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Load Strength Relationships Among Lamination Thicknesses For White Pine and Red Oak

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LOAD STRENGTH RELATIONSHIPS AMONG LAMINATION THICKNESSES FOR WHITE PINE AND RED OAK

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This thesis submitted by Randall G. Souser in partial fulfillment of the requirements for the Degree of Master of Science from the University of North Dakota is hereby approved by the Faculty Advisory Committee under whom the work has been done.

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ABSTRACT

The purpose of this study was to investigate and determine the maximum load strengths for the two most common wood species used by laminate manufacturers in laminated wood products. It was the intent of this study to determine the relationships among load strength and incremental lamination thickness change while under a continuous load.

The study included: (1) a review of literature of related topics related to wood characteristics and lamination principles, which indicated a lack of information pertaining to small laminated members, (2) the procurement of data for laminated member development of specimens were achieved through a state-of-the-art survey of manufacturers, (3) development of and performing static bend tests on ninety-six specimens and (4) the presentation and analysis of data obtained during testing.

Methods

Specimens were designed in accordance to the American Society for Testing and Measures (ASTM D805-52) specifications for small laminated members. Range of specimen samples were of 1/8 inch increments up to one inch thickness. Specimens were duplicated for six individual samplings at each thickness for both species. Specimens

were tested for load strength with the Vega tester. Data obtained through testing were presented numerically.

Conclusions

The primary conclusions obtained from this study were: (1) the criteria for wood laminations specifications are not firmly established for the industry, and recommendations currently regulate large structural members, (2) the lack of small lamination application for structural members is reflective of the prohibitive operating costs to fabricate, (3) the increase of laminations effect the load strength of the member, (4) load strength increase is not constant, (5) declining increases of load strength in relation to lamination thickness indicated nominal gain to lamination increase at specific thicknesses (.375, .625, 1750), (6) the mean load strength for white pine was 321.21 psi, and red oak indicated 460.42 psi, (7) the maximum load strength for a laminated member is independent from members of different spans and thickness, while members of equal span and thickness can be determined through probability and testing.

Recommendations

It is recommended that: (1) the optimal utilization for laminations less than one inch thickness should be assessed upon load strength and cost, (2) statistical analysis of the data could be utilized for prediction of load strength, and (3) further studies should be conducted to determine if common relationships exist among larger sample numbers and variable lamination thicknesses.

CHAPTER I

INTRODUCTION

The desire and ability to produce laminated wood products has dated to the early Egyptian pharoahs. Humankind's ability to produce laminated products with quality assurance can be noted in Greek and Roman works. Their endurance to time attest to a very conscious effort toward quality.

With the advent of the European Industrial Revolution in the middle of the eighteenth century, production machinery and processes largely suspended the tools and skills of individual craftsmanship. Concurrent with the introduction of complex production techniques and technological advances in the material sciences, the need for quality assurance in manufacturing has grown. This need for quality assurance growth was noted by Halpern (1978), "no two objects in the world around us, nor any two actions performed by the same or by different individuals are exactly identical" (p. 66).

Material variability may cause slight differences that affect the outcome of a product. Selection of material from different lots with various degrees of quality, methods of treatment, working utility and design of a product for utilization are contributors to the success or failure of manufactured products. In more recent years, the control of the integrity of material selection and design for product reliability has been given increased attention. This is to insure product performance for its intended use. According to Hoadley (1980), and Lento (1979), the utilization and design of laminated members are influenced in accordance with specific application of materials in combination. The utilization of inappropriate (or inferior) selection of material combinations would influence the performance value.

The conformation of material quality and design of products available to consumers came under scrutiny during the 1960's. The United States Government has since enacted the Consumer Product Safety Act of 1972. The objective was and is to set and enforce standards for compliance to specific regulations which would insure product reliability. In 1966, some regulations were established in the industry of wood lamination. Specific regulation or examination of quality standards were based in reference to the U. S. Department of Agriculture (USDA), Wood Handbook No. 72 (1955). According to the authors, "lamination thickness has no effect on the strength of straight laminated members" (p. 253). The American Institute of Timber Construction (AITC 119-71) pointed out (p. 7) that: "Quality materials and workmanship that are used in structural glue laminated timber members shall be vested in the laminator's quality control in day-to-day operations."

Because of the influx in material sciences and potential application of laminated wood in the commercial and consumer markets, questions arise as to the reliability of laminated wood members strength currently produced.

Statement of the Problem

The problem for this study was to determine the maximum load-strength for two selected laminated wood species by altering the thickness by 1/8 inch increments up to one inch.

Objectives of the Study

The objectives of this study were to:

1. Identify the most common variables involved in wood lamination.
2. Identify and select the two most common wood species used in wood lamination.
3. Determine the maximum load-strength of graduated thickness utilizing The American Society for Testing Materials (ASTM D805-52) static bend test specifications.

Assumption

Alteration of lamination thickness has no effect on the laminated member load-strength.

Limitations of the Study

The scope of this study was limited to the variables related to lamination load strength, and testing of lamination thickness alteration. Further limitations:

1. The study was limited to two wood species selected on the highest percentage of industrial application, as noted by laminate wood products manufacturers.
2. The testing of the two wood species were conducted in a laboratory environment.

Definition of Terms

Adhesive:

A bonding substance capable of holding lamination materials together.

Deflection:

The structural movement of the lamination in a direction constant to the applied load, a stress displacement of wood fibers.

Lamination:

The process of combining similar materials with the application of an adhesive to form a new member, with the direction of wood grain being parallel to each other.

Load-Strength:

The ability of a structural member to resist stress when a force (load) is applied to the member.

Moisture Content:

The total amount of moisture in a given piece of wood is expressed as a percentage of the oven dry weight of the wood.

$$\text{M.C. \%} = \frac{\text{weight of water in wood}}{\text{OD weight of wood}} \times 100$$

Quality Assurance:

The level or degree that a laminated product is expected to perform when meeting specific requirements.

Specific Gravity:

The volume of wood fiber mass, composed of various types of cells and water. It is usually expressed as a ratio of weight of the substance to the weight of an equal volume of water.

$$\text{Specific Gravity} = \frac{\text{OD weight of wood}}{\text{weight of the displaced volume of water}}$$

Stress:

The system of forces that are applied to cross-sectional areas of the member, or the load level resulting in the fiber stress and deformation of the member.

Abbreviations

AITC:

The American Institute of Timber Construction.

ASTM:

The American Society for Testing and Measures.

<u>USDA</u>:

The United States Department of Agriculture.

CHAPTER II

REVIEW OF LITERATURE

Introduction

This chapter is divided into four sections: First, an explanation of the variables encountered in wood laminated products; second, the functional need for quality assurance control; third, a view of the wood specie selection utilized in laminated products; and fourth, the considerations relating to wood lamination.

Wood Lamination Variables

The conversion of raw materials into a wood laminated product is a series of systematic processes. The application of wood conversion comes from scientific research and the knowledge acquired pertaining to its characteristics. Difficulty arises in the conversion of wood materials when technical knowledge is limited and chance becomes dominant during the conversion process.

The actual conversion of wood materials takes on many applicable processes and forms of conversion. These are directed towards specific tasks and job requirements. Wood lamination is the combination of any number of wood pieces, cut parallel or perpendicular to the grain at a specific thickness. The pieces are bonded together in a parallel direction utilizing an adhesive and clamping device, to form a new member.

Simplification of the process is not highly regarded when specific characteristics in wood lamination are determinant to the outcome requirements desired for specific applications. Variables that are of the mechanical and physical property groups have been identified as those properties which have the most relative influence on the outcome of wood transformation success. The variables of moisture content, surface quality, wood specie and thickness are the primary properties. Secondary properties are specific gravity and relative humidity. The variables of mechanical application which are critical to the conversion have been identified to be the adhesive and clamping pressure. The sum of the variables are instrumental to the total design-quality of the wood laminated member.

Boise Cascade and Weyerhauser Corporations, 1981, indicated that in the conversion process many of the variables encountered in wood lamination production are held relatively constant. The discrepancy among the variables in lamination operations is obtaining raw materials to meet corporate in house quality control specifications. There is no specific attribution as to why quality materials are not available, but the speculative answer could lie in the chemical breeding of young saplings.

The advantages and disadvantages of wood lamination are:

Advantages

1. Deformation changes are reduced.
2. Production of members takes little time.
3. Production of members can utilize low quality materials.
4. Products can be made in various sizes and shapes.
5. Strength qualities can be improved.

Disadvantages

1. Operation/conversion time.
2. Capital/tooling set up.
3. Equipment/variability.
4. Raw materials/quality and cost.
5. Skilled labor/reduction.
6. Extensive waste/materials and time.

Control for Quality Assurance

The sciences connected with wood technology have grown rapidly in the past fifty years. Halpern (1978) and Hayes (1974) surmised that a high level technology demands the appropriation of quality assurance (control).

Hopeman (1980) and Stanton (1981) spoke of the control of quality as the process of planning, inspection and perceived expectations of the consumer. The context of product quality has three major aspects: (1) the product must be designed to meet the least minimum requirements for its use, (2) the materials should conform to the requirements of the design, (3) consumer and commercial awareness of the production application should be identified.

Products may have the same functional use, but may be different in design and quality of materials. If one product contained low grade nondurable materials, inappropriate for their production application and another contains high-grade durable materials and is well designed, all indications clearly point out which product is of superior quality.

Within the wood lamination industry surveyed (Appendix A), no one specific action was taken to insure product quality during or after production (Table 1). To determine

TABLE 1

QUALITY ASSURANCE TEST(S) PERFORMED BY WOOD LAMINATION INDUSTRIES

Test	Percentage
Visual	22.72
Moisture	18.18
Adhesive	18.18
Shear	13.63
None	13.63
Pressure	9.09
Destructive	9.09
Field	9.09
Boil	9.09
Micro-measure	4.54
Temperature	4.54

what test(s) might be performed to insure quality is dependent upon the manufacturer as to the extent of his/her product reliability and responsibilities.

Wood Species Utilized in Wood Laminated Products

The wood species that are used in the manufacture of wood laminated products are numerous. Panshin and De Zeeuw (1980) signified the conservative estimate of 1027 kinds of trees exist in the United States. This estimate dramatizes the importance of appropriate selection of wood species for wood lamination applications. There are, however, fewer commercially important species in the United States. The total number of commercial species is eighty, comprising thirty softwoods and fifty hardwoods.

According to the selected manufacturers of wood laminators and service organizations surveyed, the application of a particular specie or combination of species is dependent upon: (1) its initial cost, (2) availability of quality wood, (3) end product appearance, (4) expected durability to perform adequately while in service, and (5) its ability to be adapted to a particular operation. The wood laminators surveyed further identified those species most often utilized in Table 2, and selected species in accordance to product types in Table 3. The industries specifically indicated that Red Oak is the predominant of the hardwood classification, and that either

White or Yellow Pines are predominate in the softwood classification in the manufacture of wood laminated products. Single species were further preferred over multiple species in combination.

TABLE 2

TYPE OF WOOD SPECIE MOST OFTEN UTILIZED IN LAMINATIONS

Name	Percentage
Red Oak	45.45
Pine(s)	36.36
Ash	27.27
Cherry	27.27
Maple(s)	27.27
Hemlock	22.72
White Oak	22.72
Walnut	22.72
Birch	18.18
Douglas Fir	18.18
Pecan	18.18
Sitka Spruce	18.18
Mahogany	9.09
Ebony	4.50
Gum	4.50
Hickory	4.50
Poplar	4.50
Rosewood	4.50

TABLE 3

COMMON WOOD SPECIES USED IN THE CONSTRUCTION OF LAMINATED WOOD PRODUCTS

Product	Wood Specie(s)
Aircraft Spar Blanks	Ash
Arches	Douglas Fir Hemlock Oak Poplar
Archery--Bows	Ash Oak Maple Mahogany
Beams	Cherry Hard Maple Pine(s) Walnut
Cutting Boards	Ash Birch Cherry Red Oak Walnut White Oak
Decking	Douglas Fir Hemlock Pine(s) Sitka Spruce Western Cedar
Doors	Birch Douglas Fir Hemlock Pine(s) Maple Oak
Flooring	Oak Walnut
Furniture Components	Ash Birch Cherry Douglas Fir

TABLE 3--(Continued)

Product	Wood Specie(s)
Furniture Components (Continued)	Gum Mahogany Pecan Pine(s) Poplar Oak Sitka Spruce
Guitars	Ebony Hemlock Mahogany Rosewood
Rails	Birch Oak Pine(s)
Spiral Stairs--Railing	Ash Oak
Sporting Goods	Ash Balsa Mahogany Maple Oak Sitka Spruce Teak Walnut

Wood Lamination Considerations

The most relative factors influencing the strength of laminated wood are: (1) moisture content, (2) specific quality, (3) laminate thickness, (4) bonding agents, (5) duration of stress, and (6) load strength.

Moisture Content

The amount of water in a given piece of wood is called the moisture content (M.C.). It is expressed as a percentage of the ovendry weight (OD) of the wood. The weight of water present is the difference in weights before and after drying.

$$\text{M.C. \%} = \frac{\text{weight of water in wood}}{\text{OD weight of wood}} \times 100$$

Wood increases in strength with a corresponding reduction in moisture. However, not all strength properties of wood increase with a decrease in moisture content. Properties that represent toughness, or shock resistance sometimes decrease as the wood loses moisture. This is because OD wood will not bend as far as green wood before failure, although it will sustain a greater load, because toughness is dependent upon both strength and pliability. The USDA (1955) proposes that the percentage of increase or decline for a 1 percent decrease or incline in the M.C. is 4 percent for the modulus of rupture, and one-half of 1 percent for work to maximum load (p. 85). The AITC (1971) indicates that the strength is considerably lower with a high moisture content, and in some cases more than 50 percent lower than those woods at 12 percent. Lento (1979), Feirer (1977) and Hoadley (1980) identify the mean moisture content of dried wood to be at 12 percent Moisture Content. This moisture content percentage was verified in the state-of-the-art survey of the manufacturers producing laminated wood products in Table 4.

Certain industrial respondents identified the specific moisture content of their wood species to range 5-12 percent. The survey results show that the moisture content should be slightly lower than that desired for the finished product.

TABLE 4

WOOD SPECIE(S) MOISTURE CONTENT PERCENTAGE

Specie "A" Range of Moisture Content	Percentage
5 - 20	77.27
25 - 35	4.54
Above 35	
Specie "B"	Percentage
5 - 20	77.27
25 - 35	4.54
Above 35	0.00

* Wood specie (A or B) relative to species identified in survey, nonrestricted to any one selected specie.

Specific Gravity

The USDA (1955) and Gurfinkel (1973) contend that the specific gravity of wood is considered an index of the amount of wood substance a piece of wood contains and, is furthermore considered to be representative of its strength value. The strength value for any one piece of wood may vary within a specie. To find the specific gravity of a specific piece of wood, the following equation is employed:

$$\text{Specific Gravity} = \frac{\text{OD weight of wood}}{\text{weight of the displaced volume of water}}$$

Laminate Thickness

The USDA (1955) contends that lamination thickness has no effect on the strength of straight laminated wood members. However, they further contend that it does effect the strength of curved members. The manufacturers of wood laminated products alter the lamination thickness for the purpose of achieving a desired strength of its members. The AITC (1974) identifies specific strengths achieved giving certain sizes and length of members. However, the most frequent minimum thickness utilized is 3/4 inch for most members and second only to the most prescribed thickness of one and one fourth inch thickness. The range of lamination thickness used in the industry is 1/32 to 8 inches (Table 5). The relationship of load strength to lamination thickness is not well defined for thicknesses less than two inches. The load strength of thin laminated members (less than 3/4 inch) is considered not acceptable because of the return on investment. There is believed to be a relationship of load strength and lamination thickness, but when the laminate is considered too thin, the adhesive is the strength variable that off-sets the measurable wood strength.

Bonding Agents

The utilization of adhesive bonding agents in industry varies according to the selected application of the product.

TABLE 5

COMMON LAMINATE THICKNESSES USED IN PRODUCTS

Thickness In.	Percentage
1-1/4	40.90
3/4	31.81
1/8	18.18
1-1/2	18.18
1/32 - 1/20	13.63
1/16 - 1/10	13.63
1	13.63
1/4	13.63
Up to 8	9.09

The adhesive most readily employed is urea formaldehyde. Table 6 further identifies those adhesives utilized by laminators.

TABLE 6

TYPES OF ADHESIVES USED IN PRODUCING LAMINATED PRODUCTS

Name	Percentage
Urea Formaldehyde	54.54
Resorcinol	36.36
Aliphatic	18.18
Polyvinyle	4.54
Phenol Formaldehyde	4.54
Epoxy	4.54

Hoadley (1980), Kollman and Cote (1968) indicate that scientific research suggests that mechanical fastening is inappropriate as compared to chemical fastening because chemical bonds due to molecular forces between the adhesive and wood is stronger. Roberts (1976) states the adhesive is applied in a way that it can flow across and into the inner lining of the cells walls. The adhesive should be spread uniformly thin (0.006 in.), held under a constant appropriate pressure until final curing (drying) takes place. Typical adhesives are obtained as a liquid, but the major portion of the industrial or commercial type adhesives are received in a powder form and subsequently mixed with water to dissolve the latent catalyst. When the liquid adhesive is applied to form a bonding layer, a chemical attraction takes place forming the bond. Patton (1976, p. 55) indicates:

> The effectiveness of a composite [laminated] material lies not in the composite, but in the complete composite. It is the composite effectiveness of the lamination and its bond to the substrate [adhesive].

Duration of Stress

Stevens and Turner (1970) and Kollman and Cote (1968) consider the duration of stress, or the time during which a load acts on a wood member, is an important factor in determining the load that a wood member can carry safely. For members that carry a load continuously for a long period of time, the load-carrying capacity is much less than that determined for the modulus of rupture. In applying a stress increase for conditions of less than full duration of load, the safe stress for the permanent part of the combined loading must not be exceeded. If the assumed loading conditions involve an infrequent large load and more frequent smaller load, the working stresses and sizes of structural members should be appropriate for each of the assumed loads for safety.

The USDA (1955) further showed that wood under continuing load takes on a continuing increment of deformation, usually very slow, but persistent over long periods of time. If deformation or deflection under long periods of loading must be limited, extra stiffness can be provided by adjusting the initial deformation limit at one-half the long-time deformation limit or by adjusting the structural member design.

Load-Strength

The load-strength for a laminated or non-laminated member can be achieved with the ASTM (1959) D805-52 static bend test procedures. These procedures were reapproved in 1971. With the application of the established procedures in conjunction with prescribed suggestions for recording of data, load-strength for a piece of wood is established. The determination of a mean score for a group of test specimens will establish the load-strength for a given thickness.

Summary of Literature

The increased demand and concern for wood laminations design-strength and security of personal domain, has stimulated continuous action towards the quality assurance of wood products. The stimulation of further research has taken an upward movement into the examination of those variables which effect the product manufacturing process. Those variables which are most chiefly connected to lamination are: (1) variability of species, (2) moisture content, (3) specific gravity, (4) adhesive used, and (5) quality of available raw materials.

Boise Cascade and Weyerhauser Corporations, 1981, stated that many of the variables remain relatively constant during production. However, discrepancy arises with obtaining raw materials that will meet in-house specifications before production.

Wood species identified by laminators indicate further utilization of Red Oak and White or Yellow Pines. The application of these species for lamination is based upon (1) their initial cost, (2) availability, (3) appearance, and performance expectations. Single specie lamination is preferred over multi-specie combination.

The employment of urea formaldehyde as the chemical bonding is dominant among laminators. Basis for the selection is due to the cost and performance record. Furthermore, the adhesive has been noted to be resistant to moisture.

The strength of laminated members is believed to be greater than non-laminated wood due to the application of technological advances in chemical bonding agents. However, the strength of a wood member can only be determined by testing under a load situation. The quality of a piece of wood can be determined by examining the moisture content and specific gravity which in effect acts upon the strength. When the quality of the raw material is considered below the norm index, it is stated to be of poor quality. When the quality of raw materials change, so too the strength of the member.

CHAPTER III

METHOD OF THE STUDY

This chapter describes the methods used to solve the problem of the study. The problem was to determine the maximum load strength for two selected wood species by altering the thickness by 1/8 inch increments up to one inch. The procedure included: (1) the literature review, (2) a survey to collect information, (3) static bend test (ASTM D805-52), and (4) data analysis for the determination of mean score relationships among specie thickness alteration. The objectives of this study were to:

1. Identify the most common variables involved in wood lamination.
2. Identify and select the two most common wood species used in wood lamination.
3. Determine the maximum load-strength of graduated thickness utilizing the American Society for Testing Materials (ASTM D805-52) static bend test specifications.

Obtaining the Data

To identify the most common variables involved in the lamination of wood, several texts and journal articles concerned with a discussion of wood lamination were studied.

The most common variables were identified as being important to wood lamination. To further investigate and validate the variables, fifty-one companies and individuals involved in wood lamination were surveyed (Appendix A). The survey was also instrumental in the determination of the two most commonly utilized wood species. Survey recipients were selected from the Thomas Registry (1979), wood industry periodicals, and marketed laminated wood products, 1981. The criteria for selection was based on quota-random sampling by product classification. Further criteria for the selection of survey recipients was the claim or advertisement of specialization or having information pertaining to wood lamination, 1981.

The recipients of the industrial survey were asked to give data relative to their operations without jeopardizing company security. The questions were directed at product identification and specific variable norms (Appendix B). The recipients of the surveys were manufacturers of: (1) furniture components, (2) sporting goods, (3) structural members, (4) wood production organizations, (5) individuals, and (6) small companies specializing in wood laminated products. The responses were then compared to determine and validate the variables and related questions effecting the wood lamination industry.

Experimental Design

The design of this study was a quasi static group comparison. Information obtained from the state-of-the-art survey updated the methods of industrial practice which were incorporated into the experimential testing procedure. The production of and specific requirements for the testing procedure are identified in Appendix C and Appendix D.

Control and examination of variables prior to specimens' preparation and static bend testing included the laboratory environment with the following conditions: (1) temperature 70° F., (2) relative humidity 26%, and (3) barometric pressure 29.5 (steady). Moisture Content and Specific Gravity measures were conducted prior to machine operations of the two wood species (Red Oak and White Pine). The recorded measures are identified in Table 7.

TABLE 7

PRE-TEST MEASURES

Specie	M.C.	Specific Gravity
Red Oak	8	.64
White Pine	11	.43

Specimens were prepared and tests conducted as stated in Appendix C and Appendix D. The test measurement devices utilized were the Vegas low range non-metallic uni-tester (Model NMT-2) (Appendix E) and the Starrett dial indicator (Series 25-4413). Load-pounds and deflection were recorded in technical data tables (Appendix F), designed to record thirteen measures for each specimen thickness. The data (load-pounds) collected for the ninety-six specimen thickness samples were key punched onto computer cards for the Statistical Package for Social Sciences (SPSS) at the University of North Dakota, Computer Center. The specific program utilized was designed to find the mean, standard deviation (STD. DEV.), and variance for each selected wood specie thickness alteration. The further handling of data included the development of tables for: (1) load-pound and deflections for assigned thicknesses, (2) correlation among variable mean load-pounds for each selected specie, (3) comparative mean score values, and (4) mean, standard deviation, and variance for selected species.

CHAPTER IV

PRESENTATION AND ANALYSIS OF DATA

This chapter is a presentation and analysis of data obtained from the static bend tests of the two wood species selected. The analysis included: load-pound measures, deflection measures, mean ($\overline{X}$) values, standard deviation (STD. DEV.), variance of STD. DEV., and percentage values. These measures provided the information necessary to determine the relationship(s) among lamination thickness and load-pounds.

Load-Pounds and Deflection Measures

The data acquired for load-pounds and deflection were achieved by static bend testing. Test procedure and requirements for the specimens (ninety-six) observed ASTM D805-52. Specimens were tested in groups of six specimens per thickness and by specie (sixteen specimen groups), for a total of forty-eight specimens per specie.

Measures observed from the center load-static bend testing of specimens generated values for load-pounds and deflection. These values were recorded in technical data tables (Tables 8 through 23). The observed values for the specimens identified the strength of the individual specimens in relation to a speciman of equal thickness.

TABLE 8

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .125 THICKNESS

AA - 1		AA - 2		AA - 3		AA - 4		AA - 5		AA - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
5	.005	4	.005	6	.005	5	.005	7	.005	8	.005	6	.005
9	.015	7	.015	10	.015	10	.015	13	.015	16	.015	11	.015
14	.025	15	.025	12	.025	12	.025	20	.025	22	.025	16	.025
16	.030	17	.030	14	.030	13	.030	24	.030	25	.030	18	.030
29	.040	31	.040	25	.040	17	.040	28	.035	30	.035	27	.038
35	.050	38	.050	34	.050	19	.045	30	.040	34	.040	32	.046
37	.060	40	.060	36	.060	20	.050	34	.050	38	.050	34	.055
40	.065	42	.065	39	.065	25	.060	39	.060	39	.060	37	.063
42	.070	45	.070	42	.070	29	.070	45	.070	41	.065	41	.069
46	.075	50	.080	47	.075	34	.080	49	.075	48	.075	46	.077
48	.080	52	.085	49	.080	36	.090	50	.080	49	.080	47	.083
50	.085	55	.090	51	.085	38	.100	55	.090	51	.085	50	.089
55	.095	60	.100	52	.090	40	.125	62	.100	52	.090	53.5	.100

TABLE 9

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .250 THICKNESS

BB - 1		BB - 2		BB - 3		BB - 4		BB - 5		BB - 6		$\bar{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
10	.008	15	.020	25	.010	30	.010	8	.010	10	.020	16	.013
15	.025	20	.030	40	.020	50	.020	15	.015	30	.040	34	.025
30	.030	65	.040	50	.030	90	.040	25	.020	70	.050	55	.045
45	.035	95	.050	55	.040	105	.050	40	.025	90	.075	72	.046
65	.040	110	.060	70	.050	120	.060	50	.030	100	.080	86	.053
90	.050	115	.070	90	.060	130	.070	60	.040	110	.090	99	.063
100	.055	125	.080	105	.070	140	.080	70	.050	120	.100	110	.073
110	.060	135	.090	115	.080	150	.090	80	.060	130	.110	120	.082
115	.070	140	.100	125	.090	155	.100	90	.070	135	.120	127	.092
125	.080	155	.110	130	.100	160	.110	100	.080	140	.130	135	.102
135	.090	170	.120	135	.110	165	.115	105	.090	145	.140	143	.111
155	.110	175	.130	145	.130	185	.140	110	.100	150	.150	153	.127
170	.120	180	.135	150	.145	190	.150	115	.105	155	.160	160	.136

TABLE 10

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .375 THICKNESS

CC - 1		CC - 2		CC - 3		CC - 4		CC - 5		CC - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
30	.020	30	.020	50	.030	25	.030	35	.020	15	.020	31	.023
72	.060	60	.060	80	.060	70	.060	55	.030	35	.040	62	.052
100	.080	90	.080	100	.080	95	.080	100	.060	50	.060	89	.055
120	.100	110	.100	125	.100	120	.100	120	.080	55	.080	108	.093
180	.160	155	.150	150	.125	150	.125	145	.100	90	.100	145	.121
190	.180	170	.170	180	.150	175	.150	160	.110	105	.120	163	.147
200	.200	180	.190	190	.160	185	.160	175	.125	130	.150	177	.164
215	.220	190	.200	195	.170	190	.170	185	.130	140	.160	186	.175
222	.240	200	.215	200	.180	200	.180	190	.150	145	.170	193	.189
227	.245	215	.250	205	.190	205	.190	200	.170	147	.180	200	.204
240	.270	220	.260	210	.200	210	.200	205	.190	150	.190	206	.218
250	.290	221	.270	220	.230	218	.220	210	.200	155	.200	212	.233
255	.310	225	.280	230	.230	220	.225	215	.220	160	.210	217.5	.246

TABLE 11

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .500 THICKNESS

DD - 1		DD - 2		DD - 3		DD - 4		DD - 5		DD - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
70	.040	55	.040	85	.040	65	.040	50	.040	60	.040	64	.040
105	.060	80	.060	115	.060	95	.060	80	.060	100	.060	96	.060
130	.080	110	.080	140	.080	125	.080	110	.080	140	.080	126	.080
160	.100	135	.100	170	.100	150	.100	140	.100	180	.100	156	.100
200	.140	185	.140	180	.140	175	.120	190	.140	210	.120	190	.133
230	.175	220	.175	230	.175	200	.140	200	.150	250	.140	222	.159
255	.200	245	.200	260	.200	215	.160	210	.160	260	.150	240	.178
275	.220	250	.220	280	.220	225	.170	225	.175	280	.160	256	.194
290	.250	255	.230	295	.250	235	.180	230	.190	285	.170	265	.218
295	.270	265	.245	300	.255	245	.190	240	.200	300	.185	274	.224
310	.300	270	.250	310	.275	255	.200	250	.210	315	.200	285	.239
320	.310	275	.255	315	.280	260	.210	275	.240	340	.225	298	.253
325	.320	280	.260	320	.285	265	.220	280	.250	345	.230	302.8	.261

TABLE 12

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .625 THICKNESS

EE - 1		EE - 2		EE - 3		EE - 4		EE - 5		EE - 6		$\bar{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
90	.040	70	.040	80	.040	80	.040	90	.040	75	.040	81	.040
115	.060	100	.060	145	.080	170	.100	145	.080	135	.080	135	.077
170	.100	125	.080	180	.100	200	.120	155	.100	150	.100	163	.100
195	.120	155	.100	205	.120	250	.150	200	.120	185	.120	198	.122
220	.140	180	.120	240	.150	280	.170	245	.150	235	.150	233	.147
240	.160	210	.140	270	.180	295	.190	270	.170	265	.180	258	.170
275	.190	235	.160	295	.200	310	.200	305	.200	290	.200	285	.192
300	.220	260	.180	325	.230	320	.210	330	.220	315	.230	308	.215
320	.240	280	.200	340	.250	340	.230	345	.240	330	.240	326	.233
340	.270	290	.210	370	.300	350	.240	355	.250	340	.260	341	.255
355	.300	295	.215	380	.330	360	.250	365	.270	350	.270	351	.273
370	.320	305	.225	400	.380	370	.270	370	.280	360	.280	363	.293
380	.330	310	.230	405	.390	375	.280	375	.285	365	.290	368.3	.301

TABLE 13

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .750 THICKNESS

FF - 1		FF - 2		FF - 3		FF - 4		FF - 5		FF - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
55	.060	90	.060	110	.060	75	.060	90	.060	100	.060	81	.060
125	.100	150	.100	170	.100	135	.100	150	.100	160	.100	115	.100
155	.120	180	.120	200	.120	170	.120	175	.120	190	.120	178	.120
240	.180	270	.180	290	.180	260	.180	270	.180	300	.180	272	.180
280	.200	300	.200	315	.200	280	.200	290	.200	320	.200	298	.200
300	.240	330	.240	350	.240	315	.240	325	.240	350	.240	328	.240
320	.260	350	.260	370	.260	335	.260	340	.260	365	.260	347	.260
335	.280	370	.280	390	.280	350	.280	360	.280	380	.280	364	.280
350	.300	390	.300	400	.300	375	.300	380	.300	400	.300	383	.300
370	.320	415	.320	410	.320	385	.310	410	.320	410	.320	400	.318
385	.340	420	.330	425	.350	390	.315	415	.330	420	.340	409	.334
390	.350	425	.340	440	.370	400	.320	420	.340	425	.360	417	.347
395	.360	430	.350	450	.380	405	.325	425	.350	440	.310	424.1	.356

TABLE 14

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT .875 THICKNESS

GG - 1		GG - 2		GG - 3		GG - 4		GG - 5		GG - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
120	.080	100	.080	110	.080	90	.080	85	.080	100	.080	101	.080
130	.100	130	.100	140	.100	120	.100	115	.100	125	.100	127	.100
200	.140	200	.140	195	.140	175	.140	175	.140	210	.140	193	.140
230	.180	260	.180	245	.180	230	.180	230	.180	240	.180	239	.180
265	.220	300	.220	280	.220	280	.220	275	.220	270	.220	278	.220
300	.240	335	.240	340	.280	330	.260	325	.260	335	.260	328	.253
325	.280	350	.260	375	.320	350	.280	350	.280	365	.280	353	.283
355	.300	370	.280	400	.350	380	.300	375	.300	390	.300	378	.305
380	.340	390	.300	410	.370	395	.320	390	.320	405	.360	395	.335
395	.360	395	.320	460	.400	410	.340	405	.340	420	.380	414	.357
410	.375	400	.325	500	.460	430	.360	425	.360	490	.420	443	.383
420	.380	415	.330	525	.480	455	.400	445	.380	505	.460	461	.405
430	.385	420	.335	540	.490	470	.420	460	.400	510	.470	471.6	.417

TABLE 15

LOAD-POUNDS AND DEFLECTION FOR WHITE PINE AT 1.00 THICKNESS

HH - 1		HH - 2		HH - 3		HH - 4		HH - 5		HH - 6		$\bar{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
110	.080	115	.080	95	.080	100	.080	105	.080	110	.080	106	.080
140	.100	150	.100	115	.100	120	.100	125	.100	145	.100	133	.100
190	.140	190	.140	175	.140	180	.140	185	.140	190	.140	185	.140
280	.200	290	.200	280	.200	285	.200	285	.200	285	.200	284	.200
350	.260	360	.260	325	.260	330	.260	340	.260	350	.260	343	.260
400	.300	405	.300	370	.300	380	.300	400	.300	410	.300	394	.300
455	.360	460	.360	435	.360	450	.360	455	.360	460	.360	453	.360
490	.400	490	.400	470	.400	475	.400	485	.400	495	.400	484	.400
530	.460	535	.460	490	.460	500	.460	515	.460	535	.460	518	.460
550	.500	555	.500	515	.500	530	.500	535	.500	555	.500	540	.500
575	.540	580	.540	520	.505	535	.510	545	.520	580	.540	556	.526
590	.560	595	.580	525	.510	540	.515	550	.525	595	.580	566	.545
595	.580	605	.585	530	.515	545	.520	555	.530	600	.585	571.6	.553

TABLE 16

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .125 THICKNESS

II - 1		II - 2		II - 3		II - 4		II - 5		II - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
10	.005	5	.005	10	.010	5	.015	10	.010	5	.010	8	.011
20	.010	10	.010	30	.015	10	.020	20	.015	15	.015	18	.014
30	.015	20	.015	40	.020	20	.025	30	.020	30	.020	28	.019
35	.020	30	.020	50	.025	30	.030	40	.025	40	.025	38	.024
45	.025	40	.025	60	.030	40	.035	50	.030	50	.030	48	.029
55	.030	50	.030	70	.035	50	.040	60	.035	60	.035	58	.034
65	.035	60	.035	80	.040	60	.045	70	.040	70	.040	68	.039
75	.040	70	.040	85	.045	70	.050	75	.045	75	.045	75	.044
85	.045	80	.045	90	.050	80	.055	80	.050	85	.050	83	.049
90	.050	90	.050	95	.055	90	.060	85	.055	90	.055	90	.054
95	.055	100	.055	100	.060	100	.065	90	.060	95	.060	97	.059
100	.060	110	.060	105	.065	110	.070	95	.065	100	.065	103	.064
110	.065	115	.065	110	.070	115	.075	100	.070	105	.070	109.1	.069

TABLE 17

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .250 THICKNESS

JJ - 1		JJ - 2		JJ - 3		JJ - 4		JJ - 5		JJ - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
30	.010	25	.010	25	.010	25	.010	25	.010	25	.010	26	.010
55	.020	40	.020	40	.020	45	.020	45	.020	35	.020	43	.020
80	.030	50	.030	50	.030	60	.030	65	.030	75	.030	63	.030
100	.040	80	.040	80	.040	90	.040	95	.040	105	.040	92	.040
125	.050	95	.050	95	.050	100	.050	115	.050	120	.050	180	.050
155	.060	110	.060	110	.060	125	.060	130	.060	135	.060	128	.060
175	.070	115	.070	125	.070	140	.070	150	.070	155	.070	143	.070
190	.080	125	.080	140	.080	150	.080	170	.080	175	.080	158	.080
210	.090	140	.090	150	.090	160	.090	185	.090	185	.090	172	.090
220	.100	150	.100	160	.100	170	.100	195	.100	190	.100	181	.100
225	.110	160	.110	175	.110	180	.110	200	.110	195	.110	189	.110
230	.120	175	.120	180	.120	185	.120	205	.120	200	.120	196	.120
235	.130	180	.130	185	.130	190	.130	210	.130	205	.130	200.8	.130

TABLE 18

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .375 THICKNESS

KK - 1		KK - 2		KK - 3		KK - 4		KK - 5		KK - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
115	.060	100	.060	110	.060	140	.060	180	.060	150	.060	133	.060
170	.080	160	.080	160	.080	170	.080	230	.080	210	.080	183	.080
200	.100	220	.100	195	.100	210	.100	270	.100	225	.100	220	.100
230	.110	240	.110	225	.120	240	.110	285	.120	245	.110	244	.113
265	.120	255	.120	260	.140	250	.120	305	.130	260	.120	266	.125
280	.130	265	.140	290	.160	260	.130	315	.140	270	.130	280	.138
290	.140	275	.150	310	.180	270	.140	325	.150	285	.140	293	.150
300	.150	285	.160	335	.200	280	.150	340	.160	300	.150	307	.162
310	.160	295	.170	340	.210	290	.160	355	.170	310	.160	317	.172
315	.170	305	.180	350	.220	300	.170	365	.180	320	.170	326	.182
320	.180	325	.200	360	.230	310	.180	370	.190	330	.180	336	.193
330	.190	335	.205	370	.240	320	.190	385	.200	340	.185	347	.202
335	.200	340	.210	375	.250	325	.195	390	.210	345	.190	351.6	.209

TABLE 19

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .500 THICKNESS

LL - 1		LL - 2		LL - 3		LL - 4		LL - 5		LL - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
120	.060	130	.060	115	.060	100	.060	120	.060	125	.060	118	.060
205	.100	210	.100	195	.100	165	.100	175	.100	205	.100	193	.100
245	.120	250	.120	235	.120	190	.120	200	.120	250	.120	228	.120
280	.140	280	.140	265	.140	220	.140	215	.140	275	.140	256	.140
310	.160	310	.160	300	.160	245	.160	240	.160	305	.160	285	.160
320	.180	320	.180	310	.170	255	.170	255	.170	315	.180	296	.177
345	.190	345	.190	320	.180	265	.180	265	.180	340	.190	313	.185
360	.200	360	.200	330	.190	275	.190	275	.190	350	.200	325	.195
370	.210	370	.210	340	.200	285	.200	290	.200	360	.210	336	.203
380	.220	380	.220	350	.210	295	.220	305	.220	370	.220	347	.218
390	.230	390	.230	355	.215	300	.230	315	.230	380	.230	355	.228
395	.240	395	.240	360	.220	305	.240	320	.240	385	.240	360	.237
400	.250	400	.250	365	.225	315	.250	325	.245	390	.245	365.8	.244

TABLE 20

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .625 THICKNESS

MM - 1		MM - 2		MM - 3		MM - 4		MM - 5		MM - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
90	.060	80	.060	120	.060	80	.060	100	.060	80	.060	92	.060
180	.100	150	.100	210	.100	170	.100	180	.100	165	.100	176	.100
220	.120	185	.120	250	.120	230	.120	225	.120	210	.120	220	.120
265	.140	225	.140	280	.140	290	.140	265	.140	250	.140	263	.140
305	.160	250	.160	320	.160	340	.160	300	.160	300	.160	303	.160
345	.180	300	.180	350	.180	380	.180	340	.180	350	.180	344	.180
370	.200	335	.200	380	.200	425	.200	370	.200	390	.200	378	.200
405	.220	365	.220	410	.220	460	.220	390	.220	430	.220	410	.220
425	.240	390	.240	430	.240	490	.240	410	.240	465	.240	435	.240
455	.260	425	.260	465	.260	520	.260	435	.260	490	.260	465	.260
495	.300	470	.300	490	.280	540	.280	470	.280	510	.280	496	.287
510	.320	495	.320	510	.300	545	.300	485	.300	525	.300	512	.307
515	.340	500	.340	525	.320	550	.340	490	.310	560	.340	523.3	.332

TABLE 21

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .750 THICKNESS

NN - 1		NN - 2		NN - 3		NN - 4		NN - 5		NN - 6		$\bar{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
125	.060	110	.060	110	.060	120	.060	115	.060	125	.060	118	.060
180	.100	175	.100	175	.100	175	.100	165	.100	180	.100	175	.100
225	.120	210	.120	215	.120	220	.120	215	.120	220	.120	218	.120
270	.140	250	.140	265	.140	260	.140	265	.140	255	.140	261	.140
310	.160	295	.160	310	.160	305	.160	300	.160	300	.160	303	.160
360	.180	340	.180	355	.180	365	.180	360	.180	345	.180	354	.180
400	.200	370	.200	390	.200	385	.200	415	.200	380	.200	390	.200
430	.220	410	.240	460	.240	425	.220	435	.220	420	.220	432	.227
465	.240	440	.260	480	.260	465	.240	470	.240	450	.240	462	.247
495	.260	490	.300	535	.300	515	.260	505	.260	490	.280	505	.277
520	.280	515	.320	555	.320	540	.280	535	.280	515	.320	530	.300
540	.300	575	.360	595	.370	560	.300	555	.320	540	.340	561	.332
550	.320	580	.370	600	.380	565	.320	560	.340	585	.360	573.3	.348

TABLE 22

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT .875 THICKNESS

OO - 1		OO - 2		OO - 3		OO - 4		OO - 5		OO - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
130	.060	110	.060	140	.060	125	.060	115	.060	145	.060	128	.060
210	.100	200	.100	215	.100	220	.100	205	.100	225	.100	213	.100
250	.120	240	.120	255	.120	260	.120	235	.120	250	.120	248	.120
290	.140	280	.140	295	.140	295	.140	280	.140	290	.140	288	.140
370	.180	360	.180	380	.180	380	.180	355	.180	380	.180	371	.180
480	.240	470	.240	490	.240	485	.240	460	.240	495	.240	480	.240
555	.300	540	.300	560	.300	555	.300	535	.300	560	.300	551	.300
570	.320	565	.320	575	.320	560	.320	560	.320	630	.360	577	.327
610	.360	605	.360	620	.360	605	.360	595	.360	650	.400	614	.367
650	.400	635	.400	645	.400	635	.400	630	.400	660	.420	643	.403
660	.420	650	.420	660	.440	655	.440	645	.440	675	.460	658	.437
675	.460	660	.440	685	.475	670	.450	650	.460	690	.475	672	.460
685	.470	670	.460	690	.480	675	.460	660	.475	695	.480	679.1	.471

TABLE 23

LOAD-POUNDS AND DEFLECTION FOR RED OAK AT 1.00 THICKNESS

PP - 1		PP - 2		PP - 3		PP - 4		PP - 5		PP - 6		$\overline{X}$	
lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
140	.060	130	.060	145	.060	150	.060	140	.060	140	.060	141	.060
230	.100	210	.100	240	.100	245	.100	260	.100	240	.100	238	.100
280	.120	260	.120	290	.120	305	.120	295	.120	300	.120	289	.120
335	.140	310	.140	350	.140	360	.140	325	.140	365	.140	341	.140
435	.180	410	.180	445	.180	450	.180	465	.180	460	.180	444	.180
545	.240	530	.240	550	.240	585	.240	590	.240	590	.240	566	.240
650	.300	630	.300	655	.300	665	.300	685	.300	660	.300	658	.300
705	.340	700	.340	715	.340	710	.340	775	.340	710	.340	719	.340
765	.400	720	.400	775	.400	780	.400	835	.400	775	.400	775	.400
800	.440	740	.420	805	.420	815	.420	855	.420	795	.420	802	.423
840	.480	760	.430	845	.440	840	.440	885	.460	855	.440	843	.448
865	.510	795	.460	870	.480	875	.460	895	.470	880	.460	864	.473
870	.520	865	.480	875	.500	880	.485	900	.480	890	.480	880	.490

The deflection increments were further identified by thirteen different measurements for each of the test specimens.

Tables 8 through 15 identify the values for load-pounds and deflection of white pine specimens. These specimens ranged from 1/8 thickness (.125) with a length of three and three-quarter inches to one inch (1.00) thickness and sixteen inches in length. Specimen groups were identified by thickness-number, and a code reference for each specimen group. The generated mean values for the specimen thickness identifies the deflection and load-pounds for each of the thirteen measures. The maximum load-pounds for each thickness is identified as a mean value for each group. Load-pounds range for each group were identified in column thirteen, rows one through six.

Tables 16 through 23 identify the values for load-pounds and deflection for red oak specimens. Their size and thickness range were identical to the white pine specimens. ASTM requirements specified that specimens' length was not to exceed fourteen times the thickness. Load-pounds and deflection values were recorded in the same manner as white pine, and identified values are located in the same proximity.

The values obtained in Tables 8 through 23 were representative of the wood species flexibility and limitations under a load condition. The mean values for load-pounds and deflection were determined from the base data.

TABLE 24

CORRELATION AMONG THE VARIABLE MEAN
LOAD-POUNDS FOR WHITE PINE

Variables	Load-Pound Increase	Load-Pound Percentage
1-2	106.5 lb.	229%
2-3	57.5 lb.	36%
3-4	83.3 lb.	39%
4-5	65.5 lb.	22%
5-6	55.8 lb.	15%
6-7	47.5 lb.	11%
7-8	100.0 lb.	21%

The relationship among the combined mean values indicates a trend (linear) for the red oak specie. This indicates an increase in load-pounds and is related to thickness alteration. The optimal (trend for) load-pounds (strength) for this specie was identified and is further illustrated in Table 25.

<u>Correlation Within the Species</u>

The correlation among the thickness change and load-pounds for each specie were identified in Tables 24 through 28. Tables 24 and 25 identify the percentage change among the variable mean load-pounds for the species. Correlation among the incremental increase in thickness were analyzed for trend relationships.

The mean load-pounds correlations in Table 24 indicate

TABLE 25

CORRELATION AMONG THE VARIABLE MEAN LOAD-POUNDS FOR RED OAK

Variables	Load-Pound Increase	Load-Pound Percentage
1-2	91.6 lb.	84%
2-3	150.8 lb.	75%
3-4	14.1 lb.	4%
4-5	157.5 lb.	43%
5-6	50.0 lb.	9%
6-7	105.8 lb.	18%
7-8	200.8 lb.	29%

relationships for white pine. The largest incremental change exists among variable thickness one (.125) and variable two (.250). The increase among the load-strengths were 106.5 pounds for a 229 percent increase. This increase was the result of a 100 percent increase in thickness change. The development of a large increase was not identified when approaching the next doubling point (.500) thickness. Incremental change from variable two and variable three increased from 36 to 39 percent when achieving the variable four thickness (.500). The increment change among the variables four through seven (.875) indicate a declining load-pound increase. This decline ranged from 65.5 to 47.5 load-pounds with a percentage range from 22 to 11 percent. The percentage change among variable four and seven indicates an insignificant gain of thickness increase

TABLE 26

GROUPED MEAN SCORES FOR WHITE PINE AND RED OAK

	Lamination Thickness									
	1	2	3	4	5	6	7	8	Specie	$\bar{X}$
POUNDS	53.50	160.00	217.50	302.83	368.33	424.16	471.66	571.67	White Pine	321.21
POUNDS	109.16	200.83	351.66	365.84	523.33	573.33	679.16	880.00	Red Oak	460.42

TABLE 27

MEAN, STANDARD DEVIATION AND VARIANCE OF LOAD STRENGTH FOR WHITE PINE SPECIMENS

Variable	(Thickness)	Mean	STD. DEV.	Variance
1	(.125)	53.500	7.791	60.700
2	(.250)	160.000	26.646	710.000
3	(.375)	217.500	31.425	987.500
4	(.500)	302.833	31.467	990.200
5	(.625)	368.333	31.571	996.712
6	(.750)	424.167	20.842	434.400
7	(.875)	471.667	46.226	2136.800
8	(1.00)	571.667	32.199	1036.800

TABLE 28

MEAN, STANDARD DEVIATION AND VARIANCE OF LOAD STRENGTH FOR RED OAK SPECIMENS

Variable	(Thickness)	Mean	STD. DEV.	Variance
1	(.125)	109.167	5.846	34.175
2	(.250)	200.833	20.351	414.175
3	(.375)	351.667	25.234	636.737
4	(.500)	365.833	37.871	1434.212
5	(.625)	523.333	27.510	756.800
6	(.750)	573.333	18.352	336.800
7	(.875)	679.167	13.206	174.400
8	(1.00)	800.000	13.038	170.000

in relation to load-pounds. The increase among variable seven (.875) and variable eight (1.00) was 100 pounds. The percentage increase from 11 percent among .650 and .750, increased to 21 percent among .875 and 1.00 inch thicknesses.

Incremental thickness increase for white pine indicates a significant relationship in conjunction with the group mean value for the specie. The group mean value is identified in Table 26. The relationship of lamination thickness increase effects upon the load-pounds (strength), develop a trend of significance when thickness is doubled for the first time, with decreasing effect when doubled thereafter.

The mean load-pound correlations in Table 25 indicate the largest incremental change exists among variable one and variable two. The increase among the variables were 91.6 load-pounds for an increase of 84 percent. The increase was the result of a 100 percent increase in thickness change. Thickness increase effected the percentage gain for variables two, three and four. The effect was of a declining increase. The development of load-pound increase similar to variables one and two was noted among variables four and five. Declining increase was further noted among variable five and six. Increasing load-pounds reaction to thickness change among variables six and seven were noted. Variables seven and eight with a 29 percent increase in load-pounds. The effect of doubling the thickness was noted with major significance at the first development, with declining significance thereafter.

Incremental thickness increase for red oak indicates a significant relationship in conjunction with the group mean value. The group mean value is identified in Table 26.

Table 26 identifies the mean scores for both wood species (pine and oak). The mean load-pound scores for the species were generated on the basis of the mean scores for each variable specie thickness. The mean score for pine is 321.21 load-pounds. Close relationship to the mean exists with variable thickness four or .500. The mean score for oak is 460.42 load-pounds. The relationship to one specific variable exists within a short range. The relationship range is among variables four (.500) and five (.525) thicknesses.

Tables 27 and 28 identify the mean, standard deviation and variance among the increment change in thickness for the species.

The variable indicator for Tables 24 through 28 is the thickness representation for a mean value. The standard deviation for a given thickness is the distance from the mean in relation to the recorded values for that thickness. This indicates the degree to which specimen samples alter on a whole from the mean value. The significance of the standard deviation simulates a range influx in the samples. The variance is simply the square of the standard deviation.

The development of a trend in the .375 through .625 thickness, identifies the optimal thicknesses for white pine in Table 27.

The standard deviation for red oak (Table 28) identifies a flutter in the trend range. The trend exists from .375 through .625 thicknesses. This trend further indicates the largest deviation at the trend center or .500 thickness.

Summary

In this chapter, the observed measures for ninety-six test specimens were recorded and analyzed for thickness and load-pound relationships. The presentation and analysis of data included the utilization of technical data tables, and descriptive translation of the relationships or trends developed. Load-pound relationships, trends and correlations were noted for the species. The existence of positive correlation among lamination thickness and load-strength was discovered.

CHAPTER V

SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

Restatement of the Problem

The problem of this study was to determine the maximum load-strength for two selected laminated wood species by altering the thickness by 1/8 inch increments up to one inch. The specific objectives were to: (1) identify the most common variables involved in wood lamination; (2) identify and select the two most common wood species used in wood lamination; (3) determine the maximum load-strength of graduated thickness utilizing the American Society for Testing Materials (ASTM D805-52) static bend test specifications.

Summary

The basic assumption of this study was that the alteration of lamination thickness has no effect on the laminated member load-strength. The study was limited to the White Pine and Red Oak species that were identified by laminate manufacturers.

The study began with a review of literature which included a state-of-the-art survey. The topics addressed variables involved in wood lamination and factors that effected their strength. Next, the selection and development of speciman samples were achieved within boundaries established by ASTM. Ninety-six speciman samples were developed with forty-eight specimens per specie. Each specie speciman was developed according to the specific dimensions required for their incremental thickness. The task of load-pound and deflection measure was divided into sixteen groups, eight sub-groups per specie according to thickness. Each group contained six speciman samples that were tested under a continuous load on the Vega low-range nonmetalic tester (NMT-2). Resulting data from the species were analyzed for load-pound mean value relationships and development of trends.

Conclusions

The conclusions formulated from this study were based on the results of the literature review, the analysis of data collected from static bend tests, and a comparison of the two. Based on the above, the following conclusions were derived:

1. There were no specific standards established for small laminations within the wood laminators' industry, only recommendations.
2. The availability of data for wood laminations under two inches is scarce due to the lack of commercial application of structural members in the small size range. Further, the cost of the operations is prohibitive for financial benefit to the fabricator.

3. The dependent variable of thickness when altered does effect the load-strength of the member.
4. The increase of laminations develops a linear trend within the species. The effect of declining increases signified a norm or shelf where the increase of thickness had nominal effect on strength.
5. The nominal effect noted close relation to the mean values for both species. For White Pine, the mean value indicated was 321.21 pounds. For Red Oak, the mean value indicated 460.42 pounds.
6. The maximum load strength for a laminated member is independent from members of different spans and thickness, while members of equal span and thickness can be determined through probability and testing.

Recommendations

Based on the results of this study, it was recommended:

1. A follow-up study should be conducted to determine what effect the age of the wood has on the load-strength.
2. The sample size of the speciman thickness should be increased to determine if further nominal values result under similar conditions.

3. The sample number of specimens should be increased to determine if the relationships are linear with increased numbers.
4. Statistical analysis of the data should be utilized with a two-way analysis of variance for each specie and among the species.
5. A study should be conducted to determine the effect upon the specimens when specific gravity is the dependent variable.
6. A study should be conducted to determine comparative load-strength relationships among laminated and nonlaminated members of equal size increments.

APPENDICES

APPENDIX A

SURVEY RECIPIENTS

American Panel Products Inc.
1735 Homes Rd.
Ypsilanti, MI 48197

American Sash and Door Co.
4621 E. 75th St. Ter.
Kansas City, MO 64132

Anaconda Forest Products
Drawer 2
Bonner, MT 59823

Bear Archery Co.
Groyling, MI 49738

Beltran Guitar Co.
1715 Dyke Ave.
Grand Forks, ND 58201

Bent S and Bros. Inc.
Gardner, MA 01440

Boise Cascade Corp.
Bldg. Products Div.
P. O. Box 2885-T
Portland, OR 97208

Brown Wood Products Co.
200 Northfield Rd.
Northfield, IL 60093

Browning Arms Co.
Route #1
Morgan, UT 84050

Chicago Cutlery Inc.
5422 Co. Rd. 18
P. O. Box 9494
Minneapolis, MN 55440

Custom Woodworking Inc.
Howard City, MI 49329

D and M Products Inc.
11322 N.E. Marx
Portland, OR 97208

R. Durre
R. R. 1
Strawn, IL

Steve Foley
Oregon School of Arts and Crafts
8245 S.W. Burnes Rd.
Portland, OR 97225

Fort Smith Chair Co.
Fort Smith, AR 72901

Michael Fortune
Sheridon College
School of Crafts and Design
1460 S. Sheridon Way
Mississouga, Ontario L5H127

Gamble Brothers
4666 Allmond Ave.
Louisville, KY 40209

Hannibul Woodworking Co.
P. O. Box 470
Hannibul, MI 63401

Heywood-Wakefield Co.
200 Central
Gardner, MA 01440

Hickory Mfg. Co.
Hickory, NC 28601

Jasper Cabinet Co.
P. O. Box 69
Jasper, IN 47546

Knipp and Co. Inc.
3401 S. Hanover
Baltimore, MD 21225

Levin Bros. Inc.
406 Chicago Ave.
Minneapolis, MN 55415

Little Rock Furniture Mfg. Co.
148 E. 2nd.
Little Rock, AR 72201

Lumb Woodworking Co.
185 Smith
Poughkeepsie, NY 12601

Marshall Fixture Co.
620 N. 9th
Payette, ID 83661

Metz, J. L., Furniture Co.
252 Wilwood Rd.
Hammond, IN 46320

Midwest Fabricators Inc.
26 Allen Ave.
St. Louis, MO 63119

Morgan Co.
Oshkosh, WI 54901

National Service Ind. Inc.
1180 Peachtree N.E.
Atlanta, GA 30309

Niedermeyer-Martin Co.
1727 N.E. 11th Ave.
Portland, OR 97208

Pacific Wood Treating Corp.
111 W. Division
Ridgefield, WA 98642

Paris Mfg. Co.
South Paris, ME 04281

Pearson Ben Inc.
Pine Bluff, AR 71601

Period Inc.
Henderson, KY 42420

Pittsburgh Finish and Stain Co.
2000 Sedgewick and Reichold
Pittsburgh, PA 15212

Ply-Curves Inc.
1615 Monroe at Sweet
Grand Rapids, MI 49505

Plywood Fabricator Service
American Plywood Association
Dept. TR-O
1119 A St.
Tacoma, WA 98402

Rome Sporting Goods Co.
Rome, NY 13440

Roseland Stair Works Inc.
342 W. 11th
Chicago, IL 60607

Saginaw Furniture Shops
7300 N. LeHigh Ave.
Chicago, IL 60648

Shakespeare Company
241 E. Kalamazoo
Kalamazoo, MI 49007

Smith System Mfg. Co.
Minneapolis, MN 55414

Solid Comfort Furniture
R. R. 1
Fargo, ND 58103

Tell City Mfg. Co., Inc.
201 S. Jefferson St.
Orange, NJ 07050

Tools for Bending Inc.
2133 S. Bellaire
Denver, CO 80110

Vermillion Inc.
1207 S. Scenic Ave.
Springfield, MI 68502

Virco Mfg. Corp.
S. Vermont and Redondo Blvd.
Los Angeles, CA 90052

Weyerhauser Co. Wood Products
Tacoma, WA 98402

Wham-O Mfg. Co.
San Gabrial, CA 91778

Woodwork Corp. of America
1432 W. 21st
Chicago, IL 60608

APPENDIX B

STATE OF THE ART SURVEY

LAMINATED WOOD PRODUCTS QUESTIONNAIRE

This questionnaire is divided into two sections: materials utilization and lamination variables. Please mark questions accordingly by placing a check or X in the space provided. Mark other and identify, if appropriate answer is not listed.

A. MATERIALS UTILIZATION:

1. What is/are the laminated wood product(s) that your company produces?

_____ Arches	_____ Furniture Components
_____ Beams	_____ Plywood
_____ Cutting Boards	_____ Rails
_____ Flooring	_____ Sporting Goods

Other ______________________________

2. Indicate those wood specie(s) used by your company in producing laminated wood products:

_____ Ash	_____ Red Oak
_____ Birch	_____ White Oak
_____ Cherry	_____ Pecan
_____ Hemlock	_____ Pine
_____ Red Maple	_____ Walnut

Other ______________________________

3. Does your company use a single type/specie of wood or combination of species in producing laminated wood products?

_____ Single	_____ Combination

4. Identify those wood combinations used by your company in laminated wood products:

_____ Ash/Birch	_____ Hemlock/Pine
_____ Ash/Hemlock	_____ Red Oak/White Oak
_____ Cherry/Oak	_____ Pecan/Birch

Other ______________________________

5. Which of the following mechanical properties were taken into consideration in choosing a specie of wood for lamination?

_____ Bending _____ Stress

_____ Shear Other _______________

B. LAMINATION VARIABLES:

1. Specify the appropriate wood thickness most commonly used in your laminated members:

_____ 1/8 in. _____ 3/4 in.

_____ 1/4 in. Other _______________

2. Indicate the pressure utilized in the clamping of wood laminated product(s), manufactured by your company:

_____ 0-35 psi. _____ 95-125 psi.

_____ 35-65 psi. _____ 125-175 psi.

_____ 65-95 psi. _____ Above 175 psi.

3. Which adhesive best suits your wood laminated product(s)?

_____ Aliphatic _____ Resorcinol

_____ Polyvinyl _____ Urea Formaldehyde

Other _______________________________

4. Do you utilize a curing press in the production of wood laminated products?

_____ Yes _____ No

5. What test(s) are performed to insure product quality assurance?

____

____

____

____

____

6. Specify the moisture content percentage range of each wood specie before production assembly:

A.) Specie Name __________

Moisture Content % ___ 5 - 20% ___ 20 - 35%

___ Above 35%

B.) Specie Name __________

Moisture Content % ___ 5 - 20% ___ 20 - 35%

___ Above 35%

7. What do you consider as being the most critical technical problem in today's wood laminating industry?

____

____

____

____

ADDITIONAL COMMENTS: __________________________________

____

____

____

To receive a summary of this questionnaire's findings, please complete the following.

Name ____

Title ____________________ Company ________________

Address ______________ City __________ State _____ Zip _____

Thank you for your time and assistance. A postage-paid, self-addressed envelope is enclosed for returning your completed questionnaire.

PLEASE MAIL TODAY!

Randall G. Souser
Department of Industrial Technology
University of North Dakota

APPENDIX C

ASTM D805-52 REQUIREMENTS

Test Speciman

- Grain direction shall be parallel to length of test speciman.
- Test speciman shall be rectangular in cross-section.
- Length of speciman may not be less than 14 times the depth plus (5 cm) 2 inches and the span length not less than 14 times the depth.
- Each test speciman shall be measured to an accuracy of not less than 0.3 percent.

Moisture Content and Specific Gravity

- The moisture content and specific gravity of each speciman (specie) shall be determined before load testing occurs.
- Each specie (speciman) being tested shall be not less than one percent accuracy.

Span and Supports

- Center loading shall be used.
- A one inch over hang shall be allowed at each end of the support.
- Supports shall be adjusted laterally to permit compensation for light twist or warp in speciman.

Loading Procedure

- The load shall be applied with a continuous motion of the head throughout the test.

Load Deflection Curves

- Load deflection curve readings shall be taken to the nearest 0.001 inch.
- Increments of load shall be chosen so that not less than thirteen readings of load and deflection are taken to the proportional limit.

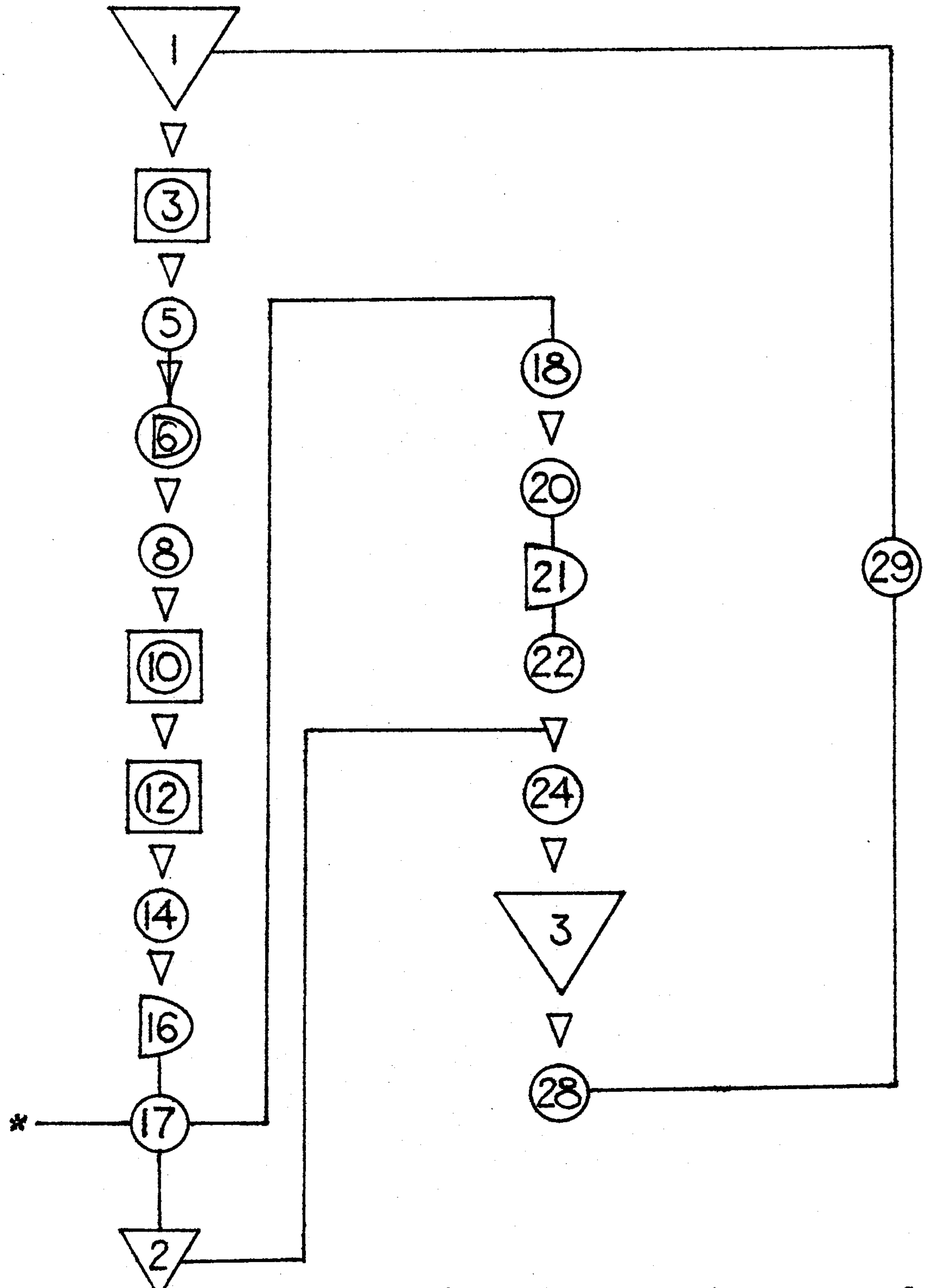
Other

- The number of test specimens to be chosen for the test are not determined.
- The reporting of test findings shall include the above mentioned data.

APPENDIX D

FLOW-PROCESS FOR SPECIMEN DEVELOPMENT AND TESTING

FLOW-PROCESS FOR SPECIMEN DEVELOPMENT AND TESTING



* Development and movement of specimens are redundant.

1. Wood specie storage (White Pine and Red Oak).
2. Transport White Pine to inspection point one, or Red Oak.
3. Measure Moisture Content (MC) and determine grain direction.
4. Transport to jointer.
5. Square one edge to face at 90°.
6. Delay (note environment conditions).
7. Transport to universal saw.
8. Set uni-saw fence at 2-1/8 inch distance to blade. Elevate blade to a one inch height, and rip stock material until the operation is completed. Inspect for cut measure.
9. Transport stock material to bandsaw.
10. Set bandsaw blade fence at a distance of 10/64 inch from blade. Rip stock material parallel to grain, repeat until all material is completed. Examine material thickness (.140 in.).
11. Transport to surface sander.
12. Adjustment of sander should remove .008 in. on first face pass. Adjust sander to remove .007 in. on second face pass. Examine material thickness, should be (.125 in.).
13. Transport materials to uni-saw for measurement cutting of lengths.
14. Set-up uni-saw for cutting each of the following lengths, utilize group coding letters to segregate specimens, and cut defined number of specimen pieces.

Length	White Pine/ Code	No.	Length	Red Oak/ Code	No.
3.75 in.	(AA)	6	3.75 in.	(II)	6
5.50 in.	(BB)	12	5.50 in.	(JJ)	12
7.25 in.	(CC)	18	7.25 in.	(KK)	18
9.00 in.	(DD)	24	9.00 in.	(LL)	24

Length	White Pine/ Code	No.	Length	Red Oak/ Code	No.
10.75 in.	(EE)	30	10.75 in.	(MM)	30
12.50 in.	(FF)	36	12.50 in.	(NN)	36
14.25 in.	(GG)	42	14.25 in.	(OO)	42
16.00 in.	(HH)	48	16.00 in.	(PP)	48

15. Transport laminate groups to adhesive application station.

16. Delay (prepare adhesive--Urea Formaldehyde and Water, ratio 5:2).

17. Prepare laminate groups (BB - HH) or (JJ - PP) for adhesive application. Groups (AA) and (II) are not to be laminated, place in storage two. The following coded groups are to be placed in combination as the number indicates, with each group having six completed combinations.

Code	Number	Code
(BB)	2	(JJ)
(CC)	3	(KK)
(DD)	4	(LL)
(EE)	5	(MM)
(FF)	6	(NN)
(GG)	7	(OO)
(HH)	8	(PP)

18. Apply adhesive with a roller to a selected specie.

19. Transport specie groups to clamps.

20. Clamp specie groups.

21. Delay (72 hours curing time).

22. Remove specie groups from clamping device.

23. Transport specie groups to uni-saw. Remove materials from storage two.

24. Set uni-saw fence at a one inch distance from the blade. Cut the specie groups to the desired width of the specimen design.

25. Transport the specimen groups to storage number three.

26. Temporary storage prior to testing.

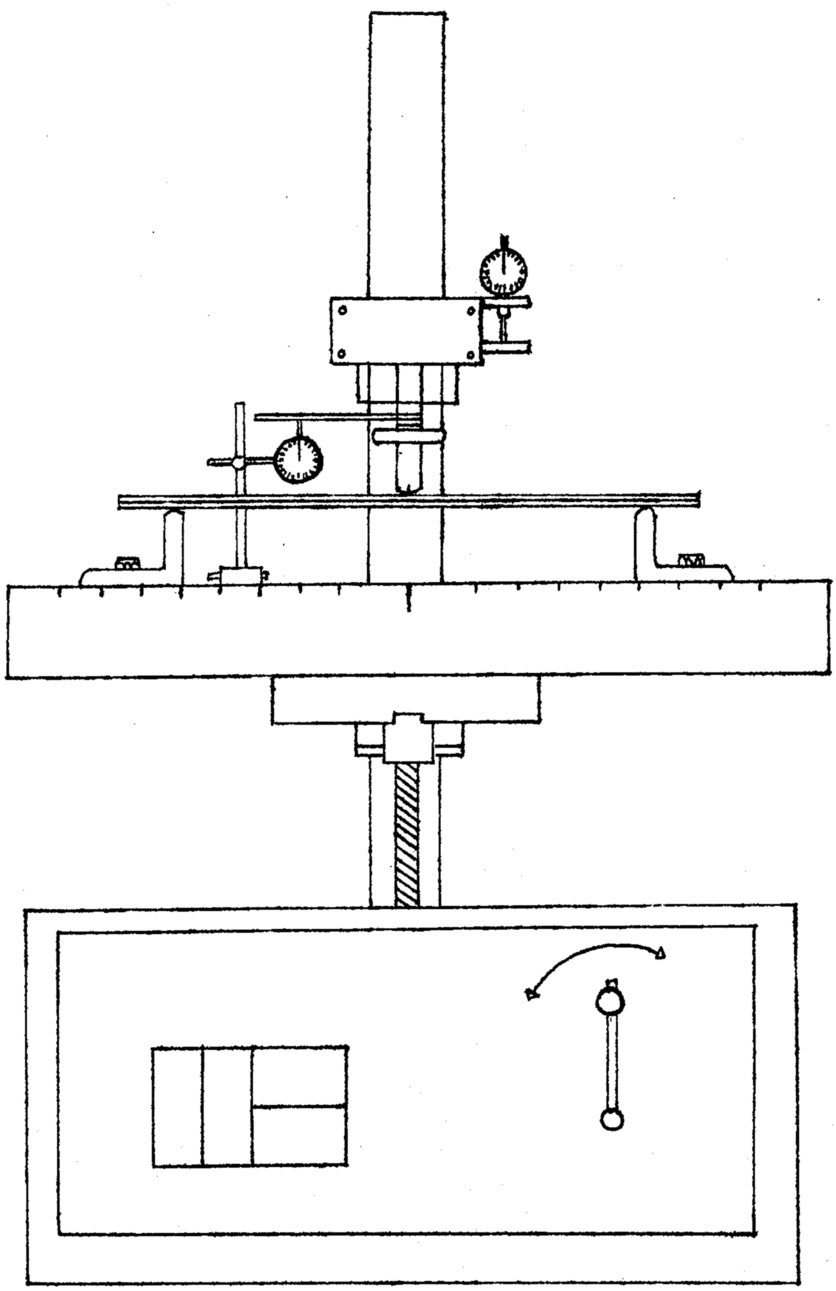
27. Transport specie groups in alphabetical order to the Vega tester.

28. Calibrate and conduct test(s) for each specie group, re-calibrate and repeat for each speciman sample.

29. Procedure return to storage number one and repeat cycle for second wood specie. When returning to number twenty-nine, terminate cycle.

APPENDIX E

VEGA TESTER



APPENDIX F

DATA RECORDING TABLE

DATA RECORDING TABLE

Code														
NO.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.	lb.	def.
1														
2														
3														
4														
5														
6														
7														
8														
9														
10														
11														
12														
13														

Specie: ____________________ Thickness: ____________________

BIBLIOGRAPHY

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American Institute of Timber Construction. Timber Construction Manual. New York: John Wiley and Sons, Inc., 1971.

American Institute of Timber Construction. Timber Construction Manual. 2nd ed. New York: John Wiley and Sons, Inc., 1974.

American Society for Testing Materials. ASTM Standards on Wood Preservatives, and Related Materials. Philadelphia: American Society for Testing Materials, 1959.

American Society for Testing Materials. ASTM Standards on Wood Preservatives, and Related Materials. 2nd ed. Philadelphia: American Society for Testing Materials, 1971.

Feirer, John L. Cabinetmaking and Millwork. Peoria, Ill.: Chas. A. Bennett Co., Inc., 1977.

Glass, Gene V. and Stanley, Julian C. Statistical Methods in Education and Psychology. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1970.

Gurfinkel, German. Wood Engineering. New Orleans, La.: Southern Forest Products Association, 1973.

Halpern, Siegmund. The Assurance Sciences: An Introduction to Quality Control and Reliability. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1978.

Hayes, Glenn E. Quality Assurance: Management and Technology. Capistrano Beach, Cal.: Charger Productions, Inc., 1974.

Hoadley, Bruce R. Understanding Wood: A Craftsman's Guide to Wood Technology. Newtown, Conn.: The Taunton Press, Inc., 1980.

Hopeman, Richard J. Production and Operations Management. Columbus: Charles E. Merrill, 1980.

Kollmann, Franz F. P. and Cote, Jr., Wilfred A. Principles of Wood Science and Technology: Solid Wood. New York: Springer-Verlag New York Inc., 1968.

Lento, Robert. Woodworking: Tools, Fabrication, Design and Manufacturing. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1979.

Lindberg, Roy A. Materials and Manufacturing Technology. Boston: Allyn and Bacon, Inc., 1968.

Panshin, A. J. and De Zeeuw, Carl. Textbook of Wood Technology. New York: McGraw-Hill, 1980.

Patton, W. J. Materials in Industry. Englewood Cliffs, N.J.: Prentice-Hall, Inc., 1976.

Roberts Consolidated Industries. "Product Data for Weldwood-Plastic Resin Glue." City of Industry, Cal., 1976. (Mimeographed.)

Stanton, William J. Fundamentals of Marketing. New York: McGraw-Hill, 1981.

Stevens, W. C. and Turner, N. Wood Bending Handbook. London: Her Majesty's Stationery Office, 1970.

Thomas Registry. New York: Thomas Publishing Company, 1979.

U.S. Department of Agriculture. The Forest Products Laboratory. Wood Handbook No. 72. Washington, D.C.: Government Printing Office, 1955.