Spring 1999

Strength Properties of Juvenile and Mature Wood of Twelve Families of Loblolly Pine (Pinus Taeda L.)

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STRENGTH PROPERTIES OF JUVENILE AND MATURE WOOD OF TWELVE FAMILIES OF LOBLOLLY PINE (*PINUS TAEDA* L.)

by

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Presented to the Faculty of the Graduate School of
Stephen F. Austin State University
In Partial Fulfillment
of the Requirements

For the Degree of
Master of Science in Forestry

STEPHEN F. AUSTIN STATE UNIVERSITY
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ABSTRACT

The wood mechanical properties of progeny from twelve open-pollinated parent trees were examined. Six families were from parents which had high wood specific gravity and six were from parents which had low wood specific gravity. Thirty-two-year-old trees, that had been planted at Many, Louisiana, were sampled and juvenile and mature wood test specimens were prepared. Maximum crushing strength, modulus of rupture, modulus of elasticity and wood specific gravity were determined from compression parallel to the grain tests and static bending tests.

Maximum crushing strength, modulus of rupture, modulus of elasticity, and specific gravity were found to vary significantly between family and between wood-type (juvenile or mature) specimens. The family by wood-type interaction was found to be not significant for all of the four wood properties measured. The six highest total tree means for modulus of rupture and modulus of elasticity were for the six families that came from parents having high specific gravity. For both maximum crushing strength and wood specific gravity, only one of the six highest total tree means was from a family having a low specific gravity parent.

For all test specimens examined, the mean maximum crushing strength, mean modulus of rupture, mean modulus of elasticity, and mean wood specific gravity were found to be 6,386 pounds per square inch (p.s.i.), 13,546 p.s.i., 1,542,342 p.s.i., and .502 respectively. For the juvenile wood, the means for these four properties were 5,269 p.s.i., 11,462 p.s.i., 1,224,470 p.s.i., and .453 respectively. For the mature wood specimens, the means for these four properties were 7,438 p.s.i., 15,533 p.s.i., 1,845,514 p.s.i., and .548 respectively.

A strong, positive relationship was found between the mechanical strength properties and wood specific gravity. A strong, positive relationship was also found between modulus of rupture and modulus of elasticity. The results of this study appear to support the hypothesis that gains made in wood specific gravity, made through parent selection, are then also realized in improved mechanical properties of the wood produced from the progeny.

ACKNOWLEDGMENTS

The author wishes to express thanks to Dr. Malcolm MacPeak, who helped set up this study and to Dr. Ed Dougal, who took over the task of helping me complete the work. Much appreciation is also due for the help of Dr. J. P. van Buijtenen, Dr. W. J. Lowe, and Mr. Dewayne Weldon, with the Texas Forest Service, for their help with materials and gathering information on the original study. Also, thanks to Dr. Brenda Young and Ms. Lisa Ganio, who helped in the understanding of the statistical significance shown, to Mr. Leslie Dale and Dr. Gordon Holley for help with the use of SAS, and to Drs. Hans Williams, Gary Kronrad and Ray Darville, who helped to make the findings legible and complete. Finally, the author wishes to thank Merlin, Morgana, Montana and Kyrie, who put up with the author's abstraction during the entire process.

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INTRODUCTION

Loblolly pine (*Pinus taeda* L.) continues to be the major species of the southern pines that is planted, grown, and utilized throughout the southeastern United States. The species is established throughout this region primarily in plantations and there is increased economic pressure to accelerate growth and reduce the length of rotations. In addition to being a major source of pulp fiber, loblolly pine plantations provide sawlogs which are processed into a wide array of structural products. Many of these products are used in light-commercial frame and home construction. These end-uses require that the wood have sufficient strength properties to meet structural design requirements. Therefore, the mechanical strength properties of loblolly pine and factors that may influence these strength properties are very important to the forest products industries using this resource.

In the early 1950's, work aimed at the genetic improvement of loblolly pine grown in the southeastern United States was begun (Stonecypher and Zobel, 1966; van Buijtenen, 1962 and 1963; Zobel and McElwee, 1958; Zobel and Rhodes, 1956). These and subsequent studies examined a range of factors, including heritability of wood specific gravity and its natural variability

(Byram and Lowe, 1988; Dorman and Zobel, 1973; Matziris and Zobel, 1973; McKinley et. al., 1982).

The specific gravity of wood provides a measure of the dry mass of fiber per unit volume. Because of the direct relationship between specific gravity and pulp yield, this wood property remains one of the most important indicators of wood quality to this sector of the forest products industry.

Wood specific gravity is also directly and positively related to the strength of wood (Panshin and de Zeeuw, 1980). Within the loblolly pine species, well-established relationships exist between specific gravity and the mechanical strength properties, such as modulus of rupture and modulus of elasticity (Koch, 1972; Pearson and Gilmore, 1971).

Because of this direct relationship between strength properties and specific gravity and because of the relatively low costs and ease of measurement associated with the determination of specific gravity, this wood property is most often examined. Numerous investigations concerning the genetic improvement of loblolly pine have measured specific gravity and have, directly or indirectly, indicated that gains made in specific gravity would be reflected in the mechanical strength properties of the wood produced (Talbert et. al., 1983; Zobel, 1956). There appears to be little quantitative information concerning the mechanical properties of loblolly pine progeny. Moreover, parent-progeny relationships concerning parent specific gravity and progeny mechanical properties appear to be lacking. There is renewed concern that gains in specific gravity may not be reflected in improved mechanical properties. Because of factors such as fast growth rates and larger percentages of juvenile wood in logs, the nature of the relationship between wood strength and wood specific gravity may be altered. Differences in wood anatomical factors, such as microfibril angle or fiber length, associated with fast growth rates of juvenile wood could contribute to a change in the wood strength-wood specific gravity relationship.

OBJECTIVES

The objectives of this study are:

1.) For each of the six families of loblolly pine that came from parent trees having high specific gravity and for each of the six families that came from parent trees having low specific gravity:

   a.) determine the mean and standard deviation for maximum crushing strength based on compression parallel to the grain strength tests on juvenile and mature wood samples.

   b.) determine the mean and standard deviation for modulus of rupture and modulus of elasticity based on static bending strength tests on juvenile and mature wood samples.

   c.) determine the mean and standard deviation for specific gravity of juvenile and mature wood samples.

2.) Examine the effects of family and wood-type (juvenile and mature wood) on the maximum crushing strength, modulus of rupture, modulus of elasticity, and specific gravity of loblolly pine.

LITERATURE REVIEW

Mechanical Properties of Loblolly Pine

The mechanical properties of loblolly pine and the other southern pines, longleaf (*Pinus palustris* Mill.), shortleaf (*Pinus echinata* Mill.), and slash (*Pinus elliottii* Engelm.), have been reported in numerous sources. Koch (1972), using data from Bendtsen and Ethington (1972), reports the average clear wood maximum crushing strength obtained from compression parallel to the grain strength tests to be 6,940 pounds per square inch (p.s.i.) at 12% moisture content. In the green condition, where wood is normally much weaker, the average maximum crushing strength was 3,420 p.s.i. Koch (1972) also reports an average modulus of rupture of 12,600 p.s.i. and an average modulus of elasticity of 1,750,000 p.s.i. for loblolly pine when tested in static bending at 12% moisture content. The average unextracted specific gravity based on volume at 12% moisture content of the loblolly pine wood examined by Koch (1972) was .51.

Haygreen and Bowyer (1996) also report mechanical strength properties for loblolly pine. They report an average maximum crushing strength obtained from compression parallel to the grain strength tests of 7,130 p.s.i. at 12% moisture content. An average modulus of rupture of 12,800 p.s.i. and an average modulus of elasticity of 1,790,000 p.s.i., both obtained from static bending tests, are also reported by Haygreen and Bowyer (1996) for loblolly pine at 12% moisture content. In their study, the test samples had an average specific gravity based on volume at 12% moisture content of .51. Using a regression method, Bendtsen and Ethington (1972), as reported by Koch (1972), provide estimated standard deviations for a number of strength properties. The standard deviations in pounds per square inch for modulus of rupture, modulus of elasticity, and maximum crushing strength were 1,318 p.s.i., 350,000 p.s.i., and 679 p.s.i., respectively.

Pearson and Gilmore (1971) examined the static bending properties of loblolly pine in order to investigate whether juvenile wood was significantly different from mature wood of the species in relation to structural characteristics. These authors indicated that although lower strength properties are expected in juvenile wood due to its lower specific gravity, there was concern that the strength-density relationships in the juvenile wood might be found to differ from that in the mature wood. For loblolly pine, Pearson and Gilmore (1971) found the grand mean for modulus of rupture to be 13,300 p.s.i. and, for modulus of elasticity, found a grand mean of 1,800,000 p.s.i. While the juvenile wood strength properties were found to be generally lower than the mature wood strength properties, the authors concluded that the differences were primarily related to differences in specific gravity and not to inherent structural differences between juvenile and mature wood (Pearson and Gilmore, 1971). As would be expected, strong relationships were found between specific gravity and both modulus of rupture and modulus of elasticity. The correlation coefficients were 0.93 and 0.84, respectively (Pearson and Gilmore, 1971).

A positive correlation between specific gravity and wood strength properties is widely acknowledged (Kramer and Smith, 1956; Panshin and de Zeeuw, 1980; Pearson and Gilmore, 1971). Because of this, it is generally desirable to produce trees with higher specific gravity when solid wood products, used in structural applications, are the projected end use. Higher wood specific gravity in trees also gives a greater mass (weight) of fiber per unit volume and this usually results in greater pulp yields. Low specific gravity wood may be advantageous when producing pulp for fine paper, such as newsprint and tissue (Williams and Neale, 1992). Because of this, trees grown on short rotations may be used for this purpose.

Strength properties are known to vary within a species. Kramer and Smith (1956) studied strength property variation within trees, within location, and between locations for plantation grown slash pine. They found most of the variation to be between locations, with the least variation being within trees.

Tree and Wood Quality Improvement

Attempting to genetically change characteristics in a wild population may not be predictable since numerous characteristics may be related and these relationships may be positive or negative. Changing one trait may cause another to change adversely. The change may also negatively affect adaptability (Duffield, 1962). Thus the overall good of the forest must be taken into account and genetic diversity is important. One of the earliest used and most widely accepted methods of tree improvement is the use of "Plus trees" for seed orchards (Duffield, 1962). This method retains the trees with superior characteristics as the ones to be used in seed production.

According to Wright (1962), genetic gains in vigor and form of about 3% to 10% per generation can be expected, depending on the heritability of the trait. One or two traits should be selected that have high heritability. Seeds can be transferred within 750 feet in elevation and within 50 miles in latitude from their source and do well (Rehfeldt, 1980). A gain of 4% in height the first generation and a gain of 8% to 14% the next generation can be made if seeds are selected from the population of highest mean performance (Rehfeldt, 1980).

Progeny tests are an important way to evaluate any tree improvement program. They provide data for seed orchard roguing and serve as populations from which advanced generation selections are made (McKinley et. al., 1982).

Roguing is the practice of thinning a stand to upgrade for some specific genetic characteristic.

The Cooperative Forest Tree Improvement Program (Byram and Lowe, 1996) is currently using the single-tree plot design to assess its breeding and progeny testing program. This method reduces the plot size required to 0.33 acres and the number of trees to 150 (one tree per plot by 50 replications per location by three locations). The tree spacing is 6 by 8 feet to reduce variation within the replications.

Loblolly pine is well suited for genetic manipulation because of its wide range, and thus its genetic diversity (Dorman and Zobel, 1973). Talbert et. al., (1983) thought specific gravity to be the most heritable of the economically important wood traits. Any means of selecting for improved wood quality are especially important since timber producers are moving more and more to utilization of intensively managed, short rotation stands. The shorter rotation causes an overall drop in specific gravity, and thus wood quality, because of the greater proportion of juvenile wood present (Bendtsen, 1978).

Specific gravity is thought to be a highly heritable trait, having 73% of the variation explained by genetics (Nebgen and Lowe, 1983; Shelbourne et. al., 1967; Stonecypher and Zobel, 1966; McKinley et. al., 1982), though a value of 45% was also found (Talbert et. al., 1983). J.P. van Buijtenen (1963) found for loblolly pine that an increase of 3.5% above the average could be obtained by open-pollinated progeny selection.

This high level of heritability means that it is possible to select high quality parent trees for future improvements. The possible negative correlation between volume and specific gravity must be considered, but it is possible to make gains in both areas (Akachuku, 1984) by combining observed traits into a single index value for each tree when considering its value as a "plus tree" (Magnussen and Keith, 1990). With linked traits, care must be taken since an emphasis on one trait will produce a smaller response, either positive or negative, in the linked trait (Vargas-Hernandez and Adams, 1991).

Most findings agree that most of the variation in specific gravity is found in tree-to-tree differences within a site (Zobel and McElwee, 1958). Trees of the same age and diameter with clear boles for 65 feet that grew within ten feet of each other were found to have the highest and lowest specific gravities, respectively, for that site (Zobel, 1956).

J. P. van Buijtenen (1963) found that if one looked at trees of different genetic makeup on a site, there was no measurable correlation between specific gravity and wood growth rate. However, if one considered trees from one family, there was a negative correlation. A positive correlation was found when averaging an entire replication. J.P. van Buijtenen (1963) found this to mean that under uniform conditions, trees which are genetically predisposed to faster growth have lower specific gravity, but that given favorable conditions, the environment producing the faster growth would also produce trees with higher specific gravity.

Stem strength can also be studied indirectly by examining wood density and ring width (McKimmy and Campbell, 1982). Offspring of trees chosen for high specific gravity appear to have somewhat better overall appearance (van Buijtenen, 1963) and straightness of bole.

For tests done on clones of Monterey pine, the largest variation in specific gravity showed between clones with differences within a particular clone being relatively small. Specific gravity was influenced to a greater extent by differences in locality than by differences in site within a locality (Fielding and Brown, 1960).

Family rankings for specific gravity often change from site to site, but families tend to remain in their respective groupings of high or low density (McKinley et. al., 1982). This seems to indicate an effect of site on specific gravity with a genetically inherited tendency toward high or low specific gravity. Blankenhorn et. al. (1992), testing four management strategies on two sites with *Populus* clones, found significant difference in average specific gravity among management strategies at each site and between sites within management strategies.

Evaluation of trees for certain characteristics by marker-aided DNA selection is now becoming available, though it is not feasible on a large scale because of prohibitive costs. As more and more is known about the DNA of trees, using gene markers will be more accurate, and probably less costly. It is estimated to cost $2.50 to $5.00 per tree for in-lab assessment, to which field collection costs must be added, as opposed to $0.05 per tree to measure height and diameter (Williams and Neale, 1992).

Wood Specific Gravity and Related Factors

Specific gravity is determined by the cellular make-up of the wood. It is widely accepted that the greater the percentage of summerwood or latewood, the higher the specific gravity. Specific gravity is influenced by cell length and diameter, cell wall thickness, relative proportion of earlywood to latewood, cellulose and lignin content and extractive content (Talbert et. al., 1983).

The specific gravity of a tree changes as it matures. Juvenile wood is considered to be the wood produced in the first 7 to 10 growth rings from the pith in loblolly pine and has significantly lower specific gravity than mature wood (Bendtsen, 1978; Spurr and Hsiung, 1954; Talbert and Jett, 1981). Specific gravity in loblolly pine (*Pinus taeda* L.) changes from an average of .45 to .54 as it matures. This means a difference of 810 pounds per cord between mature and juvenile wood (Zobel and McElwee, 1958) because of the relatively lighter juvenile wood. Specific gravity increases from an average of .44 to .47 in sycamore (*Platanus occidentalis* L.) over the first 20 to 25 years, showing that 19% of the variation in specific gravity was accounted for by distance from the pith (Land, 1981).

Juvenile wood has shorter tracheids, thinner cell walls and a lower proportion of summerwood (Talbert et. al., 1983). Akachuku (1984) stated that, in hardwoods, fiber length increased from pith to bark and decreased with height in the tree. Juvenile wood also has a larger microfibril angle, erratic and sometimes greater longitudinal shrinkage, greater spiral grain and low strength properties (Bendtsen, 1978). The same effect is observed when wood from higher in the tree is tested (Spurr and Hsiung, 1954). Specific gravity decreases rapidly to about 22 feet above the ground in loblolly pine and then declines more gradually (Tauer and Loo-Dinkins, 1990). Mitchell (1964) found age to have the most effect on specific gravity, with maturity level of the wood accounting for most of the variation in specific gravity.

While juvenile wood has a lower specific gravity than mature wood, there is a direct, positive correlation between juvenile wood specific gravity and the subsequent mature wood specific gravity (Zobel, 1956 and 1957; Stonecypher and Zobel, 1966; Dorman and Zobel, 1973). Zobel and Rhodes (1956) found a correlation of .805 and .856 between juvenile and mature wood specific gravity at the 1% probability level in loblolly pine. They also found the relation to be curvilinear rather than linear.

Szymanski and Tauer (1991) believe that one way to offset the disadvantage of lower juvenile wood specific gravity is to select for trees that have an earlier transition to mature wood. These trees show an average of seven rings of juvenile wood with an additional three rings of transitional wood. The study showed that sources west of the Mississippi have the earliest transition, though they do not recommend fast changes from seed sources. They also recommend efforts to raise the specific gravity of the juvenile wood directly by selecting trees for higher specific gravity.

Specific gravity has been found to have a significant negative correlation with moisture content (Dorman and Zobel, 1973), height and diameter (Stonecypher and Zobel, 1966; Tauer and Loo-Dinkins, 1990) and volume (McKinley et. al., 1982). It was found to have a low negative correlation with compression wood (Shelbourne et. al., 1967). Wilkes (1989) found a negative correlation between specific gravity and winter rainfall in Monterey pine (*Pinus radiata* D. Don). Zobel (1957) found no correlation between growth rate from tree to tree and tracheid length, which influences specific gravity. Little correlation was found between specific gravity and growth rate (Zobel and McElwee, 1958; Fielding and Brown, 1960), ring width (Spurr and Hsiung, 1954) or rings per inch and moisture content (Kramer and Smith, 1956).

Dorman and Zobel (1973) found that many important wood characteristics were not highly correlated with specific gravity.

Nicholls and Waring (1977) tested the wood characteristics of trees on a partially droughty site by blocking water flow in one area, leaving one untouched and irrigating another area. They found both ring width and density increased on the irrigated site, indicating that it is possible to increase both growth and specific gravity of radiata pine at the same time under proper conditions. Byram and Lowe (1988) also found specific gravity to be environmentally sensitive when looking at loblolly pine in the Western Gulf Region.

Review of Previous Work Concerning Progeny on Which This Study Is Based.

Initial studies conducted by the Texas Forest Service involved open-pollinated progenies of loblolly pine parent trees selected for either high or low wood specific gravity (van Buijtenen, 1963). In total, 17 parent trees were used, eight of high wood specific gravity and nine of low wood specific gravity (van Buijtenen, 1963). Progeny trials were established at three locations. These were the Arthur Temple, Sr. Research Area near Alto, Texas, the Stephen F.

Austin Experimental Forest near Nacogdoches, Texas, and Hodges Garden, near Many, Louisiana.

The Arthur Temple, Sr. Research Area contained offspring of 17 parents, with 15 of these families planted in three replications. Two families were represented by only two replications. The trees were planted in rows of 25 trees from each family, with the assignment of family to a row being random within each replication. Progeny of 15 of the same families were planted in two replications in 26-tree rows at Stephen F. Austin Experimental Forest. At Hodges Garden, in Many, Louisiana, 12 of the 17 families were planted, with six being from high specific gravity parents and six being from low specific gravity parents. These offspring were planted in 49-tree plots, with the family to plot assignments being randomized within each replication (van Buijtenen, 1963). It was the loblolly pine progeny trees from this site which formed the basis for the present study.

At the time of these studies, in the mid-1950's, the rational for choosing parents of extremely high or low wood specific gravity was twofold. An assumption was made that strength properties would directly follow wood specific gravity variation. If specific gravity was found to be heritable, then gains in wood specific gravity could be obtained in the progeny. High wood specific gravity was desired to produce strong wood for construction and solid wood products. Low wood specific gravity was considered of value for the production of fine paper products. Improved paper properties could be obtained using pulp with fibers having thinner cell walls. Therefore, at the time, it appeared important to select for parent trees of low wood specific gravity to provide seed for progeny to serve this sector of the industry. In recent times, the pulp and paper industry has concentrated more on producing wood of high specific gravity and volume in order to obtain a greater mass of fiber more economically. Because of this shift in wood quality requirements, much of the current focus is concerned with the potential increases in wood specific gravity, which can be obtained through tree improvement programs.

At all three sites, the results following six years of growth (van Buijtenen, 1962 and 1963) showed that there were differences between progeny in height, diameter and wood specific gravity (van Buijtenen, 1963). For wood specific gravity, an expected gain in the order of 3.5% could be obtained based on a selection differential of one standard deviation. Gains of 4.4% in height and 6.3% for diameter were also reported (van Buijtenen, 1963). Similar results for height, diameter, and wood specific gravity were reported by McKinley et. al. (1982) for the same three progeny trials following further growth and wood specific gravity measurements.

An overall conclusion concerning wood specific gravity from these papers (McKinley, et. al., 1982; van Buijtenen, 1962 and 1963) was that this wood property is under strong genetic control and that increases in wood specific gravity in industrial loblolly pine plantations can be achieved. It appears to be implied that the gains made in wood specific gravity will be reflected in improved wood mechanical strength properties. In the present study, the mechanical strength properties of the wood obtained from the progeny trees grown at the Many, Louisiana site are examined.

MATERIALS

The wood material for this study was obtained from a progeny trial established in 1956 by the Texas Forest Service. The original study was in part concerned with the inheritance of wood specific gravity and the relationship between wood specific gravity and growth rate (van Buijtenen, 1963). For this experiment, seed was collected in 1956 from twelve open-pollinated loblolly pine parent trees located in nine counties in East Texas. These parent trees were chosen for having either very high or very low wood specific gravity, as determined from increment cores.

This selection strategy of choosing parents representing the two extremes of the specific gravity range was employed in order to assess whether or not specific gravity differences would be expressed in the offspring. It was hypothesized, as is often done in biological studies of this type, that if differences in a property are not observed when the extremes are examined, then further work is not warranted. If, however, differences in properties are found when extremes are examined, then additional work aimed at further defining these differences may be justified. In total, six parent trees were chosen having high specific gravity and six were chosen having low specific gravity.

A summary of the characteristics of the parent trees is presented in Table 1. The primary source of this information was field grade sheets (project 10.8-5) used by the Texas Forest Service, Research and Education Department. These sheets were entitled "Seed Tree Description". Copies of the completed sheets for the twelve parent trees may be found in the Appendix. Individual parent tree information including collection number, specific gravity, county of origin, age, diameter, and height (Table 1) were obtained from these field grade sheets.

As may be seen on the field grade sheets, specific gravity, listed as wood density in the field grade sheets, of each parent tree was determined from a "small core" and a "large core". Also, for most of the parent trees, the small core value represents an average of two to three values, which were measured and recorded. For most of the parent trees, an average of the small core and the large core is also provided and these are the values shown in column 3 of Table 1.

Additional information concerning the high or low ranking and specific gravity of the parent trees was obtained from Table 7 in a paper by van Buijtenen (1963) which summarized the early findings of the original progeny study. This information is presented in columns 1, 4, and 5 of Table 1. Parent tree specific gravity shown in van Buijtenen's paper (1963) appear to be the small core values, which perhaps were obtained prior to measurements on

Table 1. Characteristics for twelve open-pollinated parent trees on which the present study is based.

Parent Specific Gravity Ranking[1]	Specific Gravity: Field Grade Sheets[2]		Specific Gravity: van Buijtenen(1963)[1]		County of Origin in East Texas	Age (years)	Diameter (inches)	Height (feet)
	Parent Collection Number	Specific Gravity	Family Number	Specific Gravity				
High	2C (B)	.672	7	.647	Gregg	49	21.5	80
High	6-665 (C)	.651	6	.637	Montgomery	54	14.9	70
High	1-50	.636	9	.663	Bastrop	46	12.7	80
High	12-30	.634	2	.619	Gregg	50	18.3	95
High	6-44	.597	11	.625	Polk	32	13.4	100
High	15-39	.582	12	.652	Nacogdoches	33	19.1	80
Low	15-50	.491	10	.512	Nacogdoches	34	14.1	85
Low	2-17	.479	8	.468	Newton	32	16.5	85
Low	3-15	.475	4	.490	Jasper	45	16.0	75
Low	4-14	.473	1	.465	Liberty	41	16.7	95
Low	13-31	.465	5	.486	Cherokee	36	17.1	85
Low	7-34	.450	3	.450	Montgomery	30	15.3	85

[1]Information from van Buijtenen (1963).

[2]Information from field grade sheets completed by the Texas Forest Service, Research and Education Department, and entitled "Seed Tree Description". "Specific gravity" values listed in this table are reported as "wood density" values in the field grade sheets.

large cores. It should be noted that regardless of which parent tree specific gravity value from the field grade sheet is used, the ranking as either "high" or "low" as established by van Buijtenen (1963) remains the same (Table 1).

The seedlings were planted in late 1956 to early 1957 at a test site located at Hodges Garden in Many, Louisiana. Two replications of 49-tree plots were used for each family. In the original study, "blocks" refers to the fact that the trees were not planted in rows (van Buijtenen, 1963) and could otherwise be referred to as "plots". An illustration of how the twelve families were assigned to plots within each replication is shown in Figure 1.

Sometime after the final growth measurements were made (McKinley et. al., 1982), some of the trees were removed accidentally by loggers. The trial was also infested by southern pine beetle (*Dendroctonus frontalis* Zimm.) and was salvage-cut in 1988 at approximately 32 years of age. A total of 54 trees were salvaged. The identity of three trees was inadvertently lost. Presented in Table 2 is the identification number for each offspring within each family examined in this study, listed by replication and plot number. In total, 51 trees were examined, 24 offspring from high specific gravity parents and 27 offspring from low specific gravity parents (Table 2).

The trees were cut near the ground and, where possible, two bolts, each measuring six feet in length, were removed, starting at the base of the tree.

Figure 1. Illustration showing assignment of families[1] of high or low wood specific gravity[2] to plots within each replication at Hodges Garden, Many, Louisiana.

Replication One				Replication Two			
Plot 17 Family 8[1] low[2]	Plot 18 Family 12 high	Plot 19 Family 5 low	Plot 20 Family 3 low	Plot 21 Family 8 low	Plot 22 Family 1 low	Plot 23 Family 11 high	Plot 24 Family 10 low
Plot 9 Family 7 high	Plot 10 Family 4 low	Plot 11 Family 2 high	Plot 12 Family 10 low	Plot 13 Family 2 high	Plot 14 Family 4 low	Plot 15 Family 5 low	Plot 16 Family 7 high
Plot 1 Family 9 high	Plot 2 Family 11 high	Plot 3 Family 1 low	Plot 4 Family 6 high	Plot 5 Family 9 high	Plot 6 Family 12 high	Plot 7 Family 3 low	Plot 8 Family 6 high

[1] Family numbers from van Buijtenen (1963) and as shown in column 4 of Table 1.

[2] "High" or "low" is wood specific gravity ranking of parent trees as reported by van Buijtenen (1963) and as shown in column 1 of Table 1.

Table 2. Identification number for each offspring examined in this study.

Parent Specific Gravity Ranking[1]	Family Number[2]	Replication Number	Plot Number	Number of Offspring	Offspring Tree Identification Number
High	7	1	9	2	2008,2009
		2	16	2	2097,2103
High	6	1	4	2	2243,2249
		2	8	1	2295
High	9	1	1	1	2202
		2	5	3	2252,2260,2262
High	2	1	11	2	2028,2032
		2	13	2	2063,2064
High	11	1	2	2	2220,2222
		2	23	2	2129,2133
High	12	1	18	3	2321,2327,2337
		2	6	2	2268,2275
Subtotal				24	
Low	10	1	12	2	2044,2047
		2	24	2	2122,2127
Low	4	1	10	3	2016,2019,2022
		2	14	1	2081
Low	1	1	3	3	2228,2229,2230
		2	22	2	2141,2147
Low	8	1	17	3	2300,2308,2311
		2	21	2	2161,2165
Low	5	1	19	2	2340,2343
		2	15	2	2088,2094
Low	3	1	20	3	2170,2180,2185
		2	7	2	2284,2285
Subtotal				27	
Overall Total				51	

[1]High or low specific gravity ranking of parent tree as reported by van Buijtenen (1963) and as shown in column 1 of Table 1.

[2]Family numbers from van Buijtenen (1963) and as shown in column 4 of Table 1.

The bolts were transported from Many, Louisiana to the Texas Forest Service laboratory at Lufkin, Texas for further processing.

METHODS

Mechanical Test Specimen Preparation

The six foot bolts were sawn into boards measuring approximately one and one-half to two inches in thickness. Cutting of the bolts was done in such a way as to produce the largest amount of wood as quartersawn boards. Each board was numbered so as to maintain the identity of the tree and bolt. All boards were stored indoors for a number of years allowing them to dry well below fiber saturation point to a moisture content around 10 to 14 percent.

All boards were then planed to one inch in thickness and one edge was jointed. Starting from the jointed side, which provided a 90° angle against the guide, the boards were cut into one-inch wide strips about six feet in length on a band saw. These strips, now measuring one inch by one inch in cross-section, were examined and sorted as either juvenile or mature wood. Strips cut from within the first ten growth rings from the pith were considered juvenile wood. Strips cut that contained growth rings that were greater than ten rings from the pith were considered to contain mature wood.

Each strip was then examined for the presence of knots or excessive slope of grain. As many samples as was possible, 16 inches in length and free of defects, were cut from each strip. These samples were placed in a conditioning chamber and equalized to approximately 11% moisture content.

After conditioning, the samples were re-examined and a maximum of four samples containing juvenile wood and four samples containing mature wood from each bolt were selected for mechanical testing. Samples with the least slope of grain were selected. For each bolt, two juvenile wood samples and two mature wood samples were selected for compression strength tests. Two juvenile wood samples and two mature wood samples were also designated for bending strength tests.

Fewer than the maximum number of samples were available for testing from 17 of the trees. For fourteen trees, only one bolt was available for processing. For a further three trees, one of the bolts per tree contained excessive amounts of defect, resulting in fewer than the maximum number of samples. Presented in Table 3 is a summary of the number of compression and bending samples of either juvenile or mature wood from each bolt removed from each tree.

A minimum of three compression samples were produced from 49 of the 51 trees examined. No compression samples were produced from tree number

Table 3. Number of juvenile and mature wood samples per tree by bolt number for compression parallel to the grain and bending tests.

Parent Specific Gravity Ranking	Family Number	Offspring Tree Identification Number	Bolt One Juvenile Wood	Bolt One Mature Wood	Bolt Two Juvenile Wood	Bolt Two Mature Wood	Sample Totals
High	7	2008	2/2[1]	2/2	2/2	2/2	8/8
		2009	2/2	2/2	2/2	2/2	8/8
		2097	2/2	2/2	0/0	0/0	4/4
		2103	0/0	2/2	2/2	2/2	6/6
							26/26
High	6	2243	2/2	2/2	0/0	0/0	4/4
		2249	2/2	2/2	2/2	2/2	8/8
		2295	0/0	0/0	2/2	2/2	4/4
							16/16
High	9	2202	2/2	2/2	2/2	2/2	8/8
		2252	2/2	2/2	2/2	2/2	8/8
		2260	2/2	2/2	2/2	1/1	7/7
		2262	2/2	2/2	2/2	2/2	8/8
							31/31
High	2	2028	2/2	2/2	2/2	2/2	8/8
		2032	2/2	2/2	2/2	1/2	7/8
		2063	2/2	2/2	2/2	2/2	8/8
		2064	2/1	2/2	2/2	2/2	8/7
							31/31
High	11	2129	2/2	2/2	2/2	2/2	8/8
		2133	2/2	2/2	2/2	2/2	8/8
		2220	2/2	2/2	2/2	2/2	8/8
		2222	2/2	2/2	2/2	2/2	8/8
							32/32
High	12	2268	2/1	2/2	2/2	2/2	8/7
		2275	2/2	2/2	2/2	2/2	8/8
		2321	2/2	2/2	2/2	2/2	8/8
		2327	1/1	2/2	2/2	2/2	7/7
		2337	0/0	0/0	0/2	0/2	0/4
							31/34
	Subtotal						167/170

[1]"2/2" gives number of compression specimens followed by number of bending specimens.

Table 3. (cont.)

Parent Specific Gravity Ranking	Family Number	Offspring Tree Identification Number	Bolt One Juvenile Wood	Bolt One Mature Wood	Bolt Two Juvenile Wood	Bolt Two Mature Wood	Sample Totals
Low	10	2044	2/2[1]	2/2	2/2	2/2	8/8
		2047	2/2	2/2	2/2	2/2	8/8
		2122	0/0	0/0	2/2	2/2	4/4
		2127	1/2	2/2	2/2	2/2	7/8
							27/28
Low	4	2016	2/2	2/2	2/2	2/2	8/8
		2019	2/2	2/2	2/2	2/2	8/8
		2022	2/2	2/2	0/0	0/0	4/4
		2081	2/2	2/2	2/2	2/2	8/8
							28/28
Low	1	2141	2/2	2/2	1/1	2/2	7/7
		2147	0/2	2/2	0/0	0/0	2/4
		2228	0/0	0/0	1/2	2/1	3/3
		2229	2/2	2/2	2/2	2/2	8/8
		2230	2/2	2/2	2/2	2/2	8/8
							28/30
Low	8	2161	2/2	2/2	2/2	2/2	8/8
		2165	2/2	2/2	2/2	2/2	8/8
		2300	1/1	2/2	0/0	0/0	3/3
		2308	2/2	2/2	2/2	2/2	8/8
		2311	1/1	2/2	2/2	2/2	7/4
							34/34
Low	5	2088	1/2	2/2	2/2	2/2	7/8
		2094	2/2	2/2	2/2	2/2	8/8
		2340	0/0	0/0	2/2	2/2	4/4
		2343	0/0	0/0	2/2	2/2	4/4
							23/24
Low	3	2170	0/0	0/0	2/2	2/2	4/4
		2180	2/2	2/2	0/0	0/0	4/4
		2185	1/1	2/2	2/2	2/2	7/7
		2284	2/0	2/2	2/1	2/2	8/5
		2285	2/2	2/2	0/0	0/0	4/4
							27/24
Subtotal							167/168
Overall Totals							334/338

[1]"2/2" gives number of compression specimens followed by number of bending specimens.

2337 (Family 12, Table 3), while only two compression samples were produced were from tree number 2147 (Family 1, Table 3). Again, for most trees, a total of eight compression samples were available. In total, 334 samples were used for compression tests (Table 3). A minimum of three bending samples were produced from each of the 51 trees examined in this study. For most trees a total of eight bending samples were available. In total, 338 samples were used for bending tests (Table 3).

Compression Parallel to the Grain Mechanical Strength Test

The 16-inch samples designated for compression tests (Table 3) were further reduced in length to four inches prior to testing. Also prior to testing, the length, breadth, depth, and weight of each specimen was measured and recorded. In addition to these measurements, the number of growth rings present on the end grain surface of each specimen was recorded. The one inch by one inch by four inch specimens were tested in compression parallel to grain in accordance with the American Society of Testing Materials (ASTM) Standard, D143-83 (American Society of Testing Materials, 1990).

Each specimen was tested to failure parallel to the grain at a rate of 0.12 inch of compression per minute, using a 100,000 pound Tinius-Olsen testing machine. Following the test, the maximum load at failure in pounds was recorded for each specimen. Each specimen was then oven-dried to constant weight in a convection oven maintained at 103°C, plus or minus 3°C. After drying, the oven-dry weight of each specimen was measured and recorded.

Using the weight obtained prior to testing (green weight) and the weight obtained after oven-drying (oven-dry weight), the moisture content in percent at the time of testing was calculated for each specimen. The average moisture content of the 334 compression specimens was found to be 11.26% with a standard deviation of 0.61%.

The maximum crushing strength (MCS) expressed in pounds per square inch was calculated using Formula 1 below:

Formula 1. $$MCS = L/(B*D)$$

Where:

MCS = Maximum crushing strength in pounds per square inch

L = Maximum load at failure in pounds

B = Breadth of test specimen in inches

D = Depth of test specimen in inches

The specific gravity of each test specimen was also determined, based on oven-dry weight and volume at 11% moisture content. The test specimen's oven-dry weight was divided by its volume and this value was then divided by the density of water. The length, depth, and breadth measurements for each test specimen, measured at the time of test, was used to compute the volume.

Static Bending Mechanical Strength Test

The one inch by one inch by 16 inch samples designated for bending tests (Table 3) were tested in static bending in accordance with the ASTM Standard, D143-83 (ASTM, 1990). Prior to testing, the length, breadth, and depth of each specimen was measured and recorded. The number of growth rings present on the end grain surface of each specimen was recorded and a drawing made of the orientation of the rings.

Each specimen was tested to failure using a 100,000-pound Tinius-Olsen testing machine using center-point loading with a 14 inch span. A speed of loading of 0.1 inch of deflection per minute was used. As each bending test occurred, a plot, which graphed the amount of deformation (x-axis) per unit of load (y-axis), was produced on a chart recorder. After the test was completed, a smaller wood sample measuring approximately two inches in length was cut from near the center of the 16 inch specimen but not too close to were the break occurred. Each two-inch wood block was weighed, oven-dried to constant weight, re-weighed, and percent moisture content calculated. The average moisture content for the 338 static bending specimens was 11.14%, with a standard deviation of 0.62%. Due to an inadvertent oversight, the lineal dimensions of the two-inch wood samples were not measured. Therefore, it was not possible to obtain specific gravity values for the static bending test specimens.

Using the load-deformation graph, the maximum load was recorded as the highest point achieved during the test as measured on the y-axis. This highest point occurred just prior to failure and the maximum load value at this point was used in the calculation of the modulus of rupture. From the elastic portion (straight-line portion) of the graph, the amount of deformation per unit of load was recorded. This straight-line portion of the graph, which is found before the proportional limit is reached, represents the amount of deformation (bend) of the test specimen which is fully recoverable. The applied load and deformation values obtained from this portion of the graph were used in the calculation of the modulus of elasticity.

The modulus of rupture (MOR) was calculated using Formula 2 below:

Formula 2. $$MOR = (1.5*MAX*S)/(B*D^2)$$

Where:

MOR = Modulus of rupture in pounds per square inch

MAX = Maximum load at failure in pounds

S = Span between supports in inches

B = Breadth of test specimen in inches

D = Depth of test specimen in inches

The modulus of elasticity (MOE) was calculated using Formula 3 below:

Formula 3. $$MOE = (P*S^3)/(4*B*D^3*F)$$

Where:

MOE = Modulus of elasticity in pounds per square inch

P = Applied load in pounds

S = Span between supports in inches

B = Breadth of test specimen in inches

D = Depth of test specimen in inches

F = Deflection corresponding to applied load in inches

Analyses

Four data sets were analyzed using the general linear model procedure of the analysis of variance. These data sets consisted of 334 maximum crushing strength values and 334 specific gravity values obtained from the compression strength tests and 338 modulus of rupture values and 338 modulus of elasticity values obtained from the bending strength tests. Each of the four data sets were first examined for normality using residual plots and found to be normally distributed. Therefore, no transformations were performed on any of the four data sets.

As stated earlier in the Materials section, the original experimental design had only two replications. This aspect of the original study was noted by van Buijtenen (1963), who indicated that the experiment at this location had less precision. Noting this design limitation, it was decided in the present study to analyze all four data sets without replication as a separate factor in the analysis of variance.

A summary of the sources of variation and degrees of freedom for the analysis of variance is shown in Table 4. A split plot design was used with the whole plot having family as a main factor. The family factor included the six high specific gravity families and the six low specific gravity families as

Table 4. Summary of sources of variation and degrees of freedom for analysis of variance used in the present study.

Source of Variation	Degrees of Freedom
Whole Plot	
Family	11
Error A	12
Subtotal	23
Split Plot	
Wood-type	1
Family by Wood-type	11
Error B	12
Subtotal	24
Total	47

summarized earlier in Table 1. Within the split plot, wood-type was the main factor and included two levels, the juvenile and mature wood test results. The split plot also included the family by wood-type interaction. Due to missing bolts and the unbalanced number of samples prepared from each 6-foot bolt within a tree, bolt results were combined for each tree. In the analysis of variance, significance of main effects and the interactions were tested at the 95% confidence level. Results found to be significant at the 99% level were also noted.

Means and standard deviations were calculated for each of the four wood properties examined for the juvenile and mature wood samples within each family. A "total tree" average was computed for each family, as the average of the juvenile and mature wood averages. The total tree averages were computed in this way because of the unequal number of juvenile and mature wood sample values within each family. If "total tree" averages had been computed based on individual sample results, these averages would be weighted toward either the juvenile or mature group, whichever had the largest number of samples.

The original progeny trial, planted in Many, Louisiana (van Buijtenen, 1963), was based on a selection of six parent trees having high specific gravity and six parent trees having low specific gravity. Because of this strategy involving the selection of parents at two ends of the specific gravity range, it was decided not to conduct statistical tests aimed at separation of wood property means between individual families. Instead, a qualitative assessment was made of differences in each of the four wood properties between the high and low specific gravity family groups.

RESULTS AND DISCUSSION

Compression Parallel to the Grain Strength Tests

Maximum Crushing Strength

Analysis of variance results including sums of squares, mean squares, F-values, and level of significance for maximum crushing strength obtained from the compression parallel to the grain strength tests are presented in Table 5. The mean maximum crushing strengths and standard deviations for juvenile and mature wood specimens for each of the 12 families are presented in Table 6. Also presented in Table 6 are "total tree" averages for the maximum crushing strength based on the average of the juvenile and mature averages. The six highest maximum crushing strength means for the juvenile, mature and total tree categories are also noted (Table 6).

It may be seen in Table 5 that mean maximum crushing strength varied significantly between family ($P = 0.0240$) and between the juvenile and mature wood specimens ($P = 0.0001$). The family by wood-type interaction was found to be not significant. Family 12, from a high specific gravity parent, had the

Table 5. Analysis of variance for maximum crushing strength of *Pinus taeda* L. wood from compression parallel to the grain tests.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F-value	Probability[1] Value
Whole Plot					
Family	11	7995333.960	726848.542	3.36	0.0240*
Error A	12	3474635.590	289552.966		
Subtotal	23	11469968.550			
Split Plot					
Wood-type	1	59953730.539	59953730.539	276.91	0.0001**
Family by Wood-type	11	1489012.569	135364.779	0.63	0.7775
Error B	12	2598135.914	216511.326		
Subtotal	24	64040879.022			
Total	47	75510847.572			

[1] "*" denotes significance at the 95% confidence level and "**" denotes significance at the 99% confidence level.

Table 6. Mean maximum crushing strength in pounds per square inch, standard deviation, and number of samples for juvenile and mature wood for 12 families of *Pinus taeda* L.

Parent Specific Gravity Ranking	Family Number	Juvenile Wood			Mature Wood			Total Tree		
		Number of Samples	Mean[1]	Standard Deviation	Number of Samples	Mean	Standard Deviation	Number of Samples	Mean	Standard Deviation
High	7	12	5034	550	14	6966	912	2	6000	
High	6	8	6054*	634	8	7438*	952	2	6746*	
High	9	16	5993*	945	15	7909*	1047	2	6951*	
High	2	16	5018	1015	15	7789*	741	2	6404*	
High	11	16	5351*	912	16	7699*	574	2	6525*	
High	12	15	5928*	1114	16	7958*	698	2	7443*	
Subtotal		83	5537	991	84	7655	866	6	6678	494
Low	10	13	5113	718	14	7420	562	2	6267	
Low	4	14	5138*	1058	14	7274	645	2	6206	
Low	1	12	4761	765	16	6577	617	2	5669	
Low	8	16	4600	733	18	7208	1060	2	5904	
Low	5	11	4962	827	12	7245	752	2	6104	
Low	3	13	5405*	893	14	7765*	519	2	6585*	
Subtotal		79	4987	858	88	7231	798	6	6123	315
Total		162	5269	966	172	7438	856	334	6386	1416

[1] "*" indicates highest six values in each column.

highest total tree mean maximum crushing strength, with a value of 7,443 (Table 6) pounds per square inch (p.s.i). The lowest mean of 5,669 p.s.i. was found for Family 1, which was from a low specific gravity parent (Table 6).

The overall mean maximum crushing strength obtained in this study, based on all 334 specimens, of 6,386 p.s.i. (Table 6) was found to be 8% lower than that reported by Koch (1972). Koch (1972) reports a value of 6,940 p.s.i. for loblolly pine at 12% moisture content. Specimen specific gravity, moisture content, and method of obtaining test specimens from trees differed between the two studies and would, in part, contribute to the difference between the two means.

Five out of six families having a high specific gravity parent produced five of the highest total tree mean maximum crushing strengths (Table 6). Of the six highest values, only Family 3, with a total tree mean maximum crushing strength of 6585 p.s.i. (fourth highest, Table 6), had a low specific gravity parent. The variation in mean total tree maximum crushing strength based on 334 samples was found to be 1,416 p.s.i., as indicated by the standard deviation (Table 6). This variation is greater than that reported by Koch (1972), who found a maximum standard deviation for compression strength parallel to grain of 679. In the present study, the within tree sampling resulted in a relatively large number of juvenile wood specimens. This may have contributed to the differences between the standard deviation reported by Koch (1972) and that given in the present study.

The mean maximum crushing strength for the 162 juvenile wood specimens was found to be 5,269 p.s.i. (Table 6). Based on analysis of variance results for the "wood-type" factor (Table 5), this mean for the juvenile wood was found to be significantly lower (P = 0.0001) than the mean for the 172 mature wood specimens of 7438 p.s.i. (Table 6).

A similar variation in mean maximum crushing strength was found for the juvenile and mature wood, as shown by their standard deviations of 966 and 856, respectively (Table 6). The ranking of family means for the mature wood specimens showed five of the six highest values coming from families with parents of high specific gravity (Table 6). Family 3, with a mean maximum crushing strength of 7,765 p.s.i., was the single family from a low specific gravity parent (Table 6). This mature wood mean ranked fourth highest, the same ranking as found for the total tree value discussed earlier. For the juvenile wood specimens, four families out of six from those with high specific gravity parents had mean maximum crushing strengths which fell within the ranking of the highest six. Families 4 and 3, which came from low specific gravity parents, had mean maximum crushing strengths of 5,138 and 5,405 p.s.i., respectively (Table 6). These were the fourth and sixth highest mean maximum crushing strength values of the 12 families examined (Table 6).

Based on the total sample of 334 test specimens, the relationship between maximum crushing strength and specific gravity was examined. A significant correlation (n = 334, r = 0.86, P-value = 0.0001) was found between these two properties. This positive relationship between specific gravity and strength properties is well established (Koch, 1972; Kramer and Smith, 1956; McKimmy and Campbell, 1982; Panshin and de Zeeuw, 1980) and results from the present study appear to further support this finding. Individual relationships between the maximum crushing strength and specific gravity for the juvenile wood and mature wood specimens were also examined. Significant correlations were found for the juvenile wood specimens (n = 162, r = 0.66, P-value = 0.0001) and for the mature wood specimens (n = 172, r = 0.81, P-value = 0.0001).

Static Bending Strength Tests

Modulus of Rupture

Analysis of variance results including sums of squares, mean squares, F-values, and level of significance for modulus of rupture obtained from the static bending strength tests are presented in Table 7. The means and standard deviations for modulus of rupture for the juvenile and mature wood specimens

Table 7. Analysis of variance for modulus of rupture of *Pinus taeda* L. wood obtained from static bending tests.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F-value	Probability[1] Value
Whole Plot					
Family	11	50321267.92	4574660.7	7.62	0.0007**
Error A	12	23420320.73	1951693.3		
Subtotal	23	73741588.65			
Split Plot					
Wood-type	1	195452405.06	195452405.0	325.57	0.0001**
Family by Wood-type	11	4100642.15	372785.6	0.62	0.7808
Error B	12	7204006.48	600333.8		
Subtotal	24	206756053.69			
Total	47	280497642.34			

[1]"*" denotes significance at the 95% confidence level and "**" denotes significance at the 99% confidence level.

for each of the 12 families are presented in Table 8. The total tree averages for modulus of rupture are also presented. The six highest family means out of the 12 families examined have also been identified in Table 8 for each of the juvenile, mature, and total tree categories.

Mean modulus of rupture varied significantly between family (P = 0.0007, Table 7) and between the juvenile and mature wood specimens (P = 0.0001, Table 7). Family 9, which came from a high specific gravity parent, had the highest total tree mean modulus of rupture of 14,784 p.s.i. Family 1, which came from a low specific gravity parent, had the lowest mean of 11,988 p.s.i. (Table 7). The overall mean modulus of rupture for all specimens averaged over all 12 families was found to be 13,546 p.s.i. (n=338, Table 8). This mean modulus of rupture was found to differ by 6% from the value of 12,800 p.s.i. for loblolly pine reported by Haygreen and Bowyer (1996). This mean modulus of rupture was found to also differ by 7% from the value of 12,600 p.s.i. reported by Koch (1972) for the same species. The variation of the mean, as indicated by the standard deviation of 3,036 p.s.i. obtained in this study (n = 338, Table 8), was found to be higher than the value of 1,318 p.s.i. reported by Bendtsen and Ethington (1972) as cited by Koch (1972).

The six highest total tree means, of the twelve families examined, for modulus of rupture were from the six families that came from parents of the high specific gravity group (Table 8). The average modulus of rupture for these

Table 8. Mean modulus of rupture in pounds per square inch, standard deviation, and number of samples for juvenile and mature wood for 12 families of *Pinus taeda* L.

Parent Specific Gravity Ranking	Family Number	Juvenile Wood			Mature Wood			Total Tree		
		Number of Samples	Mean[1]	Standard Deviation	Number of Samples	Mean	Standard Deviation	Number of Samples	Mean	Standard Deviation
High	7	12	12113*	1584	14	16712*	2427	2	14413*	
High	6	8	12878*	1728	8	15862*	1756	2	14370*	
High	9	16	12942*	2679	15	16625*	1921	2	14784*	
High	2	15	11800*	1705	16	16126*	1997	2	13963*	
High	11	16	12056*	1304	16	16484*	1899	2	14270*	
High	12	16	12532*	2470	18	16587*	1677	2	14560*	
Subtotal		83	12360	2002	87	16443	1922	6	14393	276
Low	10	14	10158	2318	14	14978	1956	2	12568	
Low	4	14	11713	2005	14	15000	2201	2	13357	
Low	1	15	10288	2008	15	13687	2341	2	11988	
Low	8	16	9878	1588	18	14612	3223	2	12245	
Low	5	12	10544	1619	12	13849	1557	2	12197	
Low	3	11	10941	2278	13	15577	1389	2	13259	
Subtotal		82	10554	2013	86	14613	2305	6	12602	578
Total		165	11462	2197	173	15533	2306	338	13546	3036

[1]"*" indicates highest six values in each column.

families was 14,393 p.s.i. and the average for the six families from parents with low specific gravity was 12,602 p.s.i. (Table 8). For the six families from high specific gravity parents, Family 2 had the lowest total tree mean modulus of rupture of 13,963 p.s.i.. This mean was 606 p.s.i. higher than the highest value of 13,357 p.s.i., found for Family 4, which was within the low parent wood specific gravity group (Table 8).

The largest difference, of 2,796 p.s.i., was found between the mean of 14,784 p.s.i. for Family 9, which came from a high specific gravity parent, and the mean of 11,988 p.s.i. for Family 1, which came from a low specific gravity parent. These results for modulus of rupture appear to support the hypothesis that the wood of offspring from parent trees having high specific gravity will give higher breaking loads as measured by modulus of rupture.

The mean modulus of rupture for the 165 juvenile wood specimens averaged over all 12 families was 11,462 p.s.i. (Table 8). The mean modulus of rupture for the 173 mature wood specimens was 15,533 p.s.i. and this was 26% higher than the mean for the juvenile specimens. This difference was found to be significant (P = 0.0001) in the analysis of variance (Table 7). Based on these two means, the mature wood to juvenile wood ratio for modulus of rupture was found to be 1.36. These modulus of rupture results for juvenile and mature wood are consistent with previous reports (Haygreen and Bowyer, 1996; Koch, 1972; Panshin and de Zeeuw, 1980), where the lower strength properties of juvenile wood are well documented. The standard deviation for the juvenile wood specimens was 2,197 p.s.i. (n = 165, Table 8) which was similar to the standard deviation of 2,306 p.s.i. (n = 173, Table 8) for the mature wood specimens.

Based on the results of the analysis of variance, no significant difference was found for the family by wood-type interaction (P = 0.7808, Table 7). The six highest means for modulus of rupture, based on the juvenile wood specimens, all came from parents of high specific gravity (Table 8). The same result was found for the mature wood specimens and was also the same for the total tree results discussed earlier.

Modulus of Elasticity

Analysis of variance results including sums of squares, mean squares, F-values, and level of significance for modulus of elasticity obtained from the static bending strength tests are presented in Table 9. The means and standard deviations for modulus of elasticity for the juvenile and mature wood specimens for each of the 12 families are presented in Table 10. The total tree averages for modulus of elasticity are also presented. The six highest family means out of the 12 families examined are indicated in each of the juvenile, mature, and total tree categories (Table 10).

Mean modulus of elasticity varied significantly between families

Table 9. Analysis of variance for modulus of elasticity of *Pinus taeda* L. wood, obtained from static bending tests.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F-value	Probability[1] Value
Whole Plot					
Family	11	9.661570E+11	8.783246E+10	6.17	0.0020**
Error A	12	3.063974E+11	2.553312E+10		
Subtotal	23	1.272554E+12			
Split Plot					
Wood-type	1	4.480243E+12	4.480243E+12	314.72	0.0001**
Family by Wood-type	1	8.082785E+10	7.347986E+09	0.52	0.8584
Error B	12	1.708259E+11	1.423549E+10		
Subtotal	24	4.731896E+12			
Total	47	6.004450E+12			

[1]"*" denotes significance at the 95% confidence level and "**" denotes significance at the 99% confidence level.

Table 10. Mean modulus of elasticity in pounds per square inch, standard deviation, and number of samples for juvenile and mature wood for 12 families of *Pinus taeda* L.

Parent Specific Gravity Ranking	Family Number	Juvenile Wood			Mature Wood			Total Tree		
		Number of Samples	Mean[1]	Standard Deviation	Number of Samples	Mean	Standard Deviation	Number of Samples	Mean	Standard Deviation
High	7	12	1344853*	231404	14	1903721*	226732	2	1624287*	
High	6	8	1480450*	1480450	8	2120666*	291649	2	1800558*	
High	9	16	1433320*	407911	15	2045171*	332203	2	1739246*	
High	2	15	1249397*	387411	16	1854688	302917	2	1552043*	
High	11	16	1260038*	306795	16	1986983*	378485	2	1623511*	
High	12	16	1353136*	338015	18	1880760*	328542	2	1616948*	
Subtotal		83	1342972	339813	87	1949602	320270	6	1659432	91815
Low	10	14	1053957	407140	14	1774357	278379	2	1414157	
Low	4	14	1222105	274364	14	1706369	311722	2	1464237	
Low	1	15	986556	331131	15	1591106	263663	2	1288831	
Low	8	16	1076356	310223	18	1804875	320507	2	1440616	
Low	5	12	1135614	266411	12	1670759	221281	2	1403187	
Low	3	11	1187143	322694	13	1886535*	255248	2	1536839	
Subtotal		82	1104523	323402	86	1740216	288770	6	1424645	81763
Total		165	1224470	351701	173	1845514	321745	338	1542342	457915

[1] "*" indicates highest six values in each column.

(P = 0.0020, Table 9) and between the juvenile and mature wood specimens (P = 0.0001, Table 9). Family 6, which came from a high specific gravity parent, had the highest total tree mean modulus of elasticity of 1,800,558 p.s.i. (Table 10). Family 1, which came from a low specific gravity parent, had the lowest mean of 1,288,831 p.s.i. (Table 10). The difference between these two means was 511,727 p.s.i. The overall mean modulus of elasticity for all specimens from the 12 families was found to be 1,542,342 p.s.i. (n=338, Table 10). This mean modulus of elasticity was found to differ by 16% from the value of 1,790,000 p.s.i. for loblolly pine reported by Haygreen and Bowyer (1996) and by Summitt and Sliker (1980). It was also found to differ by 12% from the value of 1,750,000 p.s.i. reported by Koch (1972) for the same species. The variation of the mean, as indicated by the standard deviation of 457,915 p.s.i. obtained in this study (n = 338, Table 10), was found to differ by 24% from the standard deviation of 350,000 p.s.i. that was reported by Bendtsen and Ethington (1972), as cited by Koch (1972).

The six highest total tree means for modulus of elasticity, of the 12 families examined, were for the six families which came from parents of high specific gravity (Table 10). The average modulus of elasticity was 1,659,432 p.s.i. for the six highest total tree means and the average for the six lowest total tree means was 1,424,645 p.s.i. (Table 10). Family 2 had the lowest whole tree mean modulus of elasticity of 1,552,043 p.s.i. from the high parent specific gravity group. This mean was 15,204 p.s.i. higher than the highest mean from the low parent specific gravity group, which was Family 3 with a mean of 1,536,839 p.s.i. (Table 10).

The mean modulus of elasticity for the 165 juvenile wood specimens averaged over all 12 families was 1,224,470 p.s.i. (Table 10). The mean modulus of elasticity for the 173 mature wood specimens was 1,845,514 p.s.i. and this was 34% higher than the mean for the juvenile specimens. This difference was found to be significant (P = 0.0001) in the analysis of variance (Table 9). Based on these two means, the mature wood to juvenile wood ratio for modulus of elasticity was found to be 1.51. As with the maximum crushing strength and modulus of rupture results discussed earlier, these modulus of elasticity results for juvenile and mature wood are consistent with previous reports (Haygreen and Bowyer, 1996; Koch, 1972; Panshin and de Zeeuw, 1980), where the lower strength properties of juvenile wood are well documented. The standard deviation for the juvenile wood specimens was 351,701 p.s.i. (n = 165, Table 10) which was similar to the standard deviation of 321,745 p.s.i. (n = 173, Table 10) for the mature wood specimens.

Based on the results of the analysis of variance, no significant difference was found for the family by wood-type interaction (P = 0.8584, Table 9). The six highest means for modulus of elasticity, based on the juvenile specimens, were from the six families which came from high specific gravity parents (Table 10).

For the mature wood specimens, Family 3, from a low specific gravity parent (Table 10), had a mean modulus of elasticity of 1,886,535 p.s.i. and this was within the six highest averages (Table 10).

The relationship between modulus of rupture and modulus of elasticity obtained from each bending test specimen was examined. These two bending strength properties were found to have a high positive correlation, with a correlation coefficient of 0.90 and a P-value of 0.0001 (n = 338). The relationship between modulus of rupture and modulus of elasticity forms the basis for the non-destructive machine stress grading of softwood lumber intended for structural products in sawmills. Pearson and Gilmore (1971) reported a correlation coefficient of 0.91 between modulus of rupture and modulus of elasticity for loblolly pine using wood from other than the butt logs. The correlation based on values from wood of the butt logs was not as high (Pearson and Gilmore, 1971).

Specific Gravity

Analysis of variance results including sums of squares, mean squares, F-values, and level of significance for specific gravity are presented in Table 11. The mean specific gravity and standard deviations for juvenile and mature wood specimens for each of the 12 families are presented in Table 12. Also

Table 11. Analysis of variance for specific gravity of *Pinus taeda* L. wood.

Source of Variation	Degrees of Freedom	Sums of Squares	Mean Squares	F-value	Probability[1] Value
Whole Plot					
Family	11	0.03353707	0.00304882	7.36	0.0009**
Error A	12	0.01478885	0.00123240		
Subtotal	23	0.04832592			
Split Plot					
Wood-type	1	0.12140768	0.12140768	293.25	0.0001**
Family by Wood-type	11	0.00216381	0.00019671	0.48	0.8859
Error B	12	0.00496808	0.00041401		
Subtotal	24	0.12853957			
Total	47	0.17686549			

[1]"*" denotes significance at the 95% confidence level and "**" denotes significance at the 99% confidence level.

Table 12. Mean specific gravity, standard deviation, and number of samples for juvenile and mature wood for 12 families for *Pinus taeda* L.

Parent Specific Gravity Ranking	Family Number	Juvenile Wood			Mature Wood			Total Tree		
		Number of Samples	Mean[1]	Standard Deviation	Number of Samples	Mean	Standard Deviation	Number of Samples	Mean	Standard Deviation
High	7	12	.414	.059	14	.555*	.053	2	.485	
High	6	8	.474*	.041	8	.548	.051	2	.511*	
High	9	16	.486*	.049	15	.580*	.074	2	.533*	
High	2	16	.449	.037	15	.575*	.049	2	.512*	
High	11	16	.473*	.038	16	.575*	.041	2	.524*	
High	12	15	.487*	.064	16	.568*	.048	2	.528*	
Subtotal		83	.474	.050	84	.568	.053	6	.516	.017
Low	10	13	.419	.037	14	.525	.043	2	.472	
Low	4	14	.459*	.044	14	.553	.049	2	.506*	
Low	1	12	.427	.032	16	.505	.034	2	.466	
Low	8	16	.414	.030	18	.522	.064	2	.468	
Low	5	11	.415	.025	12	.520	.035	2	.468	
Low	3	13	.451*	.046	14	.556*	.043	2	.504	
Subtotal		79	.431	.040	88	.529	.049	6	.481	.019
Total		162	.453	.050	172	.548	.055	334	.502	.071

[1] "*" indicates highest six values in each column.

presented in Table 12 are “total tree” averages for specific gravity based on the average of the juvenile and mature averages. The six highest means out of the 12 families examined for juvenile, mature and total tree specific gravity are also noted (Table 12).

It may be seen in Table 11 that mean specific gravity varied significantly between families (P = 0.0009) and between the juvenile and mature wood specimens (P = 0.0001). The family by wood-type interaction was found to be not significant (P = 0.8859, Table 11).

Family 9, from a high specific gravity parent, had the highest total tree specific gravity, with a value of .533 (Table 12). The lowest mean of .466 was found for Family 1, which was from a low specific gravity parent (Table 12). The overall mean specific gravity obtained in this study, based on all 334 specimens, was found to be .502 (Table 12). This mean specific gravity was approximately 2% lower than the specific gravity of .51, at 12% moisture content, reported by Haygreen and Bowyer (1996) and by Koch (1972). Given the strong relationship between specific gravity and strength properties (Panshin and de Zeeuw, 1980), the higher specific gravities in these two studies may in part account for the somewhat higher strength properties for loblolly pine reported by these authors.

Five out of six families having high specific gravity parents produced five of the highest total tree mean specific gravities (Table 12). Only Family 4, which was from a low specific gravity parent and had a mean total tree specific gravity of .506, was within the highest six mean values for the 12 families studied (Table 12).

The mean specific gravity for the 162 juvenile wood specimens was found to be .453 (Table 12). Based on analysis of variance results for the "wood-type" factor, this mean was significantly lower (P = 0.0001, Table 11) than the mean for mature wood of .548 (Table 12). These specific gravity results appear consistent with those of Zobel and McElwee (1958), who found the juvenile wood and mature wood specific gravity at breast height to be .45 and .54 respectively for loblolly pine. Pearson and Gilmore (1971) found comparable specific gravity for loblolly pine of .474 and .525 for juvenile and mature wood, respectively, measured at 3 feet above the ground. In the present study, similar standard deviations of .050 (n = 162) and .055 (n = 172) were found for the juvenile and mature wood specific gravity, respectively (Table 12).

Five out of the six highest specific gravity means for the mature wood specimens were for families that had high specific gravity parents (Table 12). Only Family 3, from a parent with low specific gravity, ranked in the highest six, with a specific gravity of .556 (Table 12). Four out of the six highest specific gravity means for the juvenile wood specimens were from families with parents of high specific gravity (Table 12). Families 4 and 3, from low specific gravity parents, with means of .459 and .451, respectively, ranked in the highest six (Table 12).

These family specific gravity results for the juvenile, mature and total tree categories appear to further substantiate the wood specific gravity results, from the same progeny trial, reported by McKinley et. al. (1982). These authors found relatively high family heritabilities for wood specific gravity based on progeny planted at Many, Louisiana and progeny planted at the two other locations in East Texas. They indicate that such heritabilities would be expected, given that parents were selected to represent the extremes of wood specific gravity.

SUMMARY AND CONCLUSIONS

In this study, the mechanical properties of 12 loblolly pine families were examined. Six families had parent trees of high wood specific gravity, based on increment core measurements. Six families had parent trees of low specific gravity. Based on the results obtained concerning the effect of family and wood-type (juvenile or mature wood) on the mechanical properties, the following summary statements and conclusions have been drawn.

1. Based on compression parallel to the grain strength tests, maximum crushing strength was found to vary significantly between family. Five out of six families from the high parent wood specific gravity group and one family from the low parent wood specific gravity group had the six highest total tree means for maximum crushing strength. The overall total tree mean maximum crushing strength based on all 12 families of loblolly pine was 6,386 p.s.i. and was found to be 8% lower than that reported by Koch (1972) for the same species.

2. The mean maximum crushing strength for the 172 mature wood specimens from all 12 families was 7,438 p.s.i. and was significantly greater than the mean of 5,269 p.s.i. found for the 162 juvenile wood specimens. The family by wood-type interaction was found to be not significant.

3. Based on wood specific gravity values determined from the compression test specimens, strong correlations were found between maximum crushing strength and juvenile, mature, and total tree wood specific gravity. It appears from these results that differences between the mean maximum crushing strengths of the juvenile and mature wood are largely due to specific gravity variation.

4. Based on static bending strength tests, modulus of rupture was found to vary significantly between family. Six out of the six families from the high parent wood specific gravity group had the six highest total tree means for modulus of rupture, with an average of 14,393 p.s.i. Six out of the six families from the low parent wood specific gravity group had the six lowest total tree means for modulus of rupture with an average of 12,602 p.s.i. The overall total tree mean modulus of rupture based on all 12 families of loblolly pine was 13,546 p.s.i. and was found to be 7% higher than that reported by Koch (1972) for the same species.

5. The mean modulus of rupture for the 173 mature wood specimens from all 12 families was 15,533 p.s.i. and was found to be significantly greater than the mean of 11,462 p.s.i. for the 165 juvenile wood specimens. The family by wood-type interaction was found to be not significant.

6. Based on the static bending strength tests, modulus of elasticity was found to vary significantly between families. Six out of the six families from the

high parent wood specific gravity group had the six highest total tree means for modulus of elasticity, with an average of 1,659,432 p.s.i. Six out of the six families from the low parent wood specific gravity group had the six lowest total tree means for modulus of elasticity, with an average of 1,424,645 p.s.i. The overall total mean modulus of elasticity based on all 12 families of loblolly pine was 1,542,342 p.s.i. and was found to be 12% lower than that reported by Koch (1972) for the same species.

7. The mean modulus of elasticity for the 173 mature wood specimens for all 12 families was 1,845,514 p.s.i. and was found to be significantly greater than the mean of 1,224,470 p.s.i. for the 165 juvenile wood specimens. The family by wood-type interaction was found to be not significant.

8. Wood specific gravity was found to vary significantly between family. Five out of the six families from high specific gravity parents and one family from a low specific gravity parent had the six highest total tree means for wood specific gravity for the 12 families examined. The overall total tree mean wood specific gravity, based on all 12 families, was .502 and was found to be about 2% lower than that reported by Koch (1972) for the same species.

9. The mean wood specific gravity for the 172 mature wood specimens from all 12 families was .548 and was significantly greater than the mean of .453 found for the 162 juvenile wood specimens. The family by wood-type interaction was found to be not significant.

10. The variation around the total tree means as measured by the standard deviations for maximum crushing strength, modulus of rupture, and modulus of elasticity were found to be higher than those reported by Koch (1972) for loblolly pine. One source of this variation in the present study may be due to the parent selection strategy used. Parent trees were selected to have either high or low wood specific gravity. The progeny also largely reflected these parent differences, with a relatively large number of values at the high and low extremes found for each wood property being examined.

11. Mean maximum crushing strength and mean modulus of elasticity were found to be lower than previously reported values (Koch, 1972). The mean wood specific gravity of the loblolly pine trees was also lower in the present study and would contribute to the lower strength properties. Also, the within-tree sampling strategy used in the present study resulted in a relatively large number of juvenile wood specimens compared to other studies of this type. Because juvenile wood is generally weaker, this has produced lower mean strength values.

12. Based on the results obtained in this study, it may be concluded that mechanical wood properties are affected by family, for loblolly pine. This effect of family on the wood mechanical properties was found for both the juvenile and mature wood without a significant interaction between family and wood-type (juvenile or mature). The results provide evidence that a strong relationship

exists between the mechanical strength properties and wood specific gravity. The results further provide evidence to substantiate the hypothesis that the gains in specific gravity of the progeny, made through parent selection, are then also found in improved mechanical properties of the wood produced from the progeny trees.

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APPENDIX

Field Grade Sheets used by the Texas Forest Service for

Twelve Loblolly Pine Parent Trees Used in The Present Study.

Form 10.8 (a)

TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project ______

Seed Tree Description

4201001

Collection Number 1-50 Number Trees 1 Species ______

Location:

TFS District — County Bowie

Detailed Location: Park flat pine mounds etc. Plat 1 detailed location

Description of Tree (Trees):

Diameter 12.7 Age 46 Growth Rate 3.2 (Rings per inch) Height 80

Bole Straight, clear ... (Straightness, clearness, taper, etc.)

Limbs Ave length, small ... (Length diameter, angle of growth)

Crown 26 % ... dense ... (Length, density, width)

Wood Density .663 ... .626 ... .622 .646 (High or low summer wood percent)

Vigor vigorous (Needle length, color, density on branch, bunchiness)

General Nearly superior tree for area

Environment:

Site Flat, intermediate for area, near ... (moisture, old field, bottomland, upland, etc.)

Competition severe (Severe, open grown, hardwood, past competition)

Soil fine sand, 20" deep, subsoil red ... mottled (Sand, gravel, clay, depth of top soil)

General Site index 90

Marking on Tree: Tag 1-50

Photographs:

404101

Form 10.8 (a) 27103 TEXAS FOREST SERVICE RESEARCH & EDUCATION DEPARTMENT Project [illegible]

Seed Tree Description

Collection Number 6-141 Number Trees 1 Species [illegible]

Location:

TFS District 4 County [illegible]

Detailed Location: [illegible]

Description of Tree (Trees):

Diameter 13.4 Age 72 Growth Rate [illegible] Height [illegible]
(Rings per inch)

Bole [illegible]
(Straightness, clearness, taper, etc.)

Limbs small
(Length diameter, angle of growth)

Crown [illegible]
(Length, density, width)

Wood Density .591 [illegible] (.577 ave) [illegible]
(High or low summer wood percent)

Vigor [illegible]
(Needle length, color, density on branch, bunchiness)

General site [illegible]

Environment:

Site [illegible]
(moisture, old field, bottomland, upland, etc.)

Competition [illegible]
(Severe, open grown, hardwood, past competition)

Soil 12" [illegible] sand, [illegible]
(Sand, gravel, clay, depth of top soil)

General

Marking on Tree: 6-141

Photographs:

406100/

Form 10.8 (a)

TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project ______

Seed Tree Description

Collection Number 4-14 Number Trees 1 Species ______

Location:

TFS District 6 County ______

Detailed Location: See detailed location sheet.

Description of Tree (Trees):

Diameter 16.7 Age 41 Growth Rate 5.6 (Rings per inch) Height 95

Bole Slight crook, clear 57' (Straightness, clearness, taper, etc.)

Limbs Small, little crown (Length / diameter, angle of growth)

Crown OK 38' long 28' wide (Length, density, width)

Wood Density .476 small, .465 small low, .473 large .471 RR (High or low summer wood percent)

Vigor Good (Needle length, color, density on branch, bunchiness)

General Site index 100

Environment:

Site Moist ______ (moisture, old field, bottomland, upland, etc.)

Competition Severe (Severe, open grown, hardwood, past competition)

Soil 12" sandy loam with yellow mottled clay subsoil (Sand, gravel, clay, depth of top soil)

General

Marking on Tree: ______ 4-14

Photographs:

4401034
4401034
Form 10.8 (a)

TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project [illegible]

Seed Tree Description

Collection Number 7-34 Number Trees / Species [illegible]

Location:

TFS District 6 County [illegible]

Detailed Location: [illegible]

Description of Tree (Trees):

Diameter 15.3 Age 30 Growth Rate 4.3 (Rings per inch) Height 65'

Bole [illegible]
(Straightness, clearness, taper, etc.)

Limbs [illegible]
(Length diameter, angle of growth)

Crown [illegible]
(Length, density, width)

Food Density [illegible]
(High or low summer wood percent)

Vigor [illegible]
(Needle length, color, density on branch, bunchiness)

General [illegible]

Environment:

Site [illegible]
(moisture, old field, bottomland, upland, etc.)

Competition [illegible]
(Severe, open grown, hardwood, past competition)

Soil 36" [illegible]
(Sand, gravel, clay, depth of top soil)

General

Marking on Tree: 7-34 Cut 1956

Photographs:

4061003

Form 10.8 (a)

TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project 10.8-5

Seed Tree Description

Collection Number 6-665 (C) Number Trees 1 Species loblolly

Location:

TFS District six County Montgomery

Detailed Location: boy Scout Camp, off Trail 13

Description of Tree (Trees):

Diameter 14.9 Age 54 Growth Rate 8.3 (Rings per inch) Height 70'

Bole Slight sweep, clear 50, rapid taper
(Straightness, clearness, taper, etc.)

Limbs few long, large, sharp angle
(Length diameter, angle of growth)

Crown 1/4 very sparse, wide on one side
(Length, density, width)

Wood Density .637 (.630, .646, .636) .664 large core, (ave. .651)
(High or low summer wood percent)

Vigor poor, sparse
(Needle length, color, density on branch, bunchiness)

General

Environment:

Site dry, upland
(moisture, old field, bottomland, upland, etc.)

Competition severe
(Severe, open grown, hardwood, past competition)

Soil sandy, underlain by clay
(Sand, gravel, clay, depth of top soil)

General

Marking on Tree:

Photographs:

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TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project 10.8-5

Seed Tree Description

Collection Number 2C (B) Number Trees 1 Species Loblolly

Location:

TFS District 2 County Gregg

Detailed Location: In patch of dense repro. to S of S2PT7-52. Seed collected from it. 200' S of S2PT7-51

Description of Tree (Trees):

Diameter 21.5 Age 49 Growth Rate 5.2 (Rings per inch) Height 80'

Bole straight clear 40 ' little
(Straightness, clearness, taper, etc.)

Limbs mod long, small diam. flat
(Length diameter, angle of growth)

Crown ~~one half, large dense, top flattened~~, needles finer, diff. color than ring

(Length, density, width)

Wood Density .647 (.656, .677, .608) .700 large core. .672 ave
(High or low summer wood percent)

Vigor Good
(Needle length, color, density on branch, bunchiness)

General Seed collected. 1952 Satisfactory tree

Environment:

Site Upland, flat, in dense repro.
(Moisture, old field, bottomland, upland, etc.)

Competition none present
(Severe, open grown, hardwood, past competition)

Soil clay loam
(Sand, gravel, clay, depth of top soil)

General

Marking on Tree: Metal tag 2C-52, blue band

Photographs: 2, Goddard collecting cones.

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TEXAS FOREST SERVICE
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Project ____

Seed Tree Description

Collection Number 3-15 Number Trees 1 Species ____

Location:

TFS District 5 County ____

Detailed Location: ____

Description of Tree (Trees):

Diameter ____ Age ____ Growth Rate ____ (Rings per inch) Height ____

Bole ____ (Straightness, clearness, taper, etc.)

Limbs ____ (Length diameter, angle of growth)

Crown ____ (Length, density, width)

Wood Density ____ (.475 ____) .470 RR (High or low summer wood percent)

Vigor Fair (Needle length, color, density on branch, bunchiness)

General ____

Environment:

Site intermediate ____ (moisture, old field, bottomland, upland, etc.)

Competition ____ (Severe, open grown, Hardwood, past competition)

Soil ____ (Sand, gravel, clay, depth of top soil)

General ____

Marking on Tree: ____

Photographs: ____

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TEXAS FOREST SERVICE
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Project 10.73-1

Seed Tree Description

Date

Collection Number 12-30 Number Trees 1 Species PT

Location:

TFS District 2 County Gregg

Detailed Location: See Plot 12

Description of Tree (Trees):

Diameter 18.3 Age 50 Growth Rate 5.4 Height 95
(Rings per inch)

Bole fairly straight, some sweep
(Straightness, clearness, taper, etc.)

Limbs average, moderate size
(Length, diameter, angle of growth)

Crown moderate
(Length, density, width)

Wood Density .634 6
(High or low summer wood percent)

Vigor good
(Needle length, color, density on branch, bunchiness)

General Used in addition to 12-8 for dense

Environment:

Site relatively dry
(Moisture, old field, bottomland, upland, etc.)

Competition severe
(Severe, open grown, hardwood, past competition)

Soil sandy clay
(Sand, gravel, clay, depth of top soil)

General -

Marking on Tree: tag no. 12-30

Photographs -

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TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project ______

Seed Tree Description

Collection Number 15-50 Number Trees 1 Species Loblolly

Location:
District ______ County Nacogdoches

Detailed Location Stephen Austin Exp. Forest, U.S.F.S.

Description of Tree (Trees):

Diameter 14.1 Age 38 Growth Rate 6.3 (Rings per inch) Height 85. ft.

Bole 76% clear bole
(Straightness, clearness, taper, etc.)

Limbs ______
(Length, diameter, angle of growth)

Crown Light, 20 ft wide.
(Length, density, width)

Wood Density .512 39% summerwood
(High or low summerwood percent)

Vigor ______
(Needle length, color, density on branch, bunchiness)

General ______

Environment:

Site Upland, intermediate
(Well drained, poorly drained)

Stand Condition ______
(Even or uneven aged - closed or open)

Soil topsoil--sandy loam; subsoil--clay.
(Sand - loam - clay)

Remarks Superior tree S3P T73

Marking on Tree:

Photographs:

4051001

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TEXAS FOREST SERVICE
RESEARCH & EDUCATION DEPARTMENT

Project ______

Seed Tree Description

Collection Number 2-17 Number Trees / Species [illegible]

Location:

TFS District 5 County Newton

Detailed Location: 5 W [illegible] Newton, [illegible] [illegible] [illegible] See detailed [illegible] [illegible]

Description of Tree (Trees):

Diameter 16.5 Age 32 Growth Rate 4.8 (Rings per inch) Height 75

Bole [illegible] (Straightness, clearness, taper, etc.)

Limbs Little large, [illegible] [illegible] (Length diameter, angle of growth)

Crown Crown 20 feet wide, [illegible] (Length, density, width)

Food Density [illegible] .462 [illegible], .468 [illegible], .435 [illegible] .482 [illegible] (High or low summer wood percent)

Vigor Fair (Needle length, color, density on branch, bunchiness)

General [illegible]

Environment:

Site Moist, coastal plain (moisture, old field, bottomland, upland, etc.)

Competition [illegible] (Severe, open grown, hardwood, past competition)

Soil [illegible] 18" deep, [illegible] (Sand, gravel, clay, depth of top soil)

General

Marking on Tree: 2-17

Photographs:

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Project 10.85

Seed Tree Description

Date

Collection Number 15-39 Number Trees 1 Species loblolly

Location:

TFS District 3 County Nacogdoches

Detailed Location: see detail plot 15

Description of Tree (Trees):

Diameter 19.1 Age 33 Growth Rate 4.2 (Rings per inch) Height 80'

Bole fairly straight clear 45'
(Straightness, clearness, taper, etc.)

Limbs relatively large
(Length, diameter, angle of growth)

Crown large, 35" long, 20' wide
(Length, density, width)

Wood Density .584 small, .652 small, less 8, .580 large. 583 large avj..582
(High or low summer wood percent)

Vigor good
(Needle length, color, density on branch, bunchiness)

General site index 100

Environment:

Site dry
(Moisture, old field, bottomland, upland, etc.)

Competition moderate
(Severe, open grown, hardwood, past competition)

Soil 12" sandy loam with red matted clay subsoil
(Sand, gravel, clay, depth of top soil)

General

Marking on Tree: Tag. 15-39

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Project [illegible]

Seed Tree Description

Collection Number 13-31 Number Trees 1 Species [illegible]

Location:

TFS District 2 County [illegible]

Detailed Location: [illegible]

Description of Tree (Trees):

Diameter 17.1 Age 36 Growth Rate 5.2 (Rings per inch) Height 85'

Bole [illegible] (Straightness, clearness, taper, etc.)

Limbs [illegible] (Length diameter, angle of growth)

Crown [illegible] (Length, density, width)

Wood Density [illegible] .462RR [illegible] (High or low summer wood percent)

Vigor Good (Needle length, color, density on branch, bunchiness)

General [illegible]

Environment:

Site [illegible] (moisture, old field, bottomland, upland, etc.)

Competition [illegible] (Severe, open grown, hardwood, past competition)

Soil [illegible] (Sand, gravel, clay, depth of top soil)

General

Marking on Tree:

Photographs:

VITA

After completing her work at Harding Academy, in Searcy, Arkansas, in 1984, Elizabeth Forbes entered Harding University as an Art major. She later changed her major to Political Science with a minor in Art. She graduated in May of 1989 with a Bachelor of Arts degree. After working for 3 years, she returned to school to get her Master of Science in Forestry. She attended Oklahoma State University in Stillwater, Oklahoma from the fall of 1992 through the spring of 1993 when she transferred to Stephen F. Austin State University in Nacogdoches, Texas. During her time there, she worked on 2 research projects and taught Dendrology labs for 2 years. She finished her degree in the Spring of 1999.

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Style Manual Description: Forest Products Journal.

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