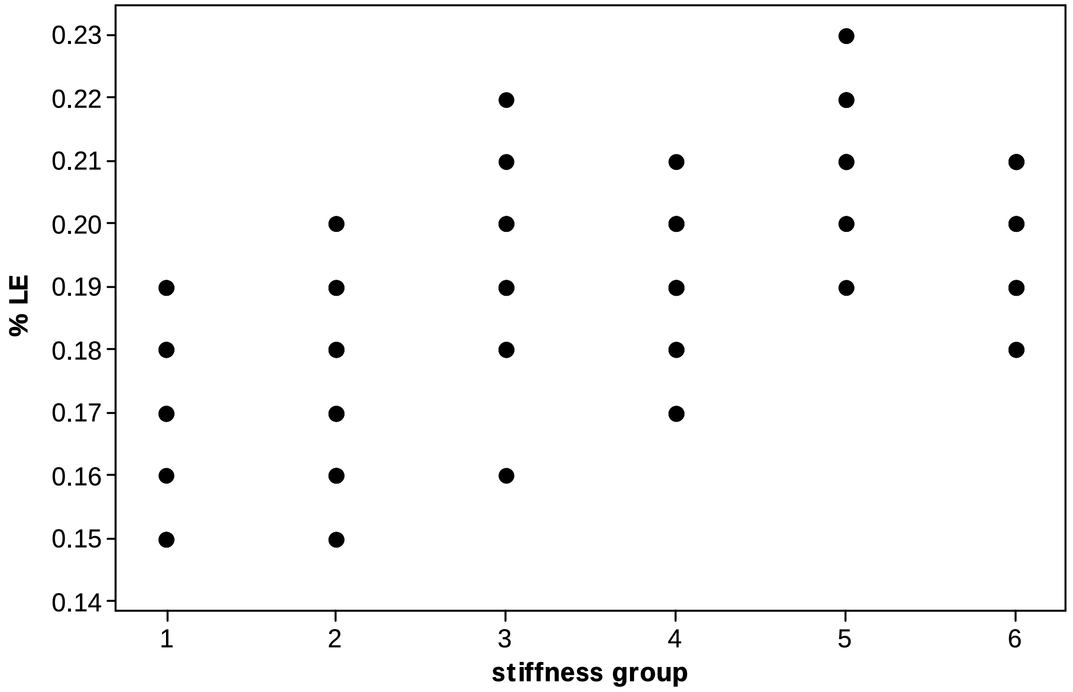

Figure 4.14. Plot of parallel linear expansion by stiffness group.

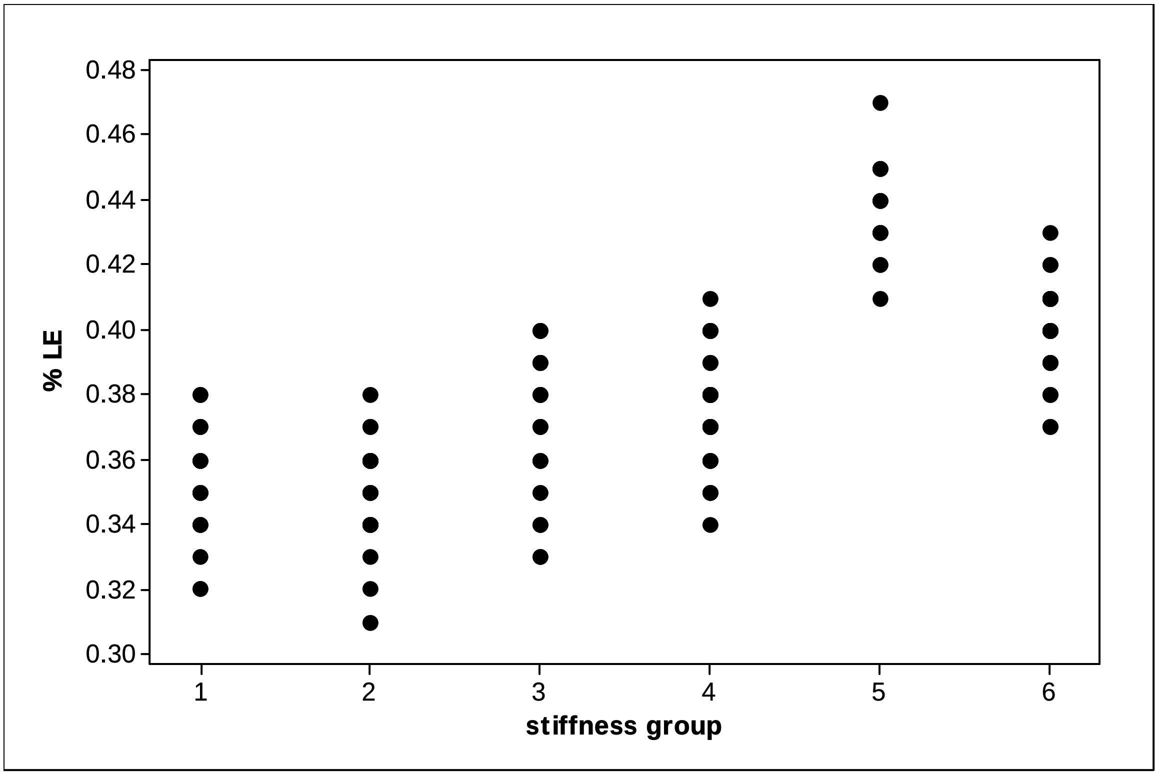

Figure 4.15. Plot of perpendicular linear expansion by stiffness group.

Table 4.9. Summary of internal bond (IB) testing.

Stiffness group	Avg. IB	StDev IB	Min IB	Max IB	N
1	80.4	17.8	46.1	121.4	48
2	98.2	22.1	37.6	141.3	56
3	91.8	27.8	5.1	156.2	48
4	89.5	22.1	50.4	137.7	56
5	87.5	18.6	55.7	121.6	32
6	87.9	17.2	57.8	120.9	48

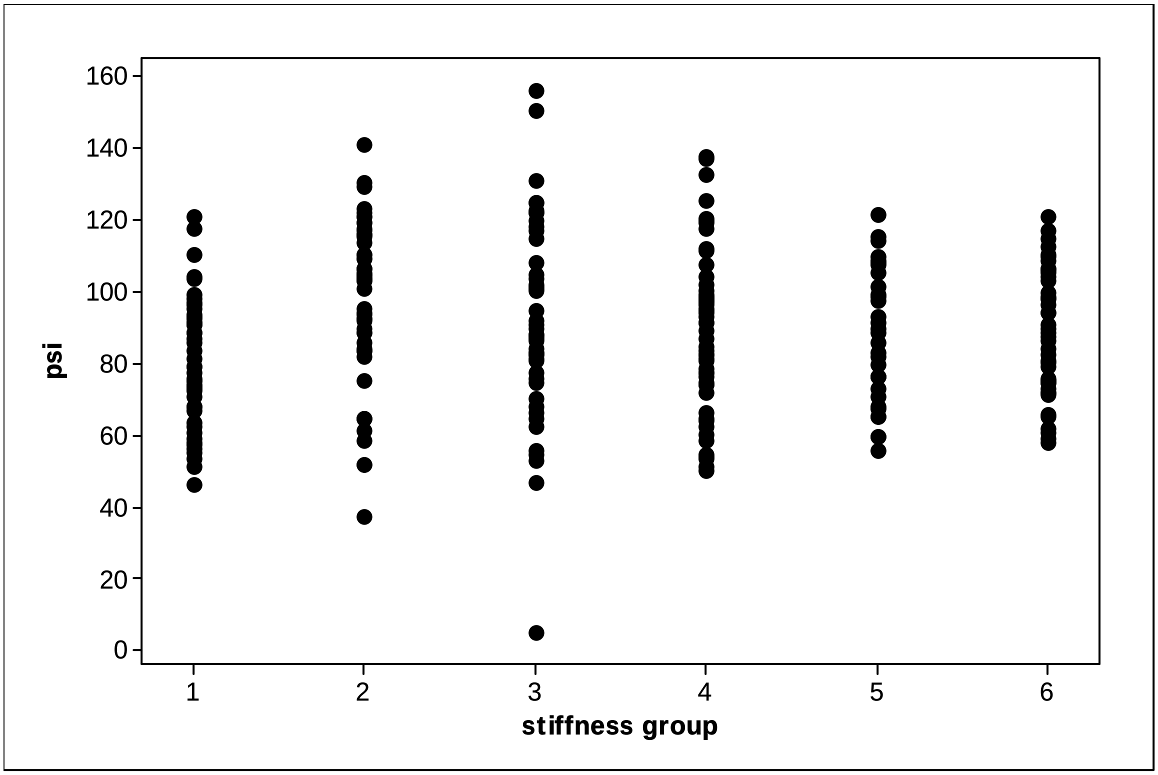

Figure 4.16. Plot of internal bond (IB) by stiffness group.

Table 4.10. Summary of water absorption and thickness swell test results.

Stiffness group	Avg. ABS	Avg. TS	StDev ABS	StDev TS	Min ABS	Min TS	Max ABS	Max TS	N
1	17.3	10.7	3.0	1.4	10.7	8.4	23.2	14.5	24
2	17.9	11.5	2.1	0.9	13.3	9.5	23.0	12.8	28
3	18.5	11.5	2.3	0.9	12.9	10.0	23.2	13.7	24
4	17.8	11.3	2.9	0.9	12.1	10.1	24.2	14.0	28
5	20.9	12.4	3.5	2.0	14.9	9.7	25.6	16.6	16
6	18.9	12.0	2.6	1.4	14.1	8.4	23.6	14.6	24

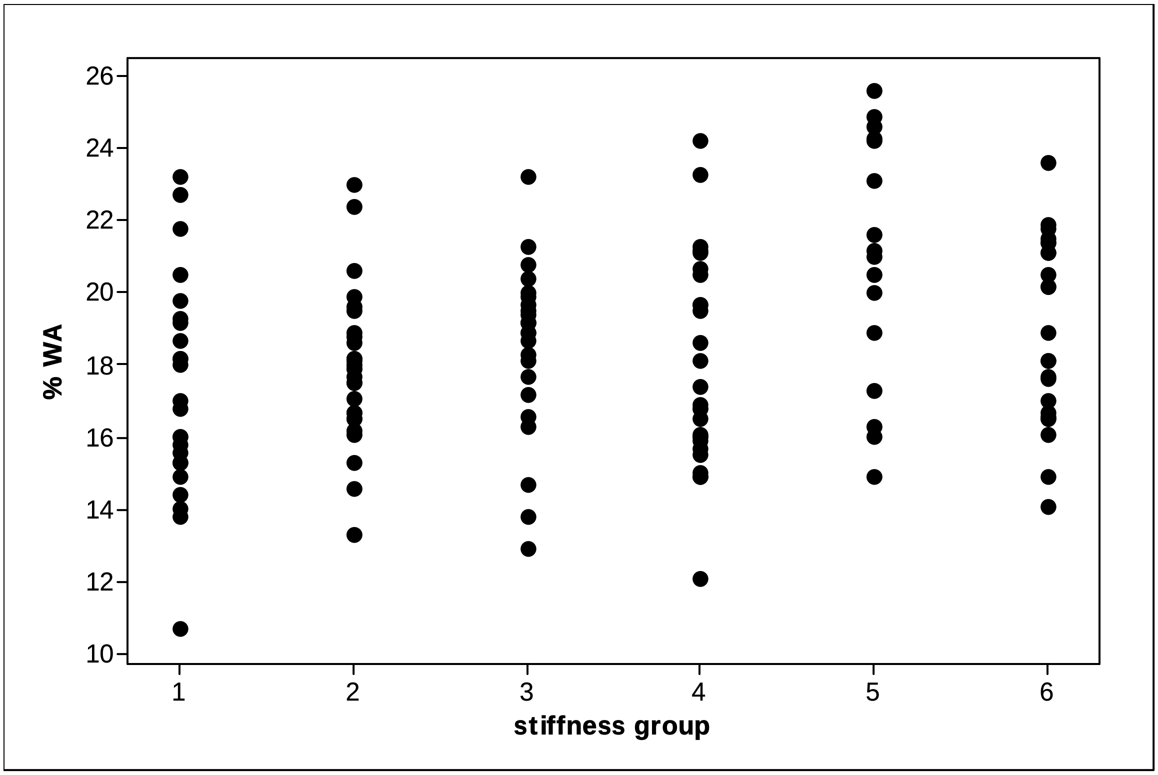

Figure 4.17. Plot of water absorption by stiffness group.

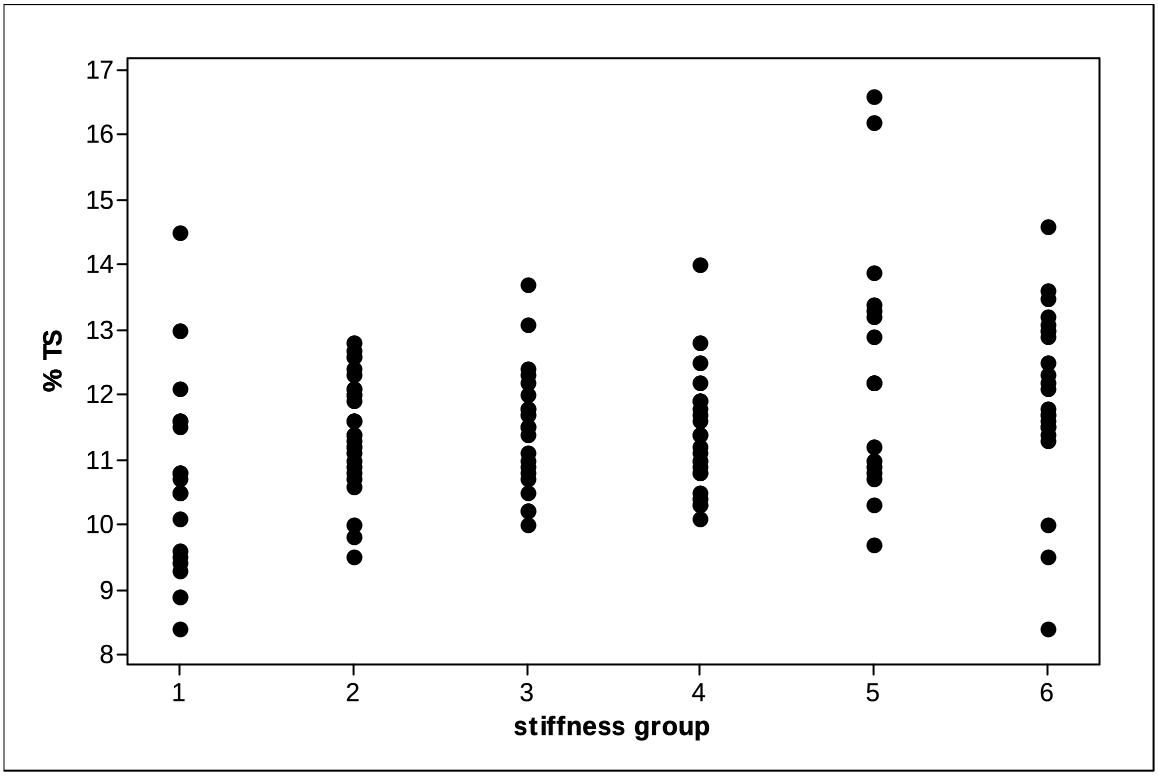

Figure 4.18. Plot of thickness swell on edge by stiffness group.

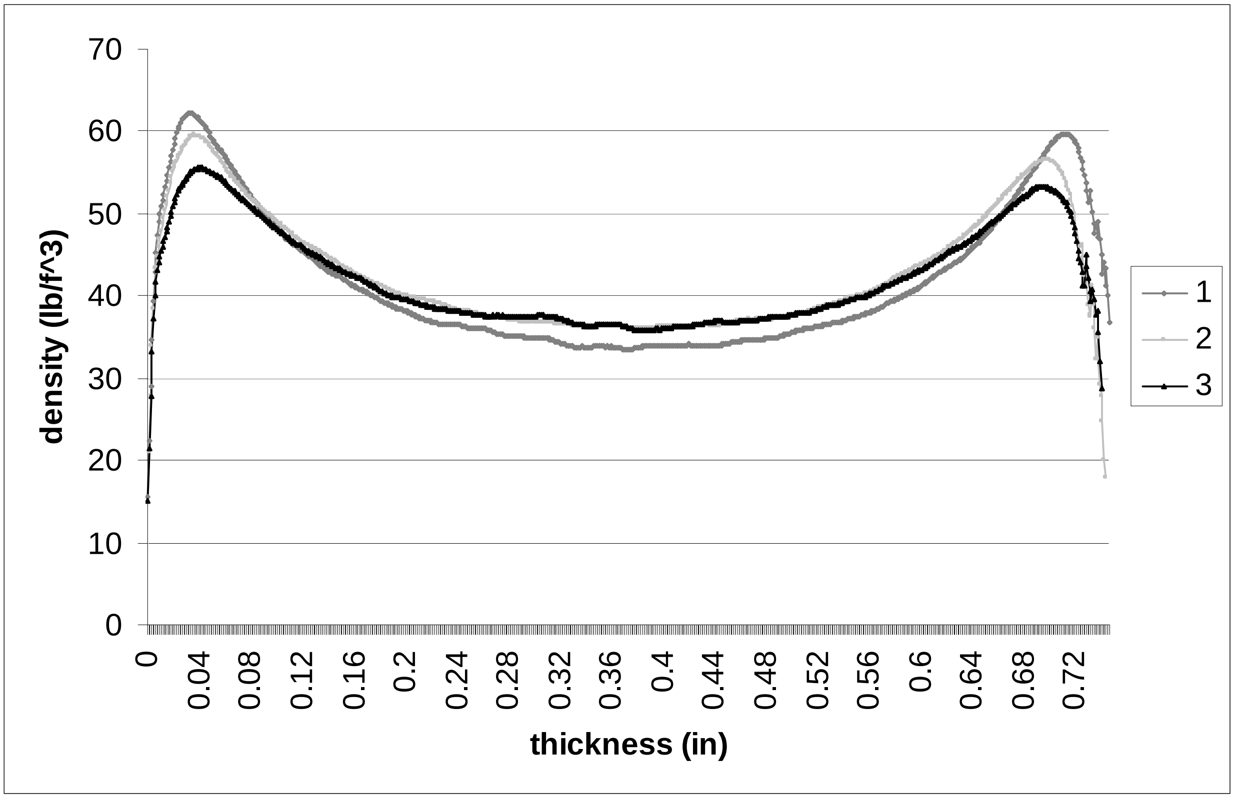

Figure 4.19. Vertical density profile averages of the plantation growth groups

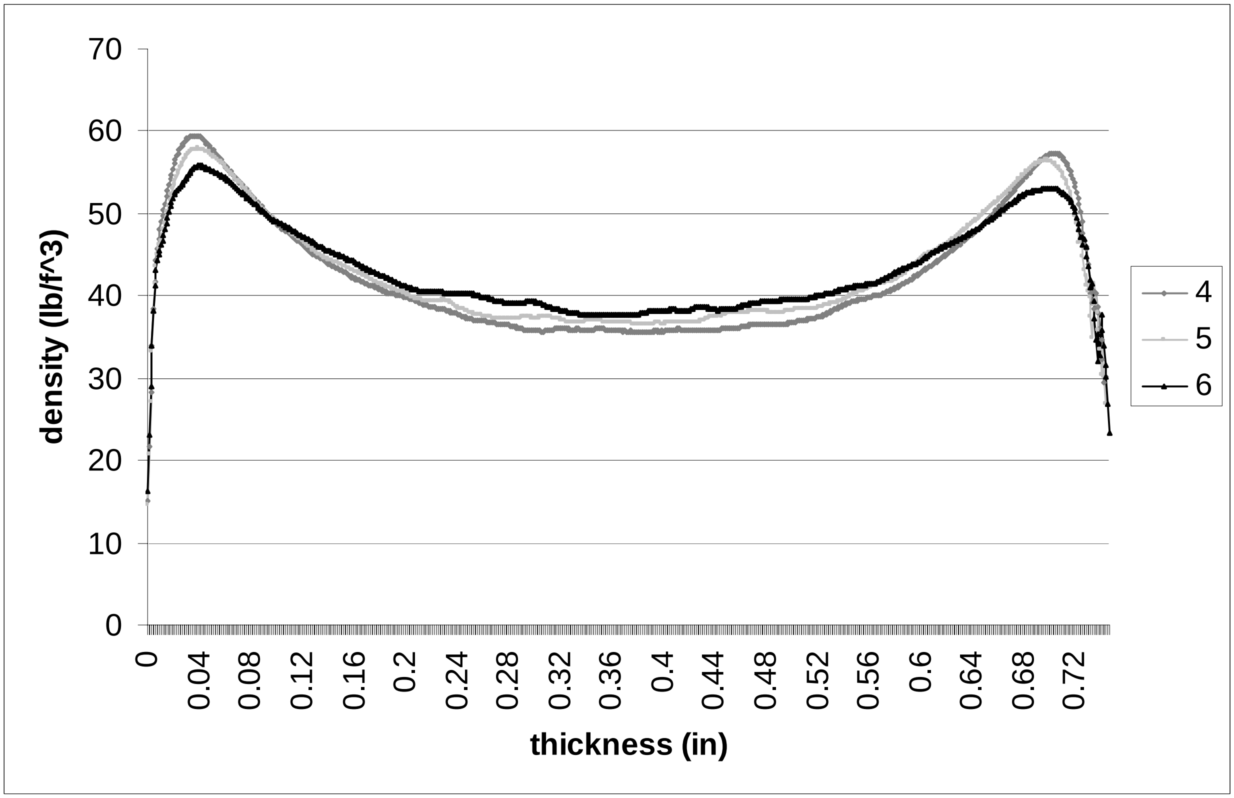

Figure 4.20. Vertical density profile averages of the natural growth groups.

Table 4.11. Summary of axial compression results.

Stiffness group	Avg. Para FcA	Avg. Perp FcA	StDev Para FcA	StDev Perp FcA	Min Para FcA	Min Perp FcA	Max Para FcA	Max Perp FcA	N
1	32,170	23,071	3,696	2,940	24,467	17,517	38,082	26,825	12
2	35,345	21,866	5,220	1,923	24,366	18,117	42,805	25,905	14
3	29,432	20,772	3,461	1,763	23,989	16,993	35,112	23,247	12
4	30,415	21,892	3,808	2,796	23,821	16,548	34,920	26,236	14
5	30,536	20,468	3,996	1,322	25,687	18,845	36,974	22,533	8
6	31,022	19,949	3,987	2,594	23,637	16,005	36,397	24,018	12

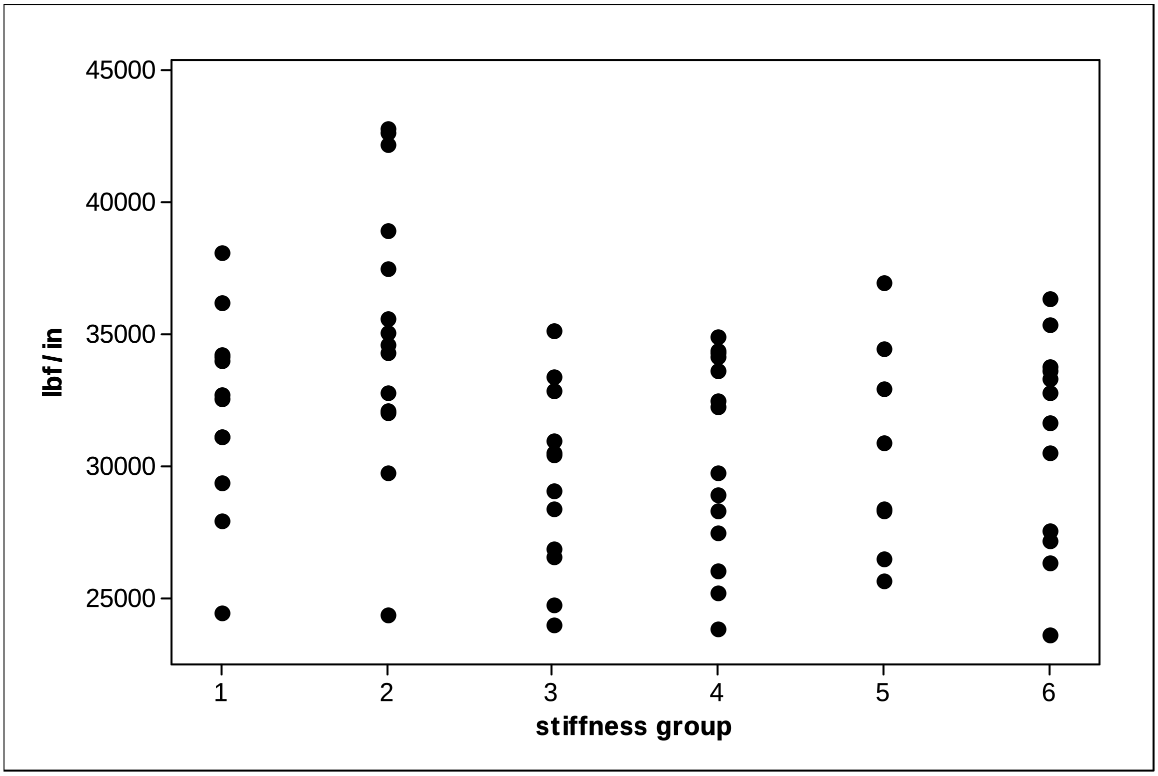

Figure 4.21. Plot of parallel axial compression (FcA) by stiffness group.

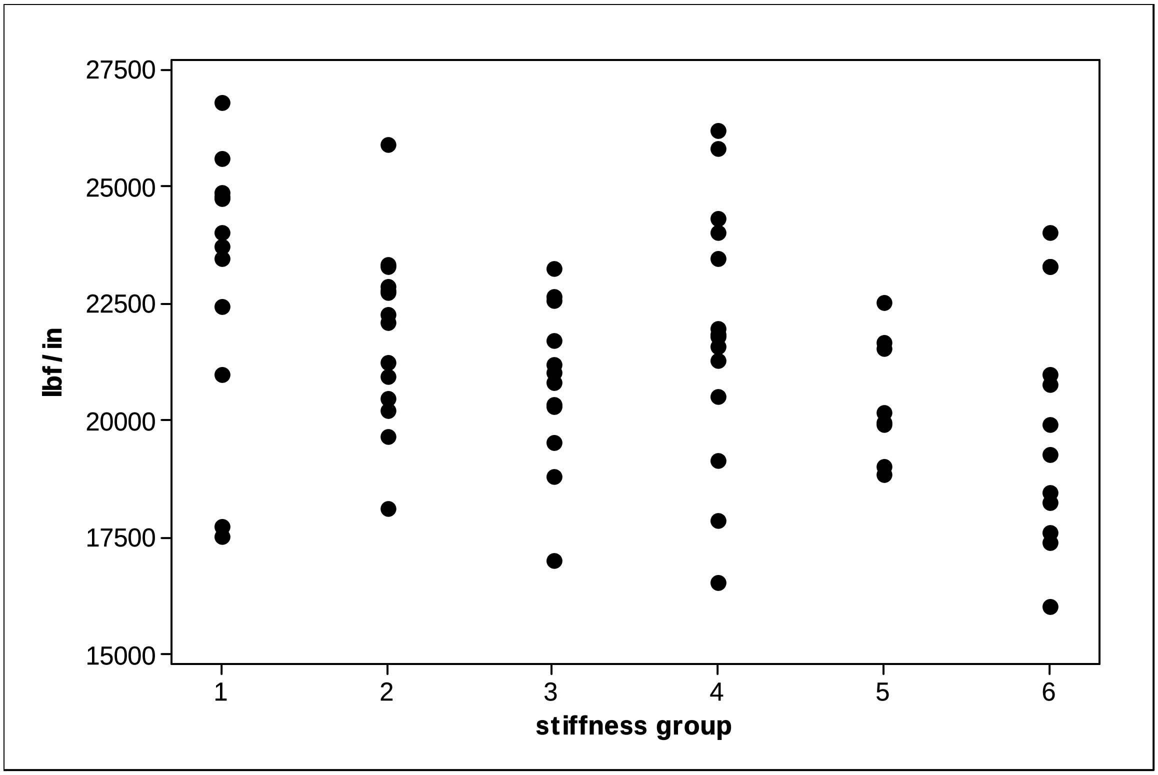

Figure 4.22. Plot of perpendicular axial compression (FcA) by stiffness group.

Table 4.12. Correlations of stiffness group by parallel EI , perpendicular EI , parallel Fs, perpendicular Fs, NW, parallel MOE, parallel EI, parallel MOR, parallel FbS, parallel LE, perpendicular LE, IB, water ABS, edge swell, and axial compression.

	Plantation group	Natural group
EI 1n	**0.440**	**0.600**
	0.007	**0.000**
EI 2n	**-0.559**	0.137
	0.000	0.439
para Fs	-0.104	-0.228
	0.535	0.194
perp Fs	0.210	0.046
	0.249	0.795
NW	-0.059	-0.196
	0.725	0.265
para MOE	**0.602**	**0.732**
	0.000	**0.000**
para EI	**0.602**	**0.732**
	0.000	**0.000**
para MOR	0.171	0.180
	0.139	0.141
para FbS	0.171	0.180
	0.139	0.141
perp MOE	**-0.414**	**-0.260**
	0.000	**0.033**
perp EI	**-0.414**	**-0.260**
	0.000	**0.033**
perp MOR	-0.060	0.008
	0.610	0.950
perp FbS	-0.060	0.008
	0.610	0.947
para LE	**0.450**	0.189

	0.000	0.123
perp LE	**0.325**	**0.410**
	0.004	**0.001**
IB	**0.190**	-0.036
	0.019	0.674
Avg. % ABS	0.191	0.163
	0.099	0.184
Avg. % Edge	**0.297**	0.222
	0.009	0.069
para FcA	-0.228	0.070
	0.168	0.695
perp FcA	**-0.390**	**-0.341**
	0.016	**0.048**

*note: top cell= Pearson Correlation Coefficient, bottom cell= p-value

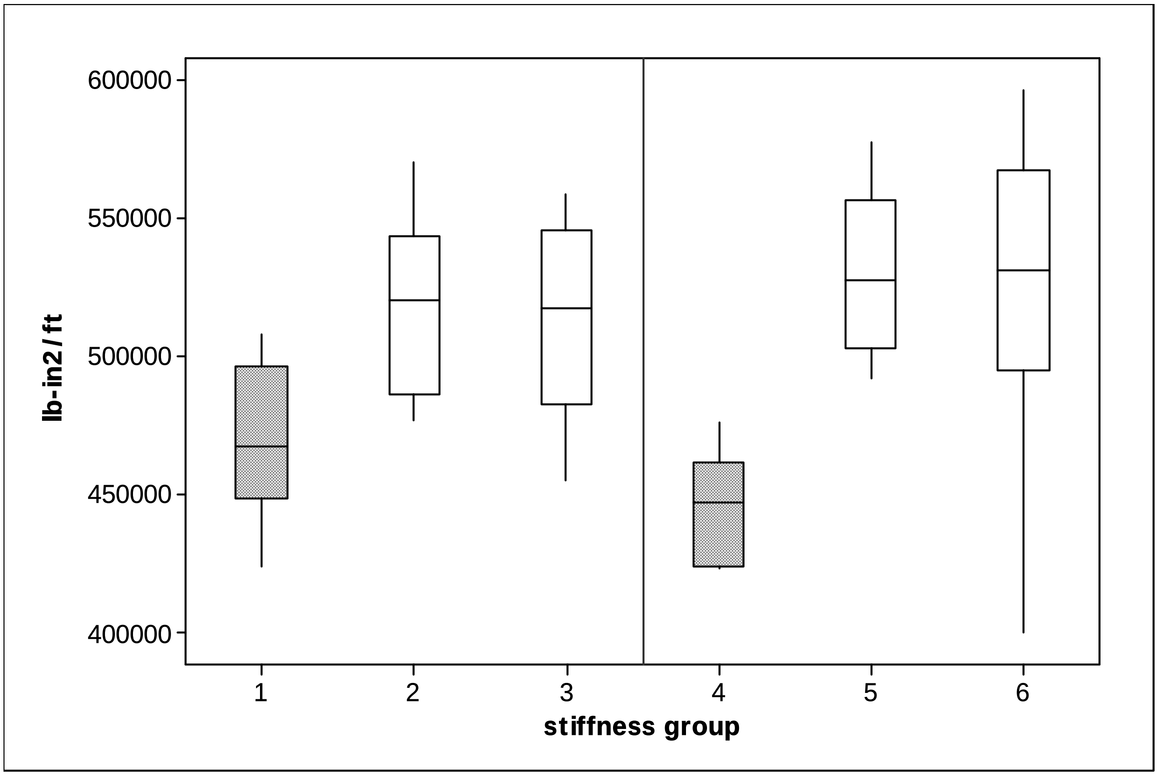

Figure 4.23. Plots of parallel full panel bending EI.
*note: significant differences denoted by patterned boxes.

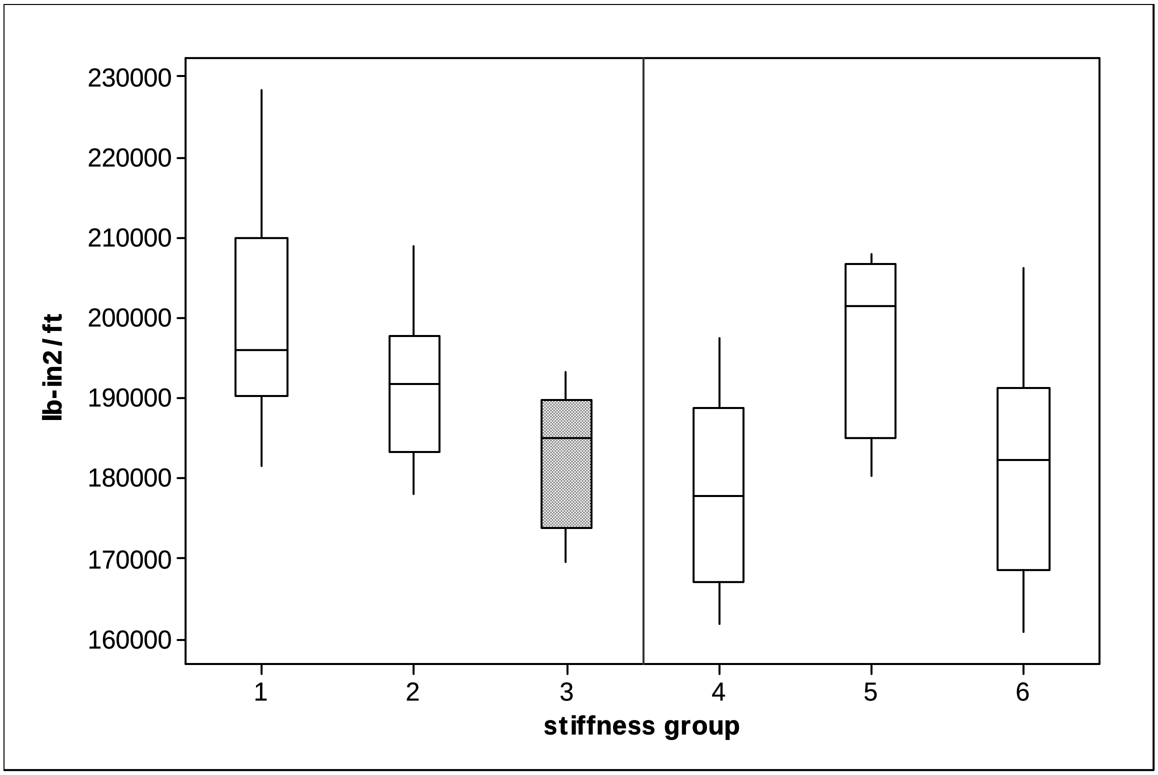

Figure 4.24. Plots of perpendicular full panel bending EI.
*note: significant differences denoted by patterned boxes.

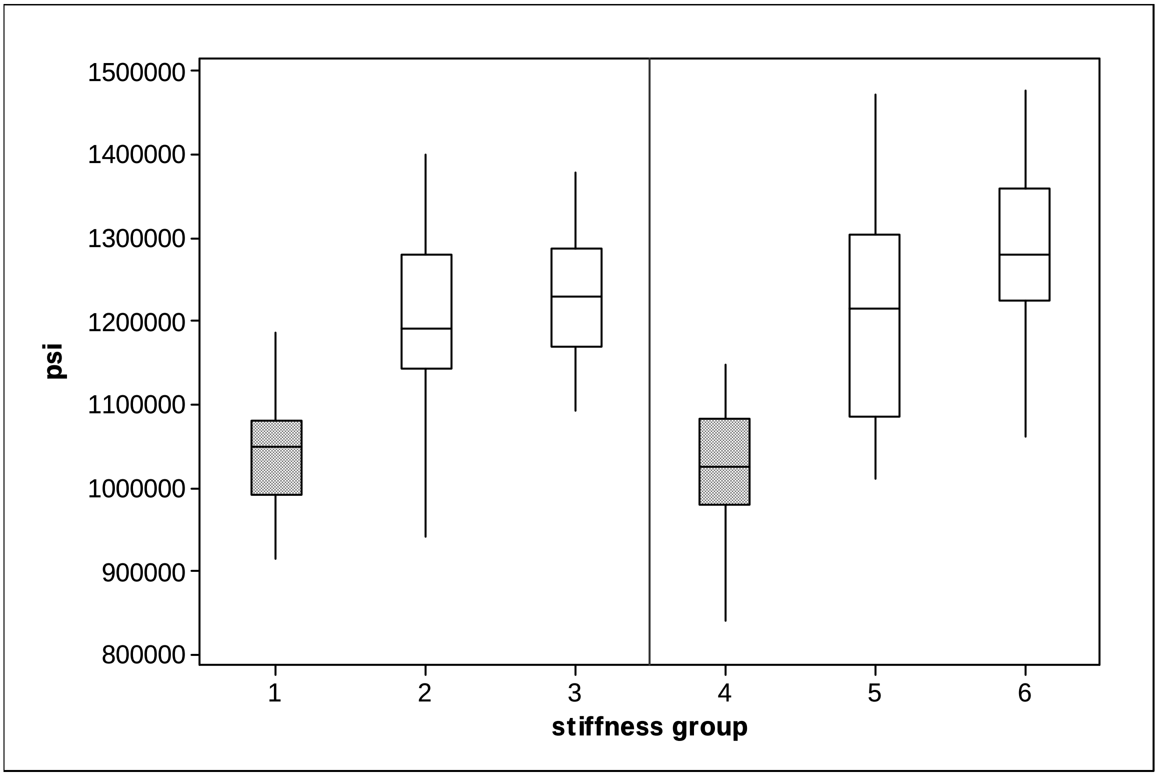

Figure 4.25. Plots of parallel small sample bending Modulus of Elasticity.
*note: significant differences denoted by patterned boxes.

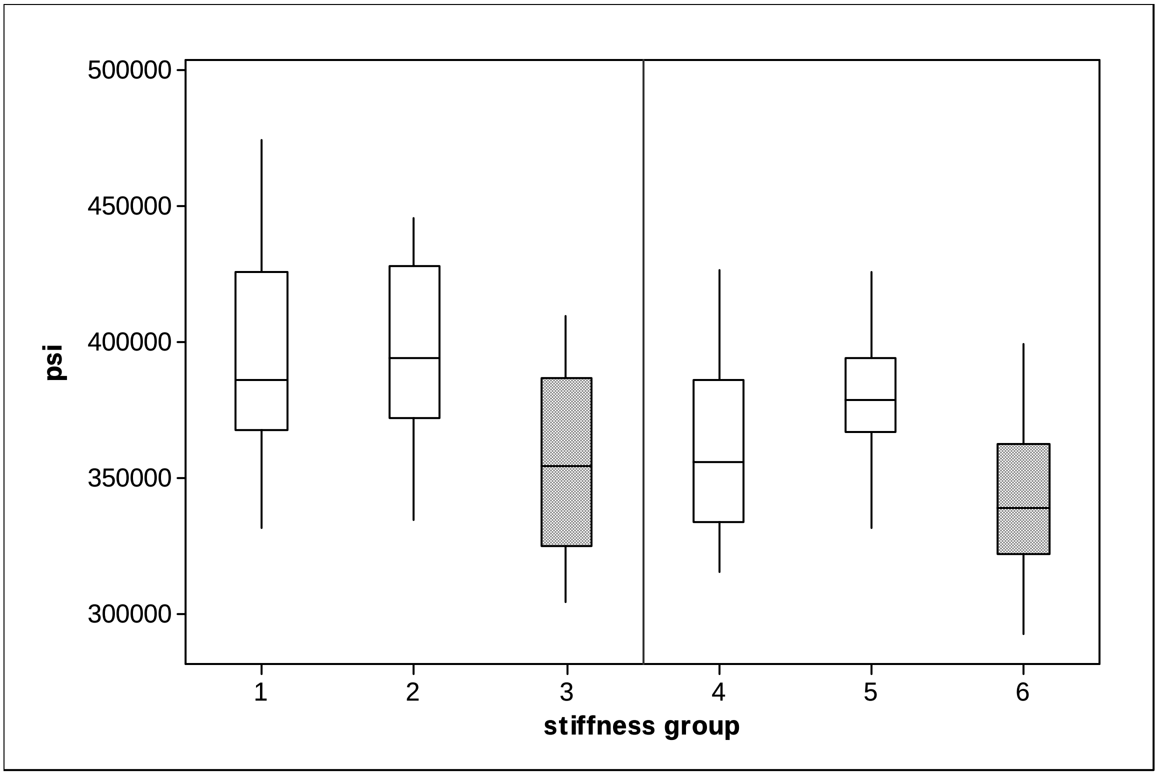

Figure 4.26. Plots of perpendicular small sample bending Modulus of Elasticity.
*note: significant differences denoted by patterned boxes.

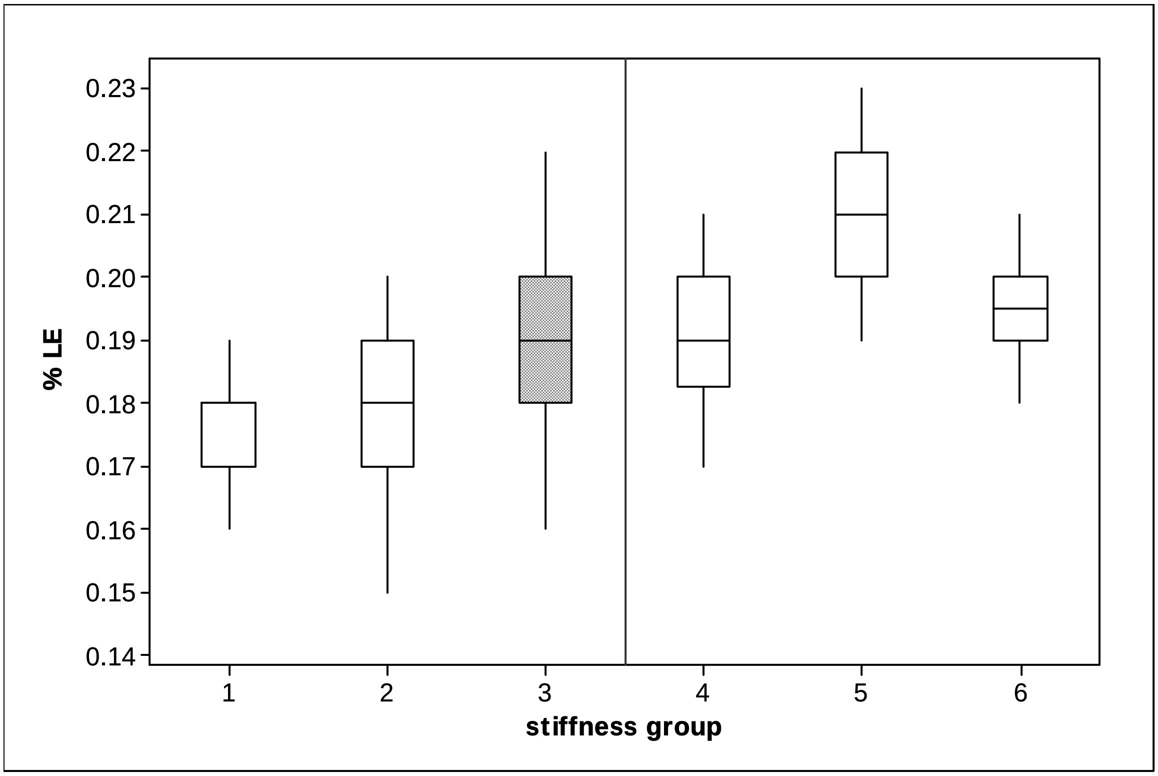

Figure 4.27. Plots of parallel linear expansion.
*note: significant differences denoted by patterned boxes.

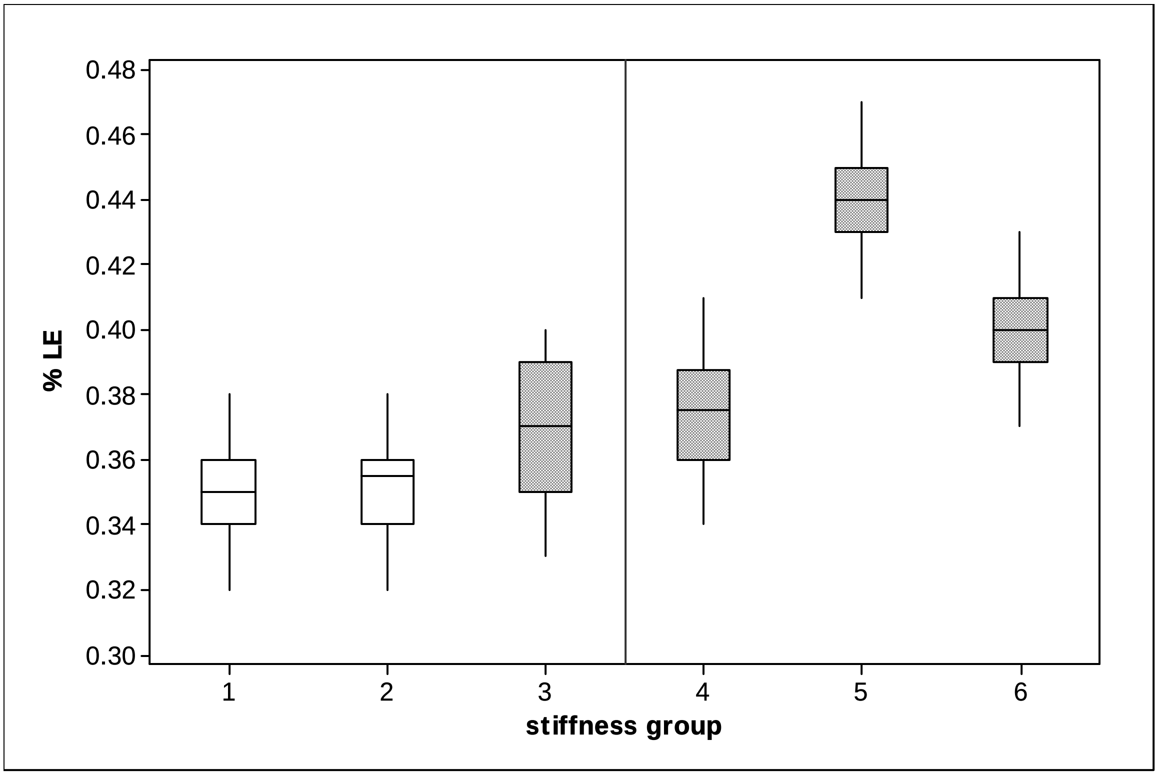

Figure 4.28. Plots of perpendicular linear expansion.
*note: significant differences denoted by patterned boxes.

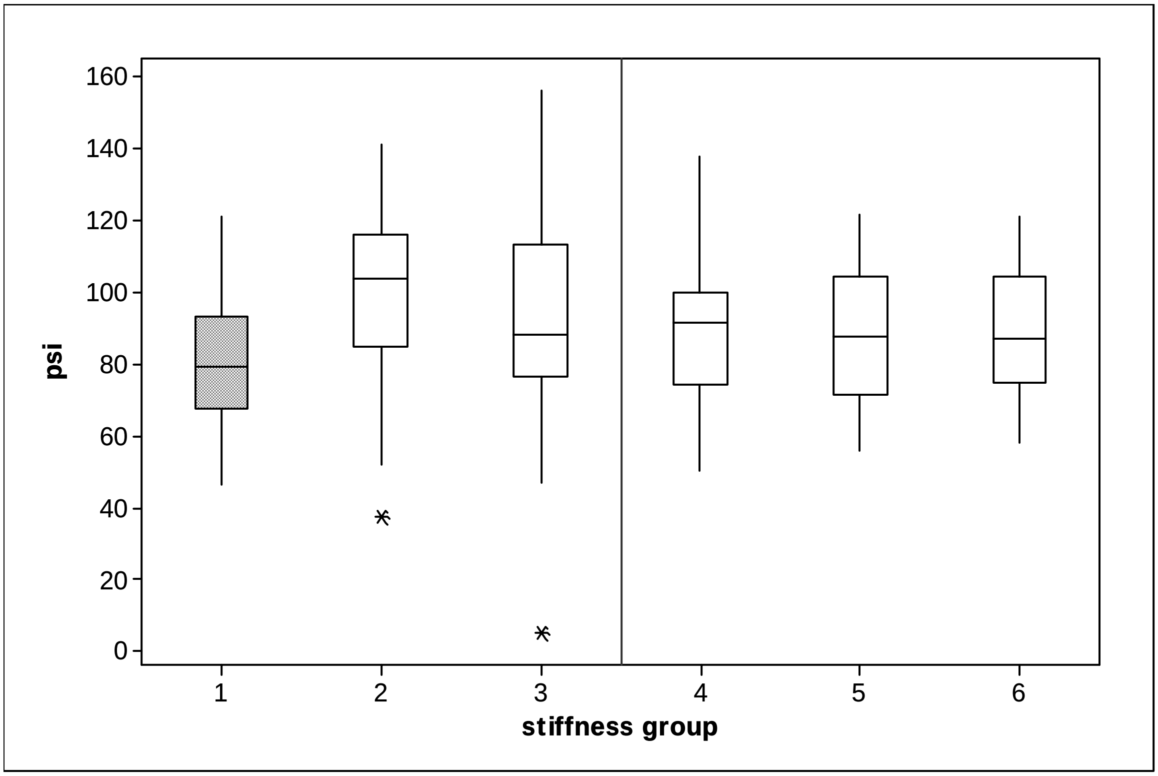

Figure 4.29. Plots of internal bond.
*note: significant differences denoted by patterned boxes.

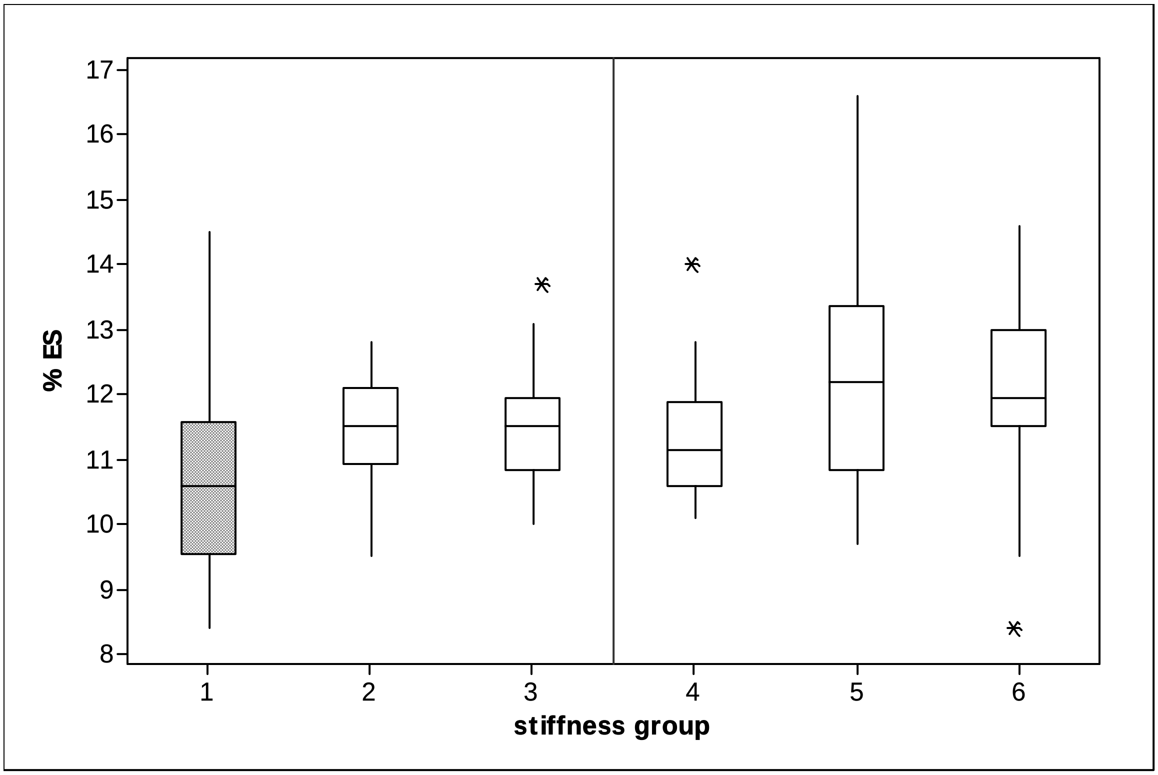

Figure 4.30. Plots of % edge swell.
*note: significant differences denoted by patterned boxes.

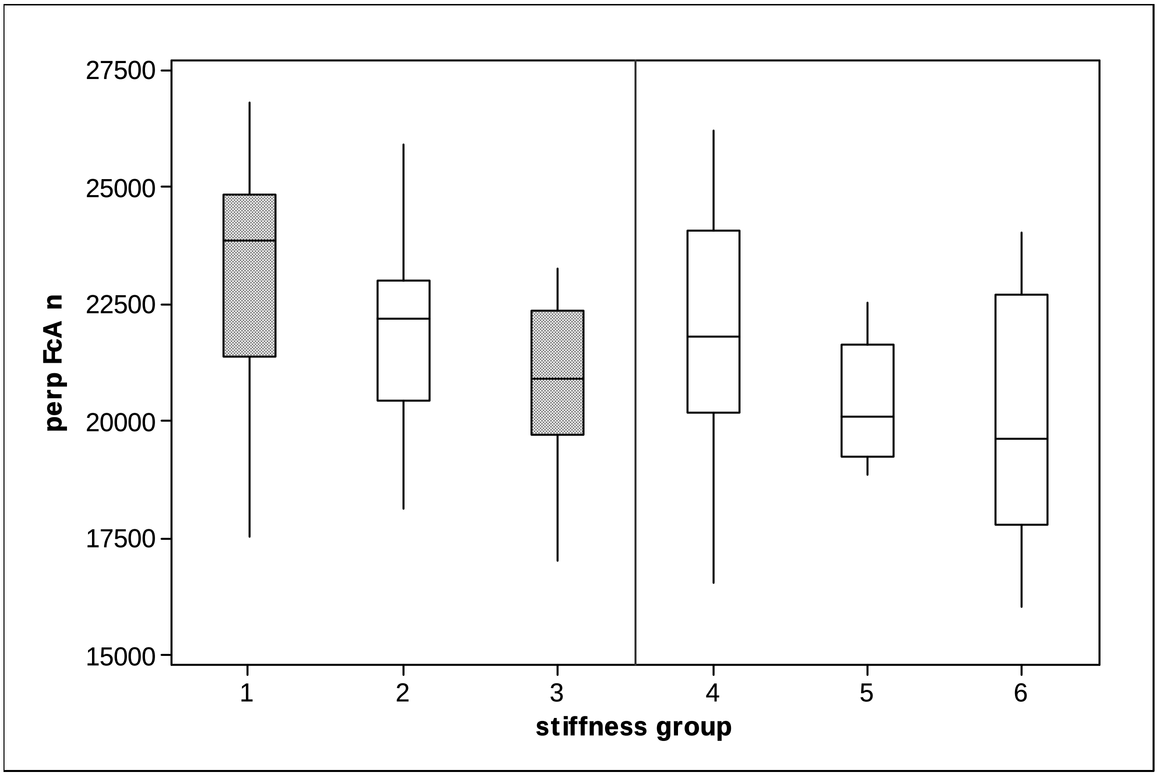

Figure 4.31. Plots of perpendicular axial compression.
*note: significant differences denoted by patterned boxes.

CHAPTER 5

CONCLUSIONS

The overall objective of this project was to determine if acoustic technology could be used to pre-sort logs for manufacturing high stiffness OSB panels. In order to carry out the major objective, many others had to be satisfied, including:

- Verification that log stiffness contributes to OSB panel stiffness;
- Establishment of the effects of log stiffness on other OSB properties;
- Determination of the stiffness range and percentage of high and low groups of logs entering the OSB facility;
- Investigation of correlations between other physical log properties that could be easier to measure in a manufacturing setting; and
- Determination of how to incorporate acoustic technology into normal manufacturing quality control operations.

The overall hypothesis was that pre-sorting logs using acoustic technology will give manufacturers a means of optimizing their current wood use by using high quality logs for structural products.

LOG PROPERTY DATA

Velocity differences were not detected between plantation grown trees and naturally grown trees. In addition the velocity groups had very similar low, medium, and high ranges, and statistical analysis showed no significant differences. A correlation analysis was conducted on log velocity and site location to determine if certain sites had low quality or high quality logs, but no trends were detected. No trends were seen in the plantation or the naturally grown trees, hence site could not be used as an indicator of log quality.

Relationships between log properties such as moisture content, specific gravity, diameter inside bark, age, and log length with log velocity were examined with the aim of using these properties as possible indicators of log quality. A few correlations were obtained, but all had very low R^2, so could not be used as quality indicators. Trends with velocity and some log properties were noted, so in areas of higher wood variability, it may be possible to find stronger relationships between velocity and other properties.

Time constraints restricted the study from being able to determine percentages of velocity groups entering the OSB facility, but the non-random sampling showed a normal distribution from low to high velocity over the 2 weeks that material was sampled. It is probable that the medium group represents the majority of the material delivered to the plant.

OSB PANEL DATA

Correlations were seen between log stiffness groups and full panel stiffness as well as small sample stiffness. Analysis showed that in general, the low log stiffness groups had poor full panel and small sample stiffness in the parallel machine direction. The middle and high log stiffness groups rarely performed differently from each other, hence the low groups negatively influenced OSB panel stiffness. This indicates that by removing the low stiffness logs from the material used to produce high quality structural panels, a higher stiffness panel will be produced. This creates opportunities to lower panel densities and reduce resin usage, as well as reducing downgrade.

Correlations were also seen between log stiffness groups and dimensional stability, internal bond, edge swell, and axial compression. The low log stiffness groups generally showed low internal bonding, better dimensional stability and edge swell, and higher axial compression. The high log stiffness groups showed the poorest results in perpendicular panel stiffness and dimensional stability. Typically those panel properties are controlled more by manufacturing operations than by raw material quality, so poor performance along the perpendicular strength axis is not a major concern for quality.

The overall goal was met in that the study showed log quality does affect OSB panel properties and acoustic technology can be used to pre-sort logs prior to processing in order to remove the damaging low stiffness logs from the high stiffness material for high strength structural panel production. However, incorporating the acoustic tools into a manufacturing facility was not completed and would be left up to the individual facilities as to how to sample material as well as the financial feasibility.

If a facility was to incorporate acoustic tools into their operations, the following approach could be used:

- Collect a random sample for baseline data. Record dates, how long the trees have been cut, where they came from, velocities, and tree lengths. It would also be beneficial to check green moisture contents. If they vary considerably, it might be necessary to use stiffness groups instead of velocity groups.
    - The baseline data needs to come from multiple days of sampling unless the wood baskets are very small and most of the basket area is delivered each day. However, the recommendation would be to sample approximately 20-30 trees for 4-5 days, limiting the sampling to 2 trees per truck.
- Calculate high, medium, and low velocity groups using the baseline data.

- Determine where is the best location for using the acoustic tool; before logs enter the plant, at the gate house, or in the log yard.
- Segregate the logs into piles based on velocity groups.
- Use the low velocity logs for low stiffness products, if there is not enough of the low material to sustain product demands, fulfill product customer demands with low and medium logs. Use the high velocity logs for high stiffness products, again using the middle logs to meet demand if necessary.
- The velocity groups need to be re-evaluated multiple times throughout the year to determine seasonality effects on log velocity and to ensure that the quality of logs being delivered to the facility is not changing.

The approach described above is one of many options as to how to incorporate acoustic tools into segregating material by log quality. Another similar approach could be used prior to plants purchasing wood if most of their logs come from procured trees. The approach would be conducted in the field as opposed to at the plant and the low velocity wood would not be purchased. Acoustic technology is also becoming commercially available to determine stiffness of standing trees. This would be another approach to determine log quality prior to purchase. However, the standing tree approach is not yet perfected and more research would need to be done.

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APPENDIX A

PSII 2004 AND APA PANEL CLASSIFICATIONS AND REQUIREMENTS

Table 1. Panel classification and descriptions. (PSII 2004)

Classification	Description
Bond Classification	The bond classification is related to the moisture resistance of the glue bond under intended end-use conditions and does not relate to the physical (erosion, ultraviolet, etc.) or biological (mold, fungal decay, insect, etc.) resistance of the panel.
- Exterior Plywood	A bond classification for plywood suitable for repeated wetting and redrying or long-term exposure to weather or other conditions of similar severity.
- Exposure 1 Plywood - Exposure 1 Composite Panels - Exposure 1 OSB - Exposure 1 Mat-formed panels	A bond classification for panels suitable for uses not permanently exposed to the weather. Panels classified as Exposure 1 are intended to resist the effects of moisture on structural performance due to construction delays, or other conditions of similar severity.
Grade	This Standard covers grades of structural-use panels designed and manufactured for sheathing, Structural I sheathing, and single-floor applications.
- Sheathing	A wood-based structural-use panel intended for use in construction applications as covering material for roofs, subfloors, and walls when fastened to supports spaced in accordance with the span rating.
- Structural I Sheathing (struc 1)	A wood-based structural-use panel similar to that described in Section 4.1.2.1., except that Structural I panels meet additional requirements in this Standard for cross-panel strength and stiffness and for racking load performance.
- Single Floor	A wood-based structural-use panel intended for use as combination subfloor and underlayment when fastened to supports spaced in accordance with the span rating.

Table 2. Performance standards for wood-based structural use panels. (PSII 2004)

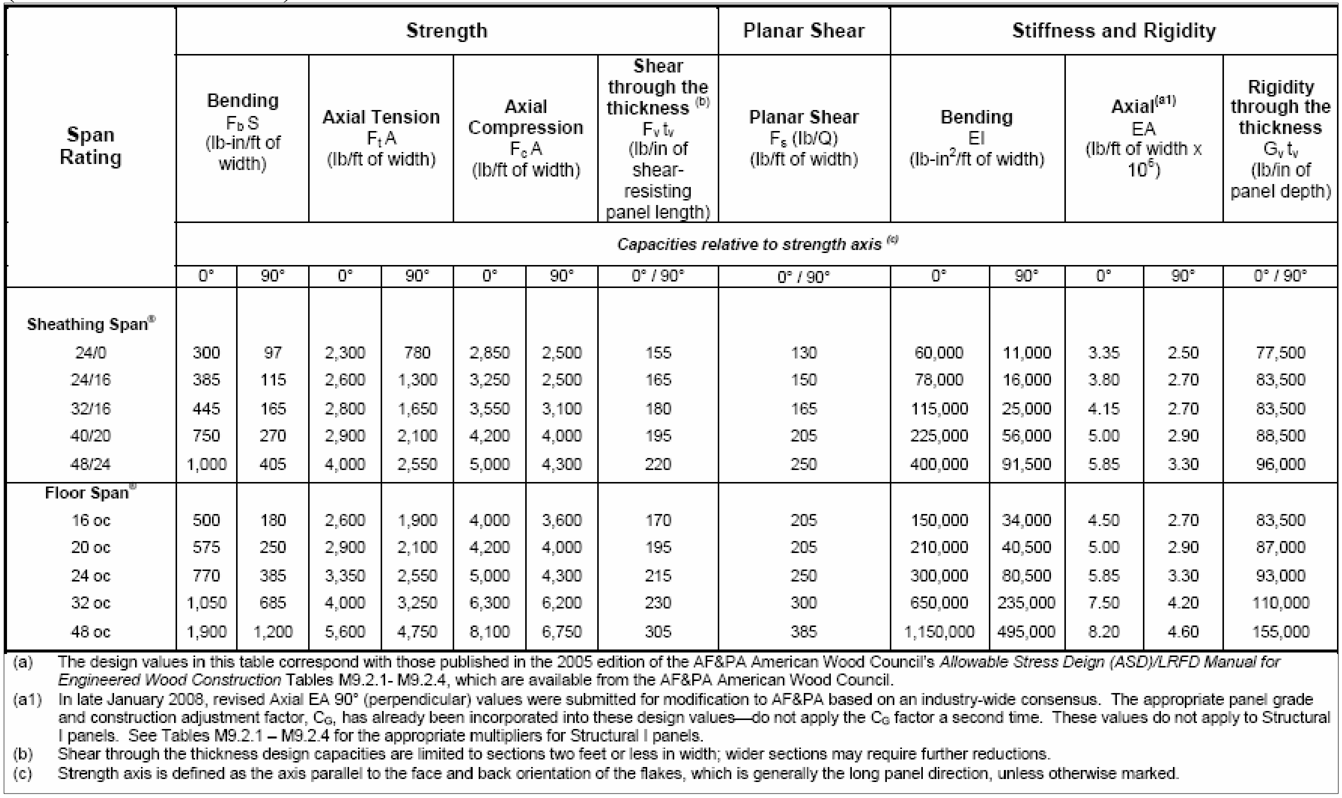
Requirements from PS II performance standard

5.1	General	
5.2	General Requirements	
5.2.1	Dimensional tolerances and squareness of panels	
5.2.1.1	Size	A tolerance of plus 0, 1/8" shall be allowed on specified length and/or width.
5.2.1.2	Thickness	A tolerance of plus or minus 1/32" shall be allowed on the trademark-specified thickness of 13/16" and less, and ±5% of the trademark-specified thickness for panels thicker than 13/16", unless a closer tolerance is determine through qualification testing.
5.2.1.3.	Squareness and straightness	Panels shall be square within 1/64" per lineal foot measured along the diagonals. All panels shall be manufactured so that a straight line drawn from one corner to the adjacent corner is within 1/16" of the panel edge.
5.2.2.	Wood materials	
5.2.2.1.	Veneer	Canadian Standard CAN/CSA-O325.0, which is the Canadian counterpart to PS 2, limits maximum size of knots and knotholes to 3" as measured across the grain.
5.2.2.2.	Other material	Other materials used in panel manufacture shall include particles or fiber produced by breaking down solid wood.
5.2.3.	Design and construction	Panels qualifying for a span rating are identified in three classes: plywood panels, composite panels, or mat-formed panels. Panels shall qualify on an individual panel construction basis for the grade and span rating upon demonstrated conformance to the appropriate requirements.
5.3.	Performance requirements	Structural-use panels to be trademarked in accordance with this Standard shall pass performance criteria established in three areas: structural performance, physical properties, and adhesive bond performance.
5.3.1.	Structural performance	Panels shall meet the performance requirements of Sections 5.3.1.1. through 5.3.1.4. when tested for each structural condition in accordance with the referenced test procedure.
5.3.1.1.	Concentrated loads	Panels shall be tested according to the procedures of Section 7.1. for concentrated static and impact loads. Panels shall conform to the criteria of Table 1 for the grade and span shown on the trademark. Panels to be identified as Structural I Sheathing and 7/16" or thicker shall also be tested according to the procedures of Section 7.1., with the framing members parallel to the strength axis direction, except the load shall be applied at panel mid-length. Minimum test panel size shall be 48" x 96". The framing shall be spaced 24" on center (o.c.). The panel ends shall not be supported by framing. Panels shall conform to the criteria of Table 1 for Roof - 24.
5.3.1.2	Uniform loads	Panels shall be tested according to the procedures of Section 7.2. for uniform loads. Panels shall conform to the criteria of Table 2 for the grade and span shown on the trademark.Panels to be identified as Structural I Sheathing shall also be tested according to procedures of Section 7.2. with the framing members parallel to the strength axis direction. Minimum test panel size shall be 48 x 48". The framing shall be spaced 24" o.c. The panel ends shall not be supported by framing. Panels shall conform to the criteriaof Table 3.

Table 3. Test standards used to measure properties. (PSII 2004)

ASTM standards Used for PSII	
E-72-02	Standard Test Methods for Conducting Strength Tests of Panels for Building Construction
E-661-88 (1997)	Standard Test Method for Performance of Wood and Wood-Based Floor and Roof Sheathing Under Concentrated Static and Impact Loads
D-1037-99	Standard Test Methods for Evaluating Properties of Wood-Base Fiber and Particle Panel Materials
D-1761-88 (2000)	Standard Test Methods for Mechanical Fasteners in Wood
D-3043-00	Standard Test Methods for Structural Panels in Flexure
D-4442-92 (2003)	Standard Test Methods for Direct Moisture Content Measurement of Wood and Wood-Base Materials
D-2915-03	Standard Practice for Evaluating Allowable Properties for Grades of Structural Lumber

Table 4. Wood Structural Panel Design Capacities Based on Span Ratings (www.tecotested.com)



Span Rating	**Strength**							**Planar Shear**	**Stiffness and Rigidity**				
	Bending $F_b S$ (lb-in/ft of width)		**Axial Tension** $F_t A$ (lb/ft of width)		**Axial Compression** $F_c A$ (lb/ft of width)		**Shear through the thickness** [(b)] $F_v t_v$ (lb/in of shear-resisting panel length)	**Planar Shear** F_s (lb/Q) (lb/ft of width)	**Bending** EI (lb-in^2/ft of width)		**Axial**[(a1)] EA (lb/ft of width x 10^6)		**Rigidity through the thickness** $G_v t_v$ (lb/in of panel depth)
	Capacities relative to strength axis [(c)]												
	0°	90°	0°	90°	0°	90°	0° / 90°	0° / 90°	0°	90°	0°	90°	0° / 90°
Sheathing Span®													
24/0	300	97	2,300	780	2,850	2,500	155	130	60,000	11,000	3.35	2.50	77,500
24/16	385	115	2,600	1,300	3,250	2,500	165	150	78,000	16,000	3.80	2.70	83,500
32/16	445	165	2,800	1,650	3,550	3,100	180	165	115,000	25,000	4.15	2.70	83,500
40/20	750	270	2,900	2,100	4,200	4,000	195	205	225,000	56,000	5.00	2.90	88,500
48/24	1,000	405	4,000	2,550	5,000	4,300	220	250	400,000	91,500	5.85	3.30	96,000
Floor Span®													
16 oc	500	180	2,600	1,900	4,000	3,600	170	205	150,000	34,000	4.50	2.70	83,500
20 oc	575	250	2,900	2,100	4,200	4,000	195	205	210,000	40,500	5.00	2.90	87,000
24 oc	770	385	3,350	2,550	5,000	4,300	215	250	300,000	80,500	5.85	3.30	93,000
32 oc	1,050	685	4,000	3,250	6,300	6,200	230	300	650,000	235,000	7.50	4.20	110,000
48 oc	1,900	1,200	5,600	4,750	8,100	6,750	305	385	1,150,000	495,000	8.20	4.60	155,000

(a) The design values in this table correspond with those published in the 2005 edition of the AF&PA American Wood Council's *Allowable Stress Deign (ASD)/LRFD Manual for Engineered Wood Construction* Tables M9.2.1- M9.2.4, which are available from the AF&PA American Wood Council.

(a1) In late January 2008, revised Axial EA 90° (perpendicular) values were submitted for modification to AF&PA based on an industry-wide consensus. The appropriate panel grade and construction adjustment factor, C_G, has already been incorporated into these design values—do not apply the C_G factor a second time. These values do not apply to Structural I panels. See Tables M9.2.1 – M9.2.4 for the appropriate multipliers for Structural I panels.

(b) Shear through the thickness design capacities are limited to sections two feet or less in width; wider sections may require further reductions.

(c) Strength axis is defined as the axis parallel to the face and back orientation of the flakes, which is generally the long panel direction, unless otherwise marked.