THE FLEXURAL STRENGTH AND STIFFNESS OF EASTERN OAK PALLET SHOOK

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(ABSTRACT)

An investigation was conducted to provide information concerning the flexural behavior of oak pallet shook. This information is to be used in the development of a rational pallet design procedure. The investigation was designed to meet three basic objectives 1) to collect basic data concerning the flexural properties of oak shook, 2) to evaluate the potential of a visual grading system and 3) to investigate the impact of growth and manufacturing defects on the flexural properties of oak pallet shook.

Strength, stiffness and selected physical property values were determined and reported. The visual grading system was found to be effective at separating oak pallet shook on the basis of strength and stiffness. A comparison of test results with published procedures indicates strength ratios may be an effective approach to accounting for the influence of growth and manufacturing defects found in oak pallet shook.

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SECTION 1. INTRODUCTION

Approximately 15 million wooden pallets were produced in the United States during 1948 (15). By 1980 U.S. pallet production reached 285 million units and consumed 18% of all the lumber manufactured in the United States (8). Although current economic conditions have produced a decline in production the growth which will come with recovery will place a great demand on our limited forest resource. Potential forest use conflicts and the need for improved product reliability necessitate standardized pallet design procedures. These procedures must yield safe durable pallets while minimizing wood waste. To date, no such procedures exist.

The development of such a pallet design methodology is currently underway. A cooperative Pallet Research Program (PRP), undertaken by Virginia Tech, the U.S. Forest Service and the National Wooden Pallet and Container Association is exploring many facets of pallet behavior. The overall objective of this program is to develop a rational means of designing pallets to achieve a consistent balance between product safety and economy.

Many variables must be quantified if this procedure is to produce consistently reliable results. Such factors as fastener type, load and support geometry, and member configuration have been shown to have a direct influence on pallet performance (13, 14). Another factor is the magnitude of and variation in mechanical properties of individual wood components. While information on some softwood materials is available, little work has been devoted to determining the mechanical properties of hardwood lumber in general or pallet shook specifically.

One approach that has been suggested for assigning allowable strength properties to hardwood lumber is with the use of strength ratios (7). This ratio is defined as the ratio of the strength of lumber with defects to that of lumber without defects. They were originally developed so that a strength reduction could be assigned to individual pieces of visually graded softwood lumber (1). Some preliminary investigation has shown that developed strength ratios may not be applicable to hardwood lumber (22). Furthermore, pallet shook sizes are unique and extrapolation of softwood lumber procedures to pallet shook, softwood or hardwood, may be questionable.

There are some guidelines presently used in the pallet industry which recognize variability of pallet shook (9). These guidelines establish pallet grades on the basis of the type and size of defects found in wooden pallet components. The primary shortfall of this technique is the lack of flexibility or reliability for specific pallet applications.

A system for visually grading hardwood pallet shook has been proposed by Wallin and Frost (21). In this system, one of five visual grades is assigned to a piece of shook. Each grade carries with it a set of allowable strength properties. These properties were determined through the use of strength ratios developed especially for pallet shook (grade factors). Implementation of such a system may allow pallets to be designed with specific applications in mind. However, some mechanical testing of pallet shook indicates that the proposed grade parameters may require further refinements (6, 20).

The overall objective of the research described in this thesis was to provide basic flexural properties data for eastern oak pallet shook to be used in the development of rational, reliability-based design procedures for wood pallets. This was accomplished in three phases. The objective of the first phase was to determine the strength and stiffness of a representative sample of mixed oak pallet components. Oak was selected for this study due to its widespread use in the pallet industry. This work is described in Section 2. The objective of the second phase was to determine the effect of growth and manufacturing defects on the strength and stiffness of the sample. The third phase assesses the potential of the visual grading system devised by Sardo and Wallin (12). The results of the second and third phase are reported in Section 3.

SECTION 2. FLEXURAL PROPERTIES OF EASTERN OAK PALLET SHOOK--EXPERIMENTAL METHODS AND POPULATION RESULTS.

2.1 Introduction

Pallets are commonly used in many industries as an economical and efficient means of transporting or storing unit loads of products. Although over 200 million pallets are made each year very little technically substantiated design information is available for planning these structural systems for specific applications within any degree of reliability.

The development of a rational pallet design methodology is currently underway. A cooperative Pallet Research Program (PRP), undertaken by Virginia Tech, the U.S. Forest Service and the National Wooden Pallet and Container Association is exploring many facets of pallet behavior. The overall objective of this program is to develop a rational means of designing pallets to achieve a consistent balance between product safety and economy.

One major input to any structural design process is an estimate of the material properties of the components. Unfortunately very little of this type of information is available for pallet shook. Almost no data is available for hardwood species such as the mixed eastern oaks which are commonly used in pallets.

The objective of this research was to provide basic flexural properties data for cut-to-size eastern oak pallet shook for use in the development of design procedures. Additionally, the influence of defects on strength and stiffness was evaluated as was a proposed grading scheme for these materials. The objective of this section is to describe the methods and materials employed in the study and to report the test results. The defect and grading system analysis are reported in Section 3.

2.2 Methods and Materials

Eastern U.S. oak species have a growth range which spreads from North Dakota south to Texas and east to the Atlantic Ocean. Variation in physical properties due to geographic location (17) dictated the necessity for including a major portion of this region in the sampling scheme. However, it was not feasible to sample the entire range. For this reason two sampling restrictions were established.

First a state to be sampled must contain a minimum of 2% of the total eastern U.S. oak saw timber volume, and second, that state must maintain a viable oak pallet shook producing industry. Two exceptions were made to the 2% volume criterion. Texas was not sampled due to a very low oak density and Connecticut was sampled due to a very high density. Density was gauged on the average number of board feet per square mile of land area (bf/mi^2).

Of the states considered, sixteen fulfilled these requirements (Table 2.1). These 16 states contain approximately 80% of the total eastern U.S. oak saw timber volume.

The number of mills sampled within each state was based on the percentage of the total oak volume found within that state. One mill was sampled in states containing less than 4%, two in states having 4-6%, and three in states with more than 6% (Table 2.2). This approach was implemented to avoid any biasing created by political boundaries. It was also decided that the location at which shook was produced may be a poten-

Table 2.1--Volume, percent, and density of eastern U.S. oaks by state

State	Volume[(a)] Oak Sawtimber (10^6BF)	Percent of Total U.S. Volume	Average Density 10^6bf/m
AL*	10,940	5.04	.212
AR*	12,512	5.76	.236
CT*	2,761	1.27	.551
DE	362	0.16	.018
FL	3.566	1.64	.061
GA*	11,324	5.21	.192
IL	3.353	1.54	.059
IN*	4,837	2.23	.133
IA	1,443	0.66	.026
KS	437	0.20	.005
KY*	14,135	6.51	.350
LA*	8,278	3.81	.171
ME	696	0.32	.021
MD	2,083	0.96	.197
MA	1.926	0,89	.233
MI*	4,925	2.27	.085
MN	2,353	1.08	.028
MS*	7,430	3.42	.156
MO*	10,715	4.93	.154
NE	124	0.06	.002
NH	1,388	0.64	.149
NJ	1,718	0.79	.219
NY	3,605	1.66	.073
NC*	16,621	7.65	.315
ND	47	0.02	.001
OH*	6,549	3.02	.159
OK	1,522	0.70	.022
PA*	15,362	7.07	.339
SC°	5,941	2.74	.191
SD	10	x	†
RI	287	0.13	.221
TN*	13,829	6.37	.327
TX	7,962	3.67	.030
VT	369	0.17	.038
VA*	19,584	9.02	.480
WV*	12,468	5.74	.516
WI°	5,730	2.64	.102
Total	217,192		

Volume statistics are taken from reference 18.
This includes select white, select red, other white and other red.

* - to be sampled

x - less than 0.01% total volume

† - less than 0.001 million board feet per square mile

° - no sizeable oak pallet producing industry

Table 2.2--Number of mills sampled within each state.

State	% Total Oak Volume	No. of Mills Sampled
AL	5.04	2†
AR	5.76	2
CT	1.27	1
GA	5.21	2
IN	2.23	1
KY	6.51	2*
LA	3.81	1
MI	2.27	1
MS	3,42	1
MO	4.93	2
NC	7.65	3
OH	3.02	1
PA	7.07	3
TN	6.37	3
VA	9.02	3
WV	5.74	2
Total	79.32	30

† - Only suitable deckboards were available at one mill in this state.

* - Only two mills were sampled due to a lack of suitable material at the time of sampling the third mill.

tial source of variation. For that reason, mills which purchase shook externally as well as those which produce it internally were sampled. A list of mills sampled is contained in Appendix 1.

At each mill a minimum of twenty 1" x 6" x 40" deckboards, thirty 1" x 4" x 40" deckboards, and fifty 2" x 4" x 48" unnotched stringers were randomly chosen from inventory. Actual dimensions varied somewhat with availability. All samples were collected in the green condition.

Upon selection each member was coded with a mill and observation number and topically treated with pentachlorophenate to prevent fungal attack. The treated shook was wrapped in 6 mm polethylene film to prevent drying and returned to the lab at Virginia Tech.

Laboratory evaluation consisted of visual grading, defect mapping, and mechanical testing. Details of these three phases are provided below.

Grading--The first four hundred specimens (200 deckboards and 200 stringers) were assigned one to five visual grades based on the criteria set forth by Wallin and Frost (21) (Appendix 2). Analysis of the data from these preliminary tests indicated that only four of the five grades were significantly different. Based on these results, which are consistent with Holland's (6), the first four hundred samples were regraded and the remaining samples were graded according to the criteria set forth by Sardo and Wallin (12), Appendix 3. These criteria prescribe a system for visual grading which contains only four grade classifications.

Defect mapping--Defects were mapped concurrently with grading using the method outlined by Wilson (23), Appendix 4. This procedure recorded information concerning three basic defect categories; the grade controlling defect, the estimated maximum strength reducing defect, and any other defects which were estimated to impact on the mechanical performance of the member. The location with respect to load points, type, size, and location with respect to edges and faces was recorded for each defect. Additionally, the x, y and z coordinates were recorded for the maximum strength reducing defect and any defects which fell into the "other" category (Figure 2.1). Each defect was color coded to facilitate identification at the time of testing. Specific examples of this technique are provided in Appendix 5. Testing was initiated upon completion of grading and mapping of one shook lot, usually 100 samples.

Testing--Static bending tests were conducted in accordance with ASTM D-198-73 (2). The only deviation from this procedure was the rate of load application. To complete testing in a reasonable time period, stringers were loaded at a cross head movement rate of one inch per minute, deckboards, two inches per minute. This is approximately ten times the rate prescribed by the standard procedure.

Deckboards were tested flatwise over a 36" span and stringers were tested edgewise over a 45" span. These member orientations were chosen to simulate service conditions. Equal loads were applied to the one-third points of each beam. The magnitude of the loads and resulting centerline deflection were recorded continuously until failure. Failure was considered as the point at which the member failed to sustain a load, whether due to mechanical breakage or excess deflection. The location, type, and cause was recorded for each failure. After testing, individual moisture contents and basic specific gravities were determined.

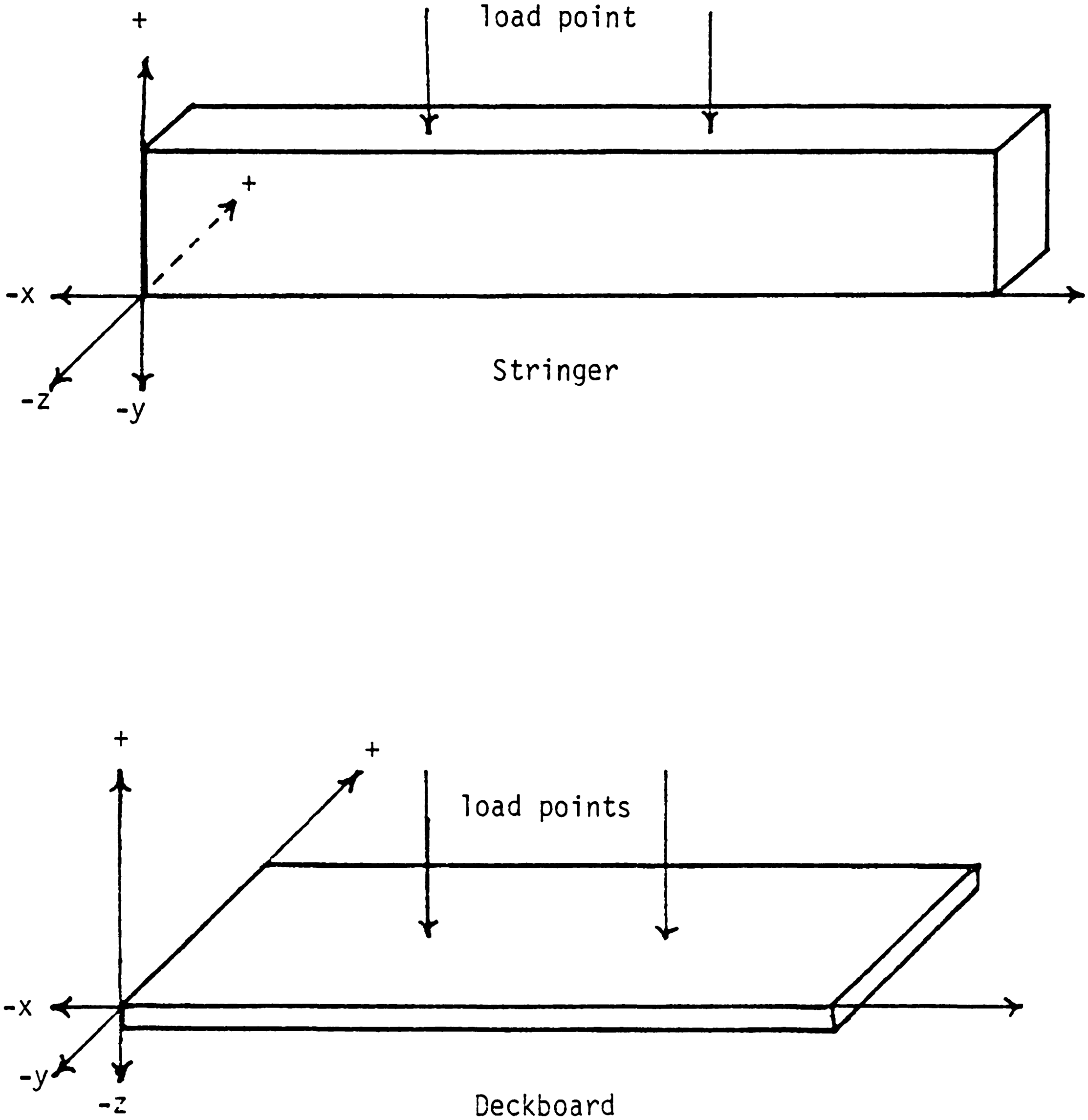

Figure 2.1. Coordinate system used for pallet shook defect mapping.

2.3 Results and Discussion

Sample statistics were computed for modulus of rupture (MOR), modulus of elasticity (MOE), stress at proportional limit (Spl), basic specific gravity (SG_B), and moisture content (MC). Due to the small span-to-depth ratio associated with stringers (approximately 13), modulus of elasticity corrected for shear stresses (MOE_G) was calculated for these members. A value of 16 was assumed for the ratio of the elastic to shear moduli. The very high span-to-depth ratio of deckboards (approximately 45) made calculation of MOE_G for boards unnecessary. A summary of these results is presented by species groups in Table 2.3 for stringers and Table 2.4 for deckboards.

Specific gravity is known to influence the strength of small clear wood beams. This relationship is not as well defined for full size material with defects such as pallet shook. A scatter plot of modulus of rupture versus specific gravity revealed no relationship between these two variables. This observation was verified by an analysis of variance of the test data which indicated no statistically significant relationships between MOR and specific gravity.

Methods are available for correcting mechanical properties of small clear samples for moisture content variation. However the extrapolation of these procedures to full size material is questionable (4). For this reason, data from any samples found to be below fiber saturation point, consertatively taken to be 30%, was eliminated.

An extensive comparison of four inch and six inch deckboards revealed no statistical or practical differences between the mechanical properties of the two board sizes. Consequently the data from the two sizes were combined.

Table 2.3--Summary of properties of red and white oak stringers

** Red Oak **

Property	sample size	mean value	standard deviation	minimum value	maximum value
Modulus of Rupture (psi)	1099	7105	2030	535	12,895
Stress at Proportional Limit (psi)	1085	3590	1175	430	7,835
Modulus of Elasticity (10^6 psi)	1085	1.18	0.31	0.14	3.55
Modulus of Elasticity Corrected for Shear Stresses (10^6 psi)	1085	1.31	0.34	0.15	3.90
Moisture Content (%)	1109	62	16	.30	1.08
Basic Specific Gravity	1109	0.58	0.05	0.40	0.75

** White Oak **

Property					
Modulus of Rupture (psi)	248	7470	2020	1570	12,120
Stress at Proportional Limit (psi)	248	3855	1225	885	7,440
Modulus of Elasticity (10^6 psi)	248	1.18	0.35	0.44	2.52
Modulus of Elasticity Corrected for Shear Stresses (10^6 psi)	248	1.30	0.39	0.48	2.77
Moisture Content (%)	248	56	09	31	78
Basic Specific Gravity	248	0.64	0.05	0.48	0.75

Table 2.4--Summary of properties of red and white oak deckboards.

Property	sample size	mean value	standard deviation	minimum value	maximum value
** Red Oak **					
Modulus of Rupture (psi)	1243	7160	1765	570	12,040
Stress at Proportional Limit (psi)	1228	3330	1245	435	7,350
Modulus of Elasticity (10^6 psi)	1239	1.33	0.37	0.63	2.63
Moisture Content (%)	1251	61	16	30	110.0
Basic Specific Gravity	1250	0.57	0.04	0.43	0.77
** White Oak **					
Modulus of Rupture (psi)	183	7215	1665	2190	11,200
Stress at Proportional Limit (psi)	182	3530	1255	1085	7,080
Modulus of Elasticity (10^6 psi)	182	1.26	0.38	0.24	2.62
Moisture Content (%)	185	57	13	30	116
Basic Specific Gravity	185	0.62	0.50	0.50	0.74

Additionally, no differences were found in mechanical properties between the mills which purchased shook and those which produced their shook internally. Therefore, no differentiation was made between these two classifications.

Examination of the results presented in Table 2.3 and 2.4 reveal no consistent differences between species groups. Moduli of rupture are statistically different (.01 level) between red oak and white oak stringers. However, there is no significant difference between moduli of elasticity for stringers of the two species groups. This trend is reversed when deckboards are considered. There is a significant difference between moduli of elasticity (.01 level) but, there is not significant difference between moduli of rupture.

It should be emphasized that although there are some statistically sitnificant differences, the magnitude of these differences, a miaximum of 5%, is of little practical consequence. There is no evidence that a pallet manufacturer would reap an economic benefit in segregating the oaks by species. Segregation is not practical in the industry today and this practice is unlikely to change in the foreseeable future. Since the goal of this research was to obtain a representative sample of commercial material the data were combined as shown in Table 2.5.

A surprising result evident in Table 2.5 is the lack of an overall size effect. According to current theory, deckboards should be significantly stronger than stringers. There are two basic reasons for this phenomenon. The first reason is related to the weakest link theory. This theory, quantified by Bohannan (5), postulates that as the depth of a wooden member increases the probability of the occurrence of a critical

Table 2.5--Combined property sample statistics for flexural properties of pallet shook.

Property	sample size	mean value	standard deviation	minimum value	maximum value
Modulus of Rupture (psi)	1347	7170	2035	535	12,895
Stress at Proportional Limit (psi)	1341	3640	1190	430	7,835
Modulus of Elasticity (10^6 psi)	1333	1.18	0.32	0.14	3.56
Modulus of Elasticity Corrected for Shear Stresses (10^6 psi)	1333	1.30	0.35	0.15	3.92
Moisture Content (%)	1364	61	15	30	109
Basic Specific Gravity	1364	0.59	0.05	0.40	0.75
Property					
Modulus of Rupture (psi)	1426	7170	1750	570	12,040
Stress at Proportional Limit (psi)	1427	3360	1250	435	7,350
Modulus of Elasticity (10^6 psi)	1410	1.31	0.37	0.06	2.64
Moisture Content (%)	1436	61	16	30	117
Basic Specific Gravity	1435	0.58	0.05	0.43	0.77

flaw also increases. However, this model was developed for clear relatively homogenous softwood materials and may not be applicable to non homogenous oak pallet shook. The other reason stringers should be weaker than deckboards is explained by considering defect orientation. The majority of defects found in deckboards are oriented in such a manner that the effective depth, which is the critical dimension, is reduced less than the effective width. In stringers, defects are oriented such that the effective depth is reduced more than the effective width. A previous study of the mechanical properties of yellow poplar pallet shook (6) indicated this expected trend. However, as seen in Table 2.5, this was not the case for oak pallet shook. No definite explanation can be found for this observation, however, the following possibility is offered.

To date, all size related research has been conducted on softwoods or light weight, uniformly structured, diffuse porous hardwoods (yellow poplar). Oak has anatomical features (such as its ring porous structure and rays) which are vastly different from those found in softwoods. It is felt that the lack of size related differences in the strength of oak pallet shook may be due to these anatomical features and the resulting lack of homogenity. This is discussed in Section 3.

The modulus of rupture and stress at proportional limit were found to be moderately related. A general linear model procedure comparing MOR and Spl produced a coefficient of deformation (R^2) value of 0.51 for stringers and 0.55 for deckboards. This relationship is significant at the 0.0001 level for both shook sizes. On the average, Spl was found to be 51% of MOR for stringers and 47% for deckboards.

Another observed relationship was between MOR and MOE. A general linear models procedure comparing these two variables produced R^2 values of 0.41 and 0.52. Both of these relationships are significant at the 0.0001 level. It should be noted that these R^2 values are much higher than those reported for yellow poplar pallet shook (0.17 for stringers and 0.25 for deckboards). No definitive reason can be offered for the differences between oak and poplar, however, it is felt it may be related to differences in experimental method and sample size.

The existence of relationships between MOR and Spl, and MOR and MOE may lead to the application of nondestructive proof loading techniques to estimate the strength and stiffness of individual pieces. These techniques could prove valuable in providing a high level of individual pallet structural reliability.

One subobjective of this investigation was to examine any trends in the variation in mechanical properties due to regional differences. Figure 2.2 indicates the sampling points plotted on a geophysical map of the eastern United States. There are several general trends which may be present. These trends were not statistically verified due to a relatively small sample size and the lack of a clear line of demarcation between upland and lowland sites.

The most obvious of these is the apparent increase in strength and stiffness associated with lowland sites. This increase also seems to be accompanied by increased specific gravity. However, no direct relationship could be found between specific gravity and strength or stiffness of the population of test material. Although these two variables do not affect each other directly, it is possible that a third variable growth

Figure 2.2 Location of mill sites.

Key to Figure 2.2

Mill Number	Site		MOR (psi)	MOE (psi x 10^6)	Spl (psi)	SG_B
01	e	1*	6725	1.09	3840	.58e
		2**	6605	1.14	3530	.59
02	l	1	7330	1.17	3450	.57
		2	7450	1.35	3685	.56
03	e	1	7035	1.17	3375	.61e
		2	7080	1.38	2945	.59
04	l	1				
		2	6865	1.14	2940	.58
05	e	1	7560	1.26	3930	.58
		2	6590	1.22	2675	.56
06	l	1	6870	1.09	3190	.59
		2	7290	1.47	3490	.54
07	l	1	8060	1.23	4140	.60
		2	7565	1.40	3455	.59
08	e	1	7600	1.20	4230	.58e
		2	5980	1.15	2645	.58
09	l	1	7555	1.15	4100	.63
		2	7410	1.15	3530	.62
10	l	1	7830	1.04	4010	.66
		2	7760	1.36	3925	.61
11	l	1	6805	1.10	3215	.61
		2	6695	1.30	3135	.58
12	l	1	6670	1.17	3555	.59
		2	8330	1.61	4340	.60
13	l	1	7620	1.19	4715	.60
		2	8120	1.45	4685	.57
14	l	1	7145	1.40	3615	.61
		2	8630	1.75	4335	.57
15	l	1	8085	1.46	4830	.58
		2	7790	1.48	4075	.58

* stringers
** deckboards

e--elevated site
l--lowland site

Key to Figure 2.2 Continued

Mill Number	Site	MOR (psi)		MOE (psi x 10^6)	Spl (psi)	SG_B
16	e	1*	6295	1.03	3085	.57e
		2**	7220	1.31	3230	.58
17	e	1	6440	1.10	3285	.55e
		2	6830	1.21	2580	.57
18	e	1	6305	1.02	3000	.59e
		2	6805	1.27	3105	.59
19	l	1	7500	1.24	3625	.60
		2	6450	1.11	2805	.60
20	e	1	6380	1.08	3855	.55e
		2	6280	1.12	2990	.56
21	l	1	6105	0.92	2815	.55
		2	6790	1.24	2610	.56
22	e	1	7365	1.21	3500	.56e
		2	6940	1.30	3110	.58
23	e	1	7065	1.15	3530	.56e
		2	6565	1.25	3190	.58
25	l	1	7360	1.52	3825	.61
		2	8020	1.47	3960	.57
26	l	1	7355	1.03	3740	.60
		2	6925	1.22	3350	.58
27	l	1	8030	1.22	3595	.58
		2	7695	1.50	3740	.58
28	l	1	7835	1.30	4020	.67
		2	6610	1.23	2640	.56
29	l	1	7120	1.11	3525	.58
		2	7575	1.35	3700	.58
30	l	1	6375	1.18	3175	.56
		2	8050	1.44	3955	.59
31	e	1	7150	1.23	3480	.54e
		2	6225	1.19	2425	.55

* stringers
** deckboards

e--elevated site
l--lowland site

Combined Means

Mill Number	Site		MOR (psi)	MOE (psi x 10^6)	Spl (psi)	SG_B
	e	1	6900	1.14	3465	.57
		2	6640	1.23	2925	.58
	l	1	7315	1.20	3730	.60
		2	7475	1.40	3600	.58

e--elevated site
l--lowland site

rate influences them both. Work by Paul (11) shows that slow grown, ring porous woods have a greater proportion of large pores in the earlywood. This high proportion of thin walled earlywood pores causes a reduction in specific gravity. Along with altered anatomical features, it would be reasonable to expect a change in fracture behavior. The increased volume of earlywood and the inherent volumetric decrease of denser, stronger latewood may influence failure by producing a shift in microscopic failure mode. This effect should be more pronounced in wood with fewer defects. That is, failure in a mamber with no localized, strength reducing defects, would be highly dependent on gross anatomical features. Results presented in another section of this report support this reasoning.

Another possible explanation is species related. As a rule the predominant lowland oak species are not the same species which inhabit higher sites. The lowland species respond differently to such manufacturing processes as drying (10). However, it cannot be determined whether this difference is attributable to species or environment. It would seem to follow that this difference, whether due to environment or species related anatomical features (16), may also influence response to mechanical stress.

2.4 Conclusions

From the results presented in Section 2 the following results and conclusions can be drawn.

- No significant relationship was found between modulus of rupture and specific gravity of the sampled oak pallet shook.
- No significant difference was found between the mechanical properties of the samples four and six inch wide deckboards.
- No significant difference was found between the mechanical properties of shook produced at the mill location and that which was produced external to the mill.

While oak stringers were about 5% stronger in bending and about equal in stiffness with red oak stringers. White oak deckboards were about 5% less stiff and of equal strength compared to red oak deckboards. These differences were deemed of no practical importance because of their low magnitude and the lack of any indication that there is an economic benefit for the pallet industry to segregate oak shook by species.

SECTION 3. FLEXURAL PROPERTIES OF EASTERN OAK PALLET SHOOK GRADE EVALUATION AND THE EFFECT OF DEFECTS

3.1 Introduction

Eastern oak species are commonly used in the manufacture of wood pallets. For this reason, flexural properties of oak shook were evaluated as part of a large project aimed at developing rational design procedures for pallets. These properties are needed input to the design procedures and also assist in evaluating the effectiveness of a visual grading scheme to segregate shook by quality.

A sampling scheme based on volume distribution of U.S. oak sawtimber resulted in the collection of fifty deckboards and fifty stringers from each of thirty mills. The mills were located in sixteen different eastern states. The samples were returned to the laboratory where the major defects on each piece were recorded and each member was assigned one of four visual grades. In this grading scheme number one was the highest quality and number four was considered cull based on criteria set forth by Sardo and Wallin (12). The samples were tested in flexure third points until failure according to ASTM D-198 (2). A rate of crosshead movement of 2 in/min for deckboards and 1 in/min for stringers was the only deviation from the standard procedure. Moduli of rupture (MOR) and elasticity (MOE), stress at proportional limit (Spl), moisture content (MC), and basic specific gravity were calculated. Due to the relatively small span to depth ratio of stringers (approximately 13) the moduli of elasticity of these members were corrected for shear forces (MOE_G).

The purpose of this paper is to present an evaluation of the visual grading system and of the effect of defects on flexural performance.

3.2 Evaluation of the Visual Grades

A grading plan for lumber to be used as pallet components should have several qualities to be attractive to the manufacturer and the pallet consumer. One major fact is that the scheme should result in the segregation of lumber into different groups on the basis of quality. That is, the quality of one group segregated from a population should be higher than another taken from the same population but with different criteria.

The term, "quality", can be interpreted several ways. For example there may be restrictions on the amount of wane that can be tolerated on the ends of a deckboard. If the wane is too great then the board may not be properly nailed to the stringer. Other visual criteria associated with consumer acceptance such as stain, skip, pin hole, etc. may be specified. Historically, quality in the lumber industry has been related to strength and stiffness of the piece. However, these properties are difficult to estimate without some physical testing. As a result an estimate of the relationship between the magnitude of a visual defect, such as a knot, and the reduction in strength due to the knot is necessary. These estimates have been developed for a number of defects in lumber and are tabulated in ASTM D 245 (1). An estimate of the minimum strength of lumber meeting certain visual defect restrictions can then be made. Usually the minimum strength is used as a starting point and visual criteria to meet this restriction are then selected. Other manufacturing or end use criteria are then superinposed on the strength and stiffness criteria.

For pallet shook several grading schemes have been proposed that are based loosely on strength and stiffness criteria (12). A study of the first of these schemes (6) showed that it was ineffective in segregation by flexural properties. A modified version of this plan as tabulated by Wallin and Frost (21) was evaluated in this study. This grading plan is based upon a 1962 Specification for Hardwood Pallets. This is a pallet specification and not a hardwood grade specification. However, the restriction constance in this document have stood the test of time and provide a reasonable starting point for a lumber grade.

One asset that a grading scheme should have is that the inventory of an "average" manufacturer should contain approximately equal quantities of material in each category. That is, the rules should be restrictive enough to preclude the majority of the manufactured shook be in the highest grade. Conversely the bulk of the material should not be in the low grades or considered "cull". If this is not the case then an individual entrepreneur will find it difficult to sell his product on the basis of a higher or different quality than another.

Table 3.1 indicates the distribution by grade for the stringers and deckboards sampled in this study. This indicates that approximately equal percentages of lumber fell into each category. This is desirable except for the high percentage falling into the "cull" category. It is unlikely that manufacturers would accept a 25% loss in production of acceptable pallet shook. This indicates that further examination of the No. 3 and cull criterion should be made.

Statistics for flexural test properties are presented by grade in Table 3.2 for stringers and deckboards. An analysis of variance indicated that MOR, Spl, and MOE were highly related to grade (significant at the

Table 3.1--Distribution of shook by size and grade

Grade	Stringers Frequency	Percent	Deckboards Frequency	Percent
1	338	25.34	363	25.76
2	339	25.41	419	29.74
3	324	24.29	259	18.38
cull	333	24.96	368	26.12
Total	1334	100.00	1409	100.00

Table 3.2--Summary of selected mechanical properties by grade.

Grade	Sample[1] Size	Modulus of Rupture (psi)		Stress @ P. Limit (psi)		Modulus of Elasticity (10^6 psi)			
						uncorrected		corrected for shear	
		mean	COV[2]	mean	COV	mean	COV	mean	COV
				Stringers					
1	338	8510	0.20	4185	0.28	1.34	0.25	1.47	0.25
2	346	7515	0.23	3790	0.30	1.21	0.22	1.33	0.22
3	331	6835	0.25	3440	0.30	1.13	0.25	1.24	0.25
cull	338	5825	0.34	3135	0.37	1.02	0.28	1.12	0.28
				Deckboards					
1	369	8035	0.19	3880	0.38	1.47	0.25	---	
2	425	7380	0.20	3305	0.36	1.35	0.24	---	
3	263	6960	0.23	3220	0.37	1.27	0.28	---	
cull	375	6220	0.29	3005	0.39	1.17	0.32	---	

[1]May vary slightly between properties.

[2]Coefficient of variation.

.0001 level). A Duncan's multiple range test showed that the grades effectively segregated oak pallet shook on the basis of flexural properties. With the exception of grade 2 and 3 deckboards, which had similar Spl, Duncan's analysis reveals significant differences between MOR, MOE and Spl for each grade considered. The magnitude of the strength and stiffness differences between grades appear to be of practical importance.

Tables 3.3 and 3.4 give frequencies and percentages of grade controlling and failure initiating defects by grade for stringers and deckboards respectively. These tables provide some insight into why the grading system is effective at segregating oak pallet shook on the basis of flexural strength and stiffness. It can be seen that in most cases the defects which the grading system keys on are the ones which actually initiated failure.

The tables also reveal another strong point of the grading system. The large number of defect types producing culls indicates the system does not overpenalize the material for one particular defect type. This means that several visual criteria will have to be adjusted if the percentage of culls is to be reduced.

The evidence presented here indicates that the grading system was relatively efficient. The system effectively segregates oak shook on the basis of flexural strength and stiffness as well as providing ample quantities of each grade. This efficiency offers strong economic incentive for grading to the pallet manufacturer who is interested in consistently producing a quality product. The relatively high percentage of culls is a relatively minor problem that could be adjusted in con-

Table 3.3--Frequencies and percentages of grade controlling and failure initiating defects by size for stringers.

Grade	Grade Controlling Defect Type	Freq.	Percent	Failure Initiating Defect Type	Freq.	Percent
1		NA		sound knots		
				centerline	40	11.8
				slope of		
				grain	93	27.5
				other*	94	27.8
2	sound knots			sound knots		
	centerline	61	18.0	centerline	90	26.5
	edge	53	15.6	edge	80	23.6
	slope of			slope of		
	grain	36	10.6	grain	81	23.9
	face pith	115	33.9	other	88	25.9
	other	74	21.9			
3	sound knots			sound knots		
	edge	43	13.3	centerline	54	16.7
	slope of			edge	76	23.5
	grain	55	17.0	unsound		
	boxed pith	109	33.6	knots		
	other	117	36.1	edge	34	10.5
				slope of		
				grain	84	25.9
				other	76	23.4
cull	unsound			sound knots		
	knots			centerline	39	11.7
	centerline	37	11.1	edge	51	15.3
	edge	51	15.3	unsound		
	slope of			knots		
	grain	48	14.4	edge	48	14.4
	local grain			slope of		
	deviation	35	10.5	grain	67	20.1
	other	171	48.6	grain		
				deviation	60	18.0
				other	68	20.4

* Other is a combination of all defects which individually comprise less than 10% of the total.

Table 3.4--Frequencies and percentages of grade controlling and failure initiating defects by grade for deckboards.

	Grade Controlling Defect					
Grade	Type	Freq.	Percent	Type	Freq.	Percent
1		NA		sound knots		
				centerline	50	13.8
				sloping		
				grain	69	19.0
				other*	244	67.2**
2	sound knots			sound knots		
	centerline	53	12.6	centerline	83	19.8
	edge	52	12.4	edge	81	19.3
	face pith	154	36.8	sloping		
	sloping			grain	90	21.5
	grain	63	15.3	other	165	39.4
	other	97	23.1			
3	sound knots			sound knots		
	edge	36	13.9	centerline	35	13.5
	unsound			edge	76	29.3
	knots			unsound		
	edge	32	12.4	knots		
	sloping			edge	31	12.0
	grain	82	31.7	sloping		
	boxed pith	31	12.0	grain	80	30.9
	other	78	30.0	other	37	14.3
cull	sound knots			sound knots		
	edge	48	13.0	centerline	39	10.6
	unsound			edge	58	15.8
	knots			unsound		
	centerline	39	10.6	knots		
	edge	71	19.3	centerline	37	10.1
	sloping			edge	67	18.2
	grain	54	14.7	sloping		
	local grain			grain	64	17.4
	deviation	40	10.9	local grain		
	other	116	31.5	deviation	47	12.8
				other	56	15.1

* Other is a combination of all defects which individually comprise less than 10% of the total.

**This high percentage is due to excess deflection failures in high quality deckboards.

sultation with shook manufacturers. Future work will address this issue.

3.3 Deckboard and Stringer Comparison

In Section 2 of this thesis it was noted that the combined sample average MOR of stringers was greater than that of the deckboards. The reverse was true for MOE. This is contrary to expectations based on the weakest link theory (5) and the relative impact of defects. However, Table 3.2 indicates that this size effect trend is not consistent between grades. For example, between grade 1 to cull the MOR of stringers decreases by 2690 psi, whereas for deckboards, MOR drops only 1815 psi. This indicates that stringers were more sensitive to strength reducing defects. Figure 3.1 indicates the cumulative distribution functions of the stringer and deckboard MOR. It is evident that whatever phenomenon causes size to influence MOR is dependent on the inherent quality of the piece. In this study, the high quality stringers were stronger than the deckboards whereas the opposite was true of the known quality material. A crossover point is as evident at about the 40th percentile. Some of this sensitivity below the 40th percentile can be explained by the greater impact that defects have on the moment of inertia of stringers as compared with that of deckboards.

The high quality stringers had an MOR greater than the high quality deckboards. This may be attributable to the ring porous structure of oak. As the quality of stringers decreases, defects may overshadow the groww anatomical features which may produce a comparatively greater strength of high quality stringers more than that of deckboards.

The effect the ring porous structure has on strength may be explained

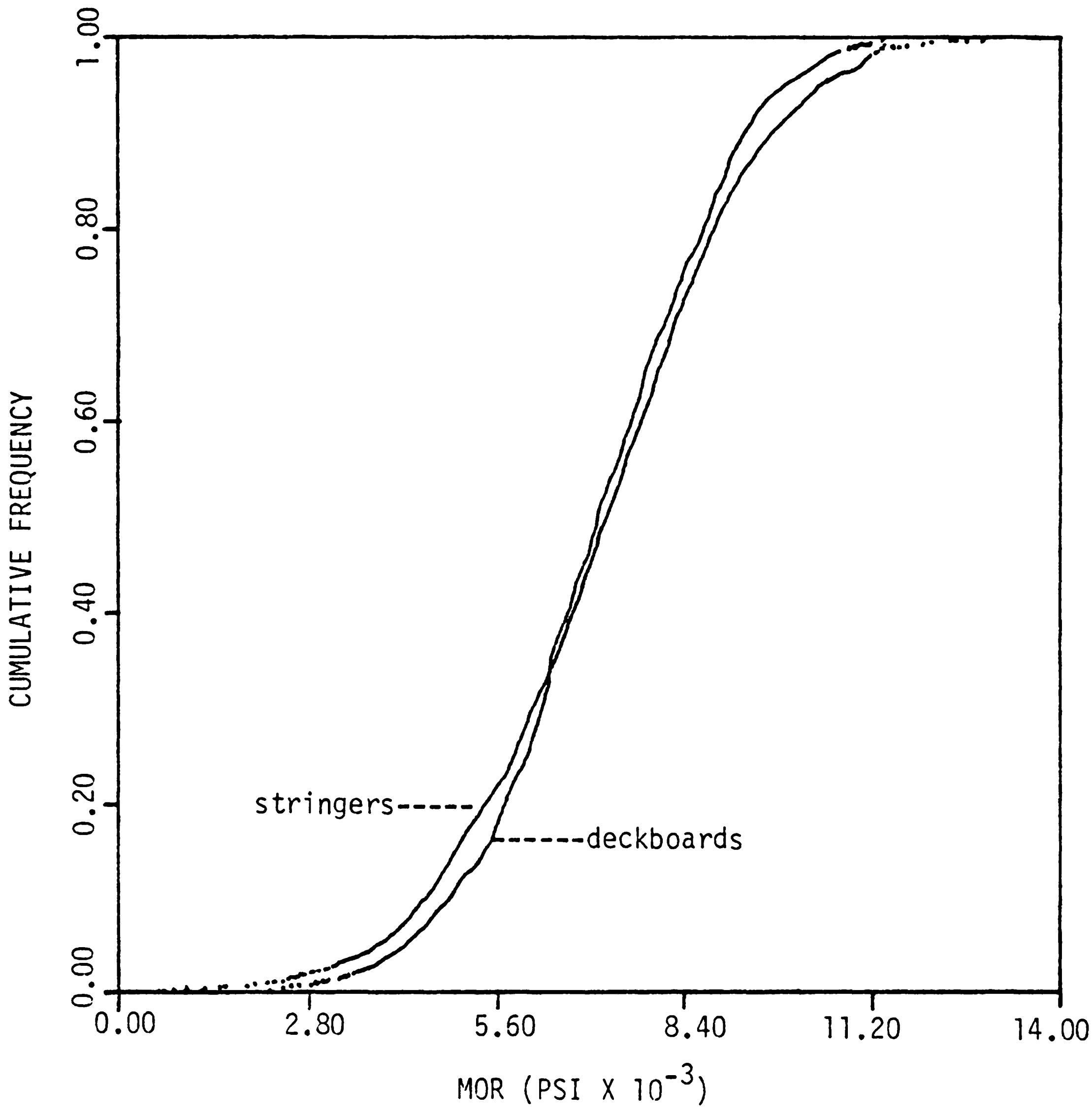

Figure 3.1--Cumulative frequency distribution of the modulus of rupture of eastern oak stringers and deckboards (all data).

as follows. With some inherent variation, the majority of the sampled shook was approximately flat sawn. With this geometry the applied load on stringers was parallel to the tangential surface, this induced bending stresses perpendicular to the growth rings (Figure 3.2). With deckboards the load was parallel to the radial face with the induced bending stresses parallel to the growth rings.

The large pored earlywood is much weaker than the dense latewood. In flat sawn deckboards the weaker earlywood spans the entire thickness of the member. This plane of weakness produces a natural path for crack propogation. In stringers the earlywood spans the depth rather than the thickness. Through a plane of the thickness, the earlywood is supported on each side by the denser, stronger latewood. This configuration would tend to halt crack propogation.

Another factor which must be considered in this mechanism is the large rays found in oaks. It is not understood at this time how ray structure would affect this pattern of failure. However, it may be conjectured that any ray influence is overshadowed by the ring porous structure. When one considers the relative size, quantity, and orientation (90°) of rays to pores and vessels it can be seen that any stress concentration occurring at rays would have less impact on flexural behavior than the ring porous structure.

Variation in properties with respect to load orientation has been noted in toughness research (19) but its influence on flexural properties needs to be investigated at a much deeper level if any definite conclusions are to be drawn.

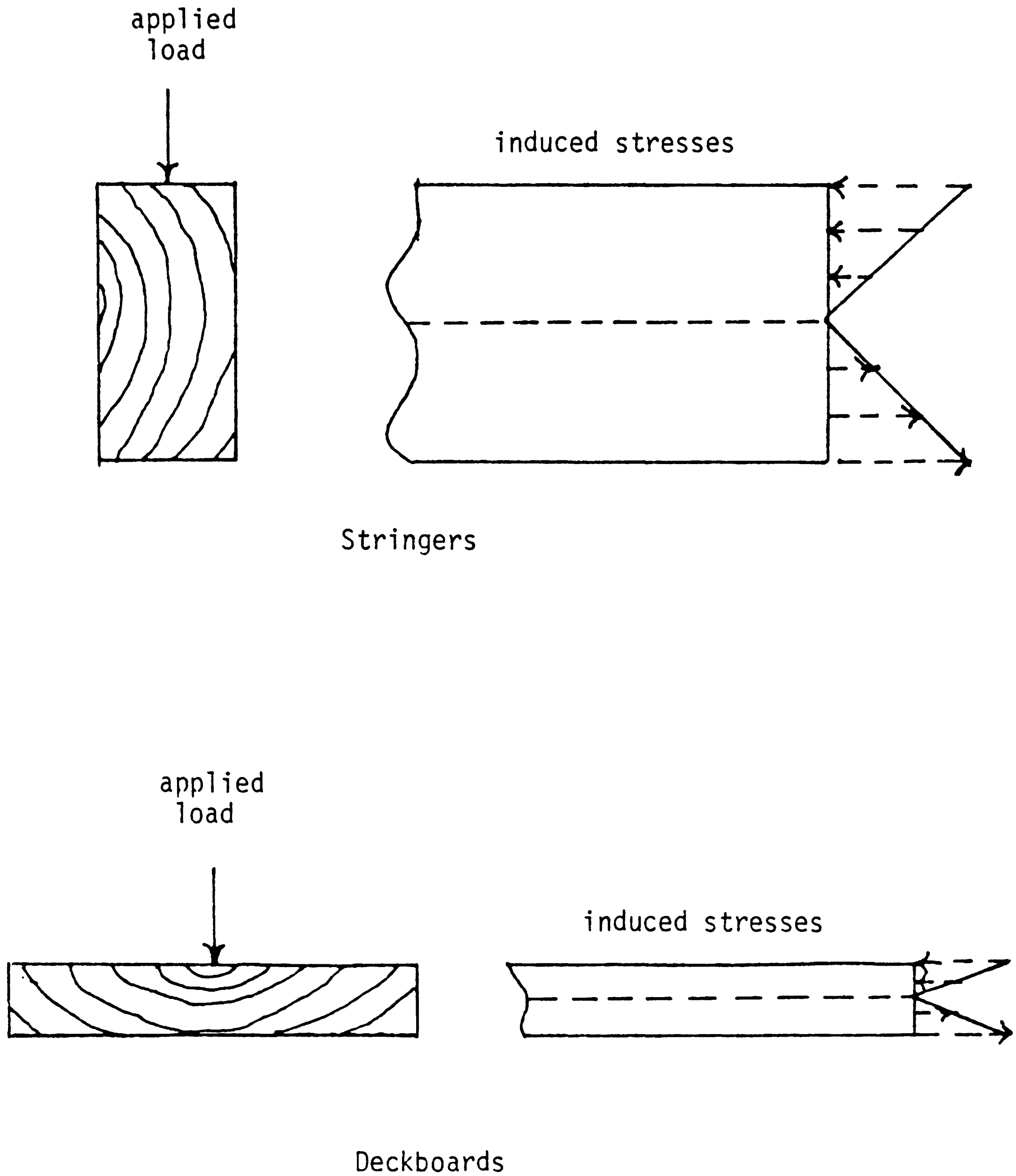

Figure 3.2. Stress distributions induced by testing flat sawn stringers and deckboards.

Cumulative distribution functions for deckboard and stringer moduli of elasticity are presented in Figure 3.3. It is evident from this figure that the influence of quality noted for MOR is absent in the case of MOE. MOE should not be influenced by quality since defects do not play a major role on elastic behavior.

Deckboards are stiffer than stringers throughout the majority of the range considered. This observation can be attributed to two basic factors. The stringer moduli of elasticity plotted were not corrected for shear deformation. Correction for shear deformation would cause the stringer curve to shift to the right, however, the deckboard moduli of elasticity remain of a greater majnitude. The remaineder of the difference may be attributed to the relative spans of the two shook sizes. The stringers were tested over a greater clear span than were deckboards. It has been shown (4) that increased span is accompanied by a decrease in stiffness.

3.4 Strength Ratios in Pallet Shook

One approach to assigning allowable design stresses that has been developed for softwood structural lumber is with strength ratios. It would be advantageous to the pallet industry if these ratios were found to be applicable to pallet shook. For that reason, a comparison of experimentally obtained results was made with those obtainable by the procedures outlined by ASTM D-245 (1). The results are presented in Tables 3.5-3.7.

The results in Table 3.5 were prepared as follows. ASTM D-2555 (3) was not used to calculate clear wood strength properties due to a lack of oak growing stock volume data. Instead, the MOE and MOR values for

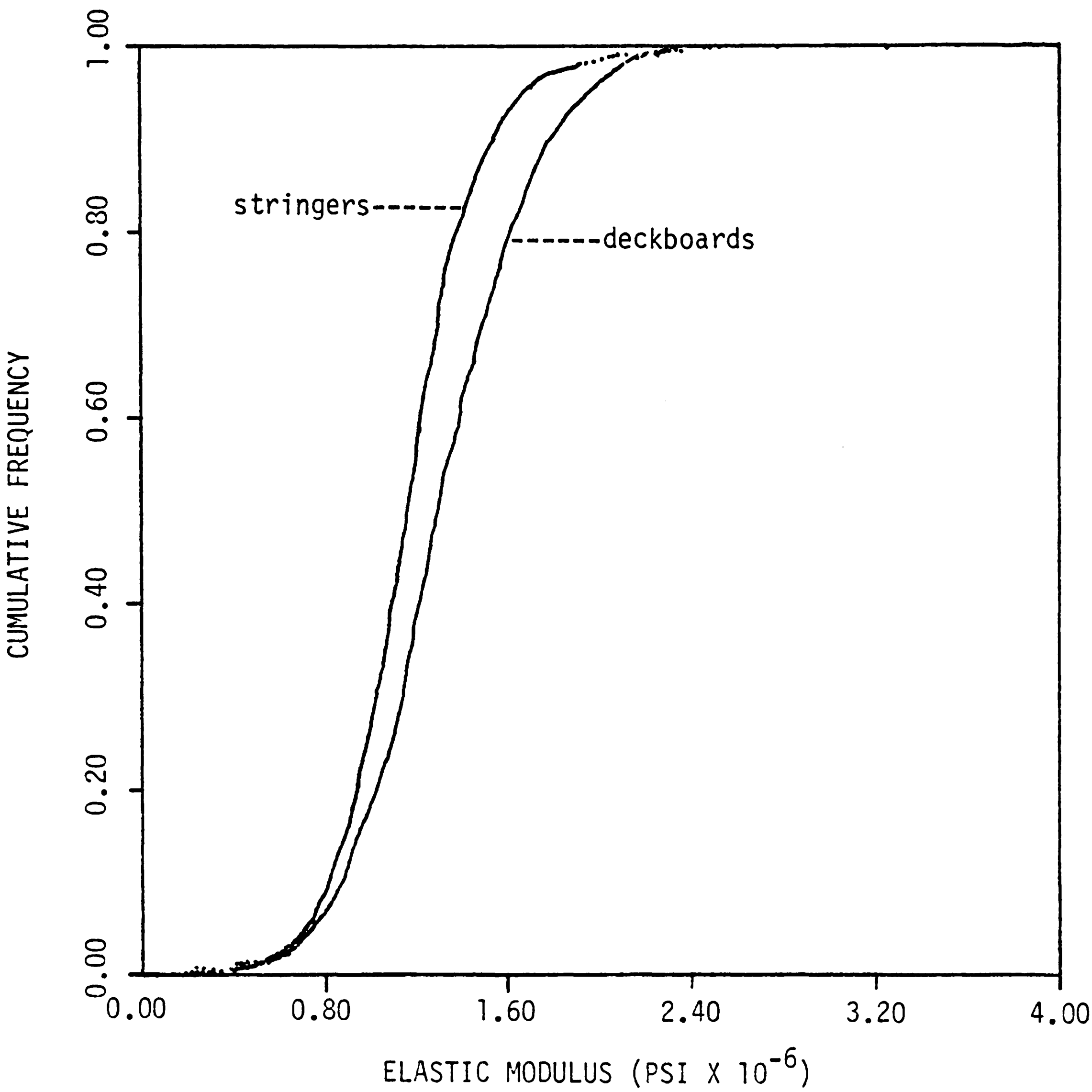

Figure 3.3--Cumulative frequency distribution of the modulus of elasticity of eastern oak stringers and deckboards (all data).

Table 3.5--Derivation of full size defect free material estimated design stresses

	stringers	4" boards	6" boards
MOR defect free full size material (psi)	8762	7998	8347
MOR--lower 5th percentile (psi) derived using two methods:			
- normal population estimate (psi)	5783	5368	6006
- NPPE**(psi)	5927	5463	6196
- lower 5th percentile MOR adjusted for safety and 10 year load duration (psi)	2511	2334	2611
- MOE adjusted for shear* (psi x 10^6)	1.48	1.45	1.52

* Deckboards were not adjusted.

** Non-parametric point estimator. This value was not used due to the similarity between it and the normal population estimate and due to the fact that a smirnov-kolmo-gorov analysis shows the data to be normal.

Table 3.6--Corrected estimated design stresses with strength ratios used to make those corrections.

	stringers	4 in. boards	6 in. boards
Grade 1			
F_b (psi)	1550	1400	1600
strength ratio	.61	.61	.61
Grade 2			
F_b (psi)	1250	1250	1350
strength ratio	.50	.53	.53
Grade 3			
F_b (psi)	650	950	1050
strength ratio	.26	.40	.40
Grade 1			
MOE (psi x 10^6)	1.48	1.45	1.52
quality factor	1.00	1.00	1.00
Grade 2			
MOE (psi x 10^6)	1.33	1.31	1.37
quality factor	.90	.90	.90
Grade 3			
MOE (psi x 10^6)	1.18	1.16	1.22
quality factor	.80	.80	.80

Table 3.7--Experimentally obtained estimated design stresses and strength ratios.

	stringers	4 in. boards	6 in. boards
Grade 1			
F_b (psi)	2500	2350	2550
strength ratio	1.00	1.00	.98
Grade 2			
F_b (psi)	2000	2200	2150
strength ratio	.80	.90	.80
Grade 3			
F_b (psi)	1800	1900	1800
strength ratio	.72	.81	.69
Grade 1			
MOE (psi x 10^6)	1.44	1.45	1.50
quality factor	.97	1.00	.99
Grade 2			
MOE (psi x 10^6)	1.31	1.32	1.39
quality factor	.89	.91	.91
Grade 3			
MOE (psi x 10^6)	1.21	1.24	1.33
quality factor	.82	.86	.88

full size defect free material were obtained experimentally. These MOR and MOE values were determined from that portion of the population of shook which contained no strength reducing defects. No adjustments were made for size. The lower 5% exclusion value was obtained by using the equation:

$$EL = \bar{x} - 1.645\,\sigma \qquad [3.1]$$

where:

EL = lower 5% exclusion limit,
$\bar{x}$ = mean MOR, and
σ = standard deviation.

MOR values were also adjusted from the test load duration up to a normal load duration (10 years) and for a factor of safety. This was done by dividing the exclusion value by 2.3. The only adjustment made to MOE was a division by 0.94 to correct for stringer shear deformation.

Results presented in Table 3.6 establish estimated allowable properties for each of the visual grades. This was accomplished for MOR by multiplying the lower 5% exclusion value of full size defect free material by a strength ratio taken from the strength ratio tables in ASTM D-245. In each case, the strength ratio used is the minimum allowed by that grade classification. MOE was adjusted by a quality factor. These factors, also taken from ASTM D-245, are based on the minimum strength ratio allowed in each grade classification.

The values in Table 3.7 were experimentally obtained. MOR and MOE values by grade, obtained by testing, were adjusted for lower 5th percentiles, normal load duration, and safety using the same procedure as outlined in Table 3.5. The strength ratios listed were derived by dividing the MOR and MOE associated with each grade by the adjusted clear wood properties (Table 3.5).

A large discrepancy was found between ASTM D-245 strength ratios and the grading rules where splits are concerned. The length of splits allowed in grade 1 material produce ASTM negative strength ratios. For comparison, data taken from samples with splits were deleted.

Likewise, data from stringers which contained narrow face knots were also deleted for the same reason. Narrow face knots did not influence treatment of deckboards because ASTM D-245 considers only wide face knots in 1" boards. The elimination of data from stringers containing splits and edgeknots resulted in a loss of 3% of the total sample.

It should be noted that the assumption of a normal (10 year) load duration may not be realistic for pallet design. In reality these estimated design values should be adjusted to a lower load duration dependent on the individual pallet and application because the average cumulative load duration of a pallet is considerably less than 10 years.

A comparison of Table 3.6 with Table 3.7 shows that allowable bending stresses obtained by using ASTM D-245 are consistently conservative. This means ASTM D-245 procedures could be used to predict allowable bending stresses for oak pallet shook if conservative estimates were deemed acceptable. If this conservatism is not acceptable (limit state design) strength ratios which reflect more realistic, less conservative, values must be developed. An example of such ratios is presented in Table 3.8. It should be emphasized that these are purely examples and due to relatively small sample sizes cannot be accepted as reliable. Slope of grain was chosen because of a relatively large sample size and high frequency

Table 3.8--Comparison of experimentally obtained strength ratios with those prescribed by ASTM for slope of grain.

stringers slope of grain	actual strength ratio	ASTM D-245 strength ratio
1 in 6	.88	.40
1 in 8	.92	.53
1 in 10	.96	.61
1 in 12	1.00	.69
1 in 14	.88	.74
	** 4 in. boards **	
1 in 6	.81	.40
1 in 8	.77	.53
1 in 10	.94	.61
1 in 12	1.00	.69
1 in 14	1.00	.74
	** 6 in. boards **	
1 in 6	.77	.40
1 in 8	.73	.53
1 in 10	.75	.61
1 in 12	.80	.69
1 in 14	--	.74

of occurrence (Appendix 6). Slope of grain was also the limiting defect in seven of the nine possible grade/size combinations. As can be seen from Table 3.8 the ratios prescribed by ASTM D-245 are consistently conservative. It is this conservatism which contributes to higher experimentally obtained bending stresses than predicted by ASTM D-245.

A similar comparison was prepared for wide face and edge knots. Graphs of MOR versus edge and certerline knot size are presented in Figures 3.4-3.5 for stringers and Figures 3.6-3.7 for 4" deckboards. These figures graphically indicate the minimum nature of the ASTM strength ratios. The only exception is with centerline knots in stringers. These results support the use of the strength ratio concept for any development of allowable stress similar to that used in softwood lumber. The use of the quality factors prescribed by ASTM D-245 also accurately reflected quality influence on MOE.

It should be emphasized that the design values and procedures generated throughout the course of this research are intended solely for comparative purposes. They should not be accepted in this form for general use in the design of wood pallets.

One major area which must be further investigated is the shook quality distribution within a single pallets. Use of a serial sampling procedure, as opposed to the random sampling procedure used for this study, would provide this information.

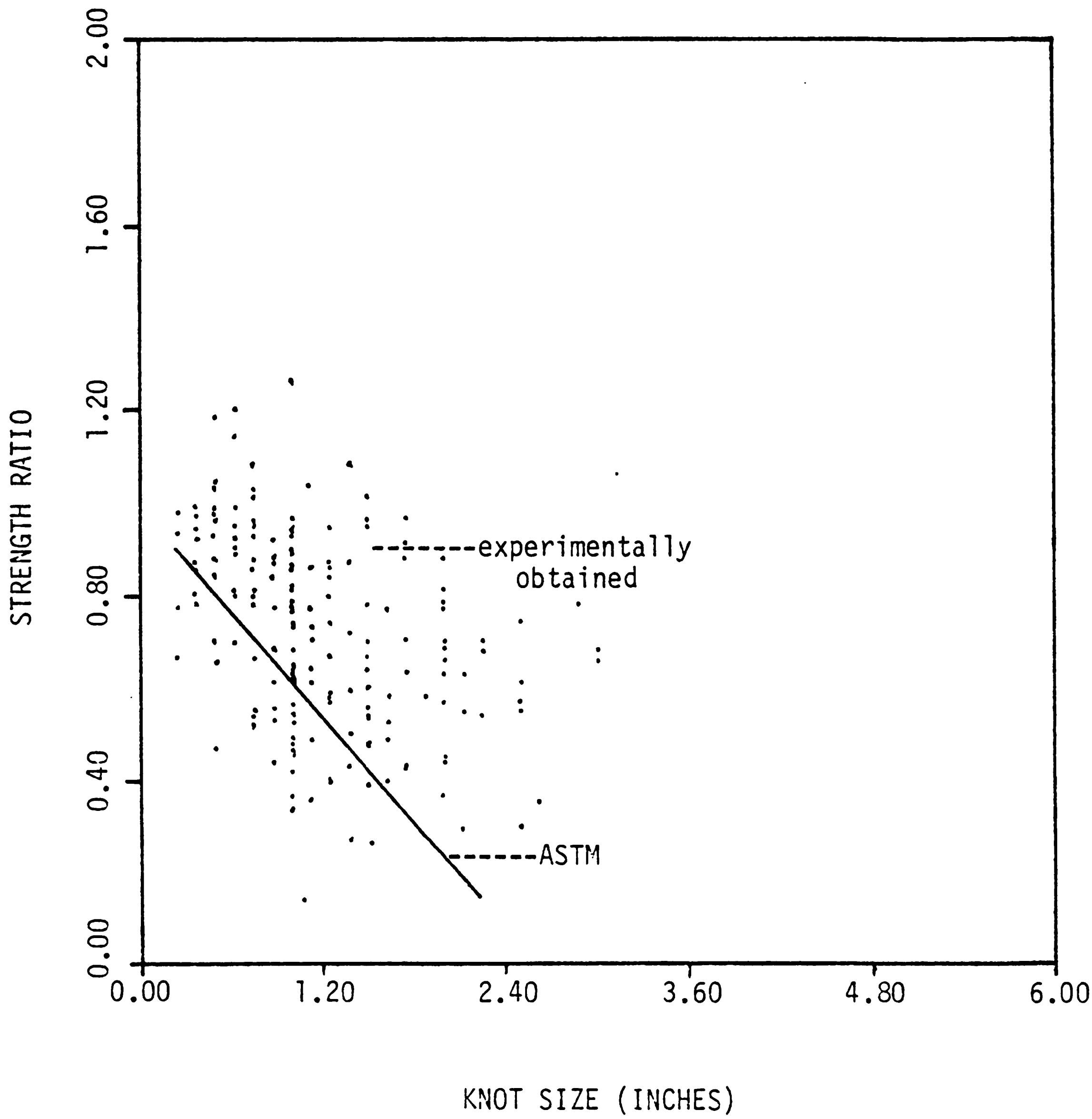

Figure 3.4--ASTM and experimentally obtained strength ratios versus edge knot size in stringers.

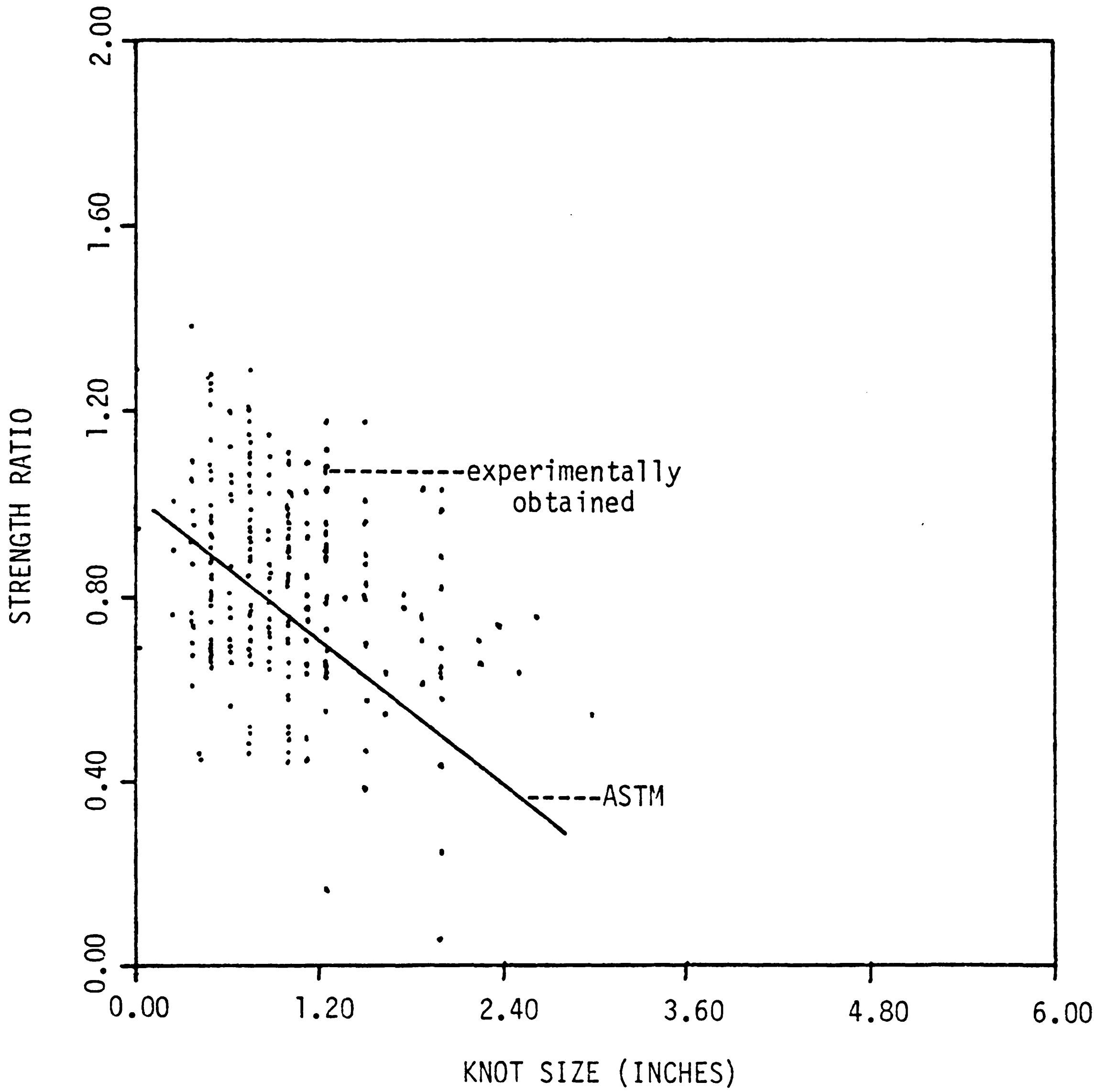

Figure 3.5--ASTM and experimentally obtained strength ratios versus centerline knot size in stringers.

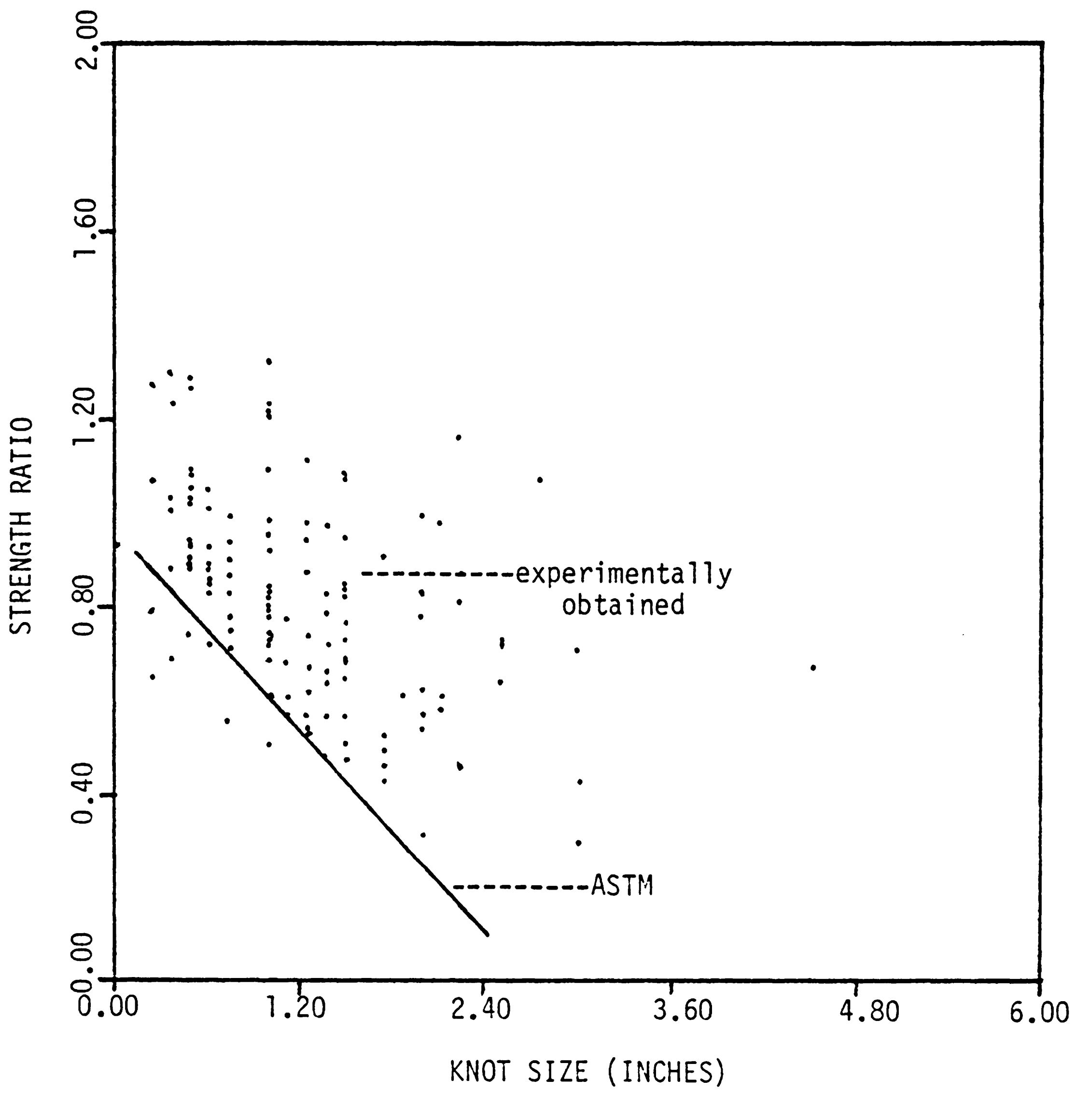

Figure 3.6--ASTM and experimentally obtained strength ratios versus edge knot size in deckboards.

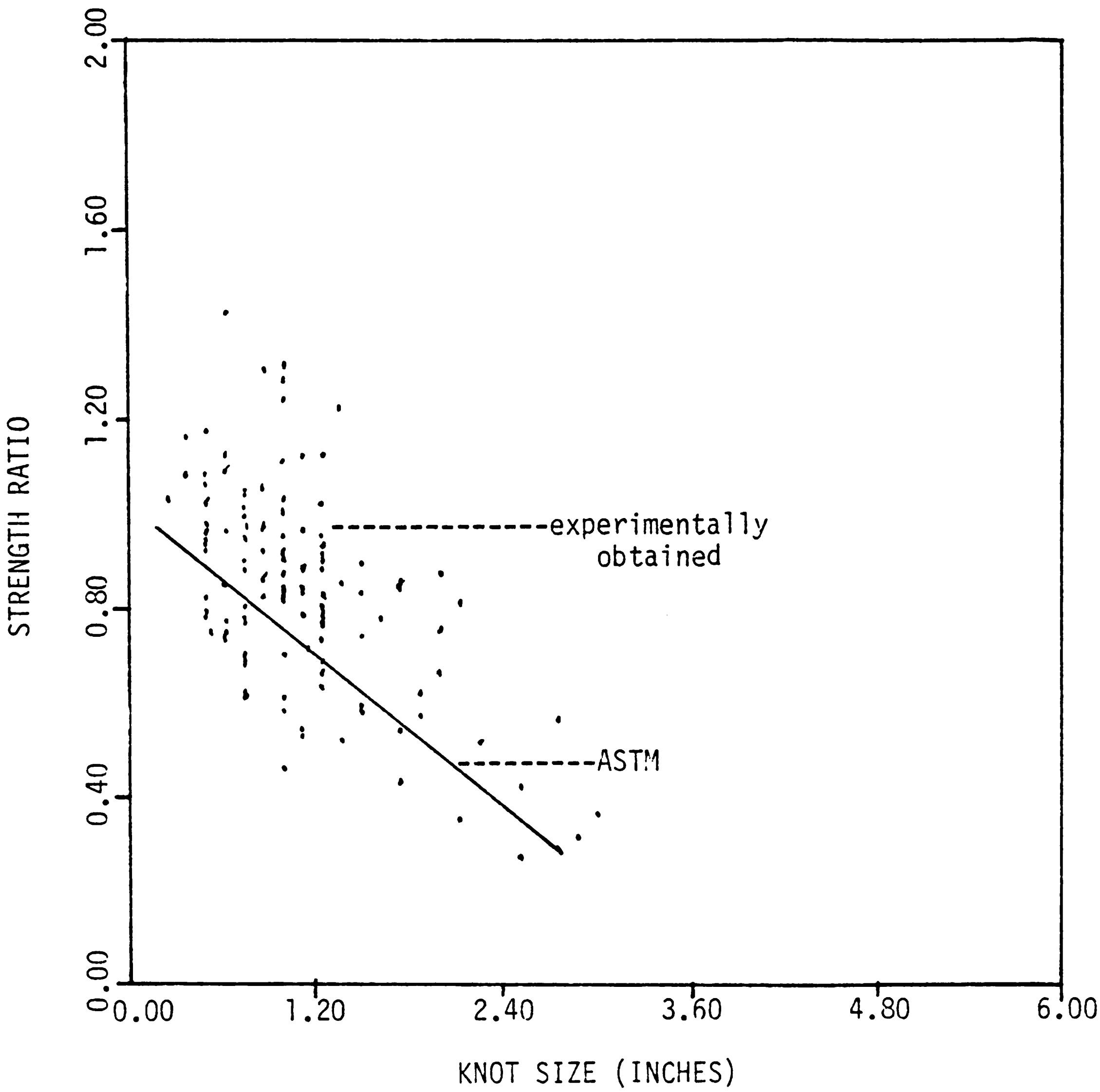

Figure 3.7--ASTM and experimentally obtained strength ratios versus centerline knots in deckboards.

3.5 Conclusions

Analysis of the test data presented in this section led to the following conclusions:

- Comparison of the sample sizes found within each visual grade category showed the shook to be approximately evenly distributed between grades.

- Due to a high percentage of cull shook, grade 3 and cull requirement may require some refinement.

- Comparison of MOR, MOE and Spl by grade showed that the visual grading system used effectively segregates shook on the basis of flexural strength and stiffness.

- Evidence shows that high quality stringers tend to be stronger than high quality deckboards. This trend is reversed with low quality material. It is believed this observation is related to the ring porous structure of oak.

- A comparison of experimentally obtained estimated design stresses with those obtained by using published strength ratios, showed that the strength ratio approach may be applicable to pallet shook.

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APPENDICES

Appendix 1

List of Contributors

List of Contributors

Mill Name	Mill Location
Arkansas Pallet Mfg. Co.	Beardon, AR
Atlanta Southern Corp.	Ellijay, GA
Benwood, Inc.	Millington, TN
Cantley-Ellis Mfg. Co.	Kingsport, TN
Clinch-Tite Corp.	Sandy Lake, PA
Eastern Wood Products Co.	Williamsport, PA
Edwards Wood Products	Marshville, NC
Elba Pallets, Inc.	Elba, AL
Foley and Sons Wood Packaging Inc.	Bargersville, IN
The Fortis Corp.	King, NC
Gates, Inc.	Oakdale, LA
Gilbert Lumber Co.	Smithville, OH
Hinchcliff Products Co.	Parsons, WV
Holman Wood Products Co.	Northport, AL
Lester Forest Products Div.	Martinsville, VA
Lowe Lumber Sales	Cookeville, TN
Morton Mfg. Co., Inc.	Morton, MS
Mountain Valley Farms and Lumber Prod., Inc.	Biglerville, PA
Mulberry Lumber Co.	Mulberry, AR
The Nelson Co.	Louisburg, KY
Pallox, Inc.	Clinton, MI
Perry Crating, Inc.	Frohna, MO
Ridge Pallets, Inc.	Hazelhurst, GA
Rossi Corp.	Higganum, CT
St. Louis Wood Products Div.	St. Louis, MO
Scott Pallets, Inc.	Amelia, VA
WNC Pallets and Forest Products, Co.	Candler, NC
J.C. Wells and Sons	Morehead, NY
Williamsburg Millwork, Corp.	Bowling Green, VA
Lannes Williamson Pallets, Inc.	Southside, WV

Appendix 2

Pallet Component Grades

PALLET STRINGER GRADES--HARDWOODS

	PRECISION - GRADE 1	PREMIUM - GRADE 2	"AA" - GRADE 3	"A" - GRADE 4
KNOTS & HOLES:				
Location:				
Over Notch:				
Size:	None	None	1/2" max. any face	1/4 cross sec. area
Nailing Face:				
Size:	Pin	1/4 of face width	3/8 of face width	1/2 of face width
Wide Face:				
Size:	1/8 of face width	1/4 of face width	3/8 of face width	1/2 of face width
Quantity:				
Notch area:	None	None	One notch only	One each notch
End area:	One, each end	One, each end	One, each end	One, each end
Center:	No restriction	Two, spaced 6"	Two, spaced 6"	No restriction
SLOPE OF GRAIN:	1 in 20 maximum	1 in 15 maximum	1 in 10 maximum	1 in 6 maximum
DISTORTED GRAIN:	None	None in notch area 1/8 width of face in other areas	None in notch area 1/4 width of face in other areas	None in notch area 3/8 width of face in other areas
CHECK, SHAKE, SPLIT:				
Check:	None	One, small, surface	One, med. surface	No restriction
Shake:	None	None	None	Light
Split:	None	None	None	One, short
PITH:	None	None	Face	Boxed
WANE:	1/8 width 1/8 thickness	1/8 width 1/8 thickness	1/6 width, 1/4 of thickness, length	1/3 width, 1/3 of thickness, full length
DECAY:	None	None	None	Area not over more than 1/4 cross section

PALLET STRINGER GRADES--HARDWOODS CONTINUATION

	PRECISION - GRADE 1	PREMIUM - GRADE 2	"AA" - GRADE 3	"A" - GRADE 4
STAIN:	Medium	Medium	No restriction	No restriction
WARP:	Very light crook	Light crook	Medium crook	No restriction
PITCH:	Light, very small streak or pocket None in nail face	Medium, very small streak or pocket None in nail face	Heavy, medium streak or pocket None in nail face	Heavy, large streak or pocket
MISMANUFACTURE:	None	None	None	No restriction
COMBINED DEFECT:	Reduction in strength equivalent to a knot defect.			
STANDARD DIMENSIONS:				
Width:	1-3/4" @ Green MC	1-3/4" @ Green MC	1-3/4" @ Green MC	1-3/4" @ Green MC
Height:	3-1/2 - 3-3/4"	3-1/2 - 3-3/4"	3-1/2 - 3-3/4"	3-1/2 - 3-3/4"
SPECIAL DIMENSIONS: Width:	For each 1/4-inch increment increase in width, the stringers may be upgraded by one grade, to a maximum width of 3-1/2" (maximum upgrade of 6 grades). For each 1/8-inch increment decrease in width, the stringers will be downgraded by one grade, to a minimum width of 1-1/2" (maximum downgrade of 2 grades).			
STANDARD MOISTURE CONTENT:	Average of 19 percent, and a maximum of 25 percent. Not downgraded if MC is higher.			
MISMANUFACTURE:	None	None	Equal to knot defect	Equal to knot defect
COMBINED DEFECT:	Reduction in strength equivalent to that caused by a knot defect.			
STANDARD DIMENSIONS:				
Thickness:	3/4" @ 12-15% MC	3/4" @ 12-15% MC	3/4" @ 12-15% MC	3/4" @ 12-15% MC
Width:	3-5/8 - 7-5/8"	3-5/8 - 7-5/8"	3-5/8 - 7-5/8"	3-5/8 - 7-5/8"

PALLET STRINGER GRADES--HARDWOODS CONTINUATION

	PRECISION - GRADE 1	PREMIUM - GRADE 2	"AA" - GRADE 3	"A" - GRADE 4
SPECIAL DIMENSIONS:	Deckboards must be of uniform thickness in a pallet structure.			
Thickness:	7/8" @ 12-15% MC	7/8" @ 12-15% MC	7/8" @ 12-15% MC	7/8" @ 12-15% MC
	Deckboards of this thickness may be upgraded one grade from that obtained from the above rules. Thicknesses of 13/16" and 25/32" will be treated as 3/4" pieces.			
STANDARD MOISTURE CONTENT:	Pertains to the moisture content of the stock at time of assembly of the pallet, and to the moisture content at time of production of the cut-to-size pieces.			
19% Average	Green Deckboards: Average moisture content above 25 percent.			
25% Maximum	Downgrade one grade if deckboards are green at time of fabrication of pallet.			

Appendix 3

Quality Class Specification for Stringers

Quality Class Specifications for Stringers

Class 1 Quality Stringers

Size of knot	Maximum dimension may not exceed one-fourth of the cross section area of the stringer.
Location of knot	No knots may be located in the area over the stringer notch or in the end 6 inches of the stringer--knots of 1/2-inch diameter or less ignored.
Number of knots	Two knots or more, over 1/2-inch diameter, will be treated as one defect by summation of the portion of the cross section area effected.
Type of knots	Unsound knots, loose knots, knot holes, and other holes--which exceed 1/2-inch diameter--either singly or in multiples may not exceed one-eighth of the cross section area.
Cross grain	General cross grain may not have a slope over a 10-inch section of the stringer greater than 1:10. Localized cross grain may not occur in more than one-fourth of the cross section area of the stringer.
Splits, Check, Shake	May not exceed one-fourth of the length of the part, either singly or in composite. Such defects which are less than 3 inches in length may be ignored.
Wane	At the point of deepest penetration, wane may not occupy more than 16 units of the cross section area, nor cover more than 3/16 of the nailing face (2-inch dimension).
Decay	Non permitted.
Pith	None permitted.
Mismanufacture	Mismanufacture which results in a reduction in the cross section dimension of the part, may not exceed 16 units.

Quality Class Specifications for Stringers Continued

Class 2 Quality Stringers

Size of knot	May not exceed one-third of the cross section area of the stringer.
Location of knot	Knots located in the notch area and/or in the end 6 inches may not exceed one-fourth of the cross section area of the stringer.
Number of knots	Multiple knots will be summed and treated as one knot, except that knots 1/2-inch or less in diameter may be ignored.
Type of knots	Unsound knots, loose knots, knot holes, and other holes may not exceed one-sixth of the cross section of the part. Such measurements may be made on single or multiple defects.
Cross grain	General cross grain may have a slope not to exceed 1:8 over a 10-inch portion of the stringer. Localized cross grain may not cover more than one-third of the cross-section area of the stringer.
Splits, Check, Shake	Such defects, singly or in combination may not exceed one-half of the length of the stringer. Those 3 inches or less in length are ignored.
Wane	At the point of deepest penetration, wane may not exceed 32 units nor one-fourth of the nailing face.
Decay	At the point of deepest penetration, may not exceed one-eighth of the cross section of the part.
Pith	May be present in any face of the stringer and/or may be boxed for less than one-third of the length.
Mismanufacture	Mismanufacture which reduces the cross-section area of the part over a length of not more than 10 inches, shall not occupy more than 32 units of the cross section.

Quality Class Specifications for Stringers Continued

Class 3 Quality Stringers

Size of knots	May not exceed one-half of the cross-section area of the stringer.
Location of knots	Knots located in the area over the notches and/or in the end 6 inches may not exceed one-third of the cross-section area.
Number of knots	Summed and treated as one defect as in classes 1 and 2.
Type of knots	Unsound knots, loose knots, knot holes, and other holes, either singly or in combination, may not exceed one-fourth of the cross-section area of the part.
Cross grain	General cross grain may not have a slope of grain greater than 1:6 over any 10-inch portion of the length. Localized cross grain may not cover more than one-half of the cross-section area of the part.
Splits, Check, Shake	Singly or in combination, may not exceed in aggregate length more than three-fourths of the length of the part. Defects 3 inches or less in length are ignored.
Wane	At the point of deepest penetration, wane may not exceed 48 units of the cross-section area of the part, nor cover more than 5/16 of the nailing face.
Decay	At point of deepest penetration, decay may not exceed one-fourth of the cross-section area of the stringer.
Pith	May occur boxed for the full length of the part.
Mismanufacture	Mismanufacture which reduces the cross-section area of the part, and which does not cover more than a 10-inch portion of the length of the part, may not occupy more than 48 units.

Quality Class Specifications for Deckboards

Class 1 Quality Deckboards

Size of knot	Maximum dimension across the width of the board is one-fourth of the board width.
Location of knot	No knots over 1/2-inch diameter are permitted in the edges or in the end 3 inches of the part.
Number of knots	Knots over 1/2-inch diameter which occur within 3 inches of each other are treated as one knot by summing the dimensions across the width of the part. Such sum may not exceed one-fourth of the width of the part.
Type of knots	Unsound knots, loose knots, knot holes, and other holes such as worm holes may not exceed one-eighth of the width of the part. Such measurement shall include summing of multiple defects within 3 inches of each other.
Cross grain	General cross grain may not have a slope of grain of more than 1:10. Such cross grain must extend for at least 10 inches along the part. Localized cross grain may not extend through more than one-fourth of the width of the part.
Splits, Check, Shake	Such defects singly or in combination may not exceed in length one-fourth of the length of the part, except that all splits, checks, and shake of 3 inches or less in length may be ignored.
Wane	At the point of deepest penetration, the wane may not occupy more than 16 units of the cross section area. Wane in end nailing areas may not interfere with more than one fastener in each joint.
Decay	None permitted
Pith	None permitted
Mismanufacture	Such mismanufacture which does not extend over more than 10 inches in length, may not occupy more than 16 units of the cross section area of the part.

Quality Class Specifications for Deckboards Continued

Class 2 Quality Deckboards

Size of knots	Maximum dimension across the width of the board is one-third of the width.
Location of knots	Knots located in the edges or in the end 3 inches may not occupy more than one-fourth of the cross section area of the board.
Number of knots	Multiple knots--over 1/2-inch diameter--shall be summed as described in class 1 and treated as one defect.
Type of knots	Unsound knots, loose knots, knot holes, and other holes, either singly or in combination, may not occupy more than one-sixth of the cross section of the part.
Cross grain	General cross grain may have a slope of grain not to exceed 1:8 over a 10-inch portion of the length. Localized cross grain may not occupy more than one-third of the cross section dimension of the part.
Splits, Check, Shake	Singly or in combination, may not exceed in the aggregate one-half of the length of the part. Defects less than 3 inches long may be ignored.
Wane	At the point of deepest penetration, wane may not exceed 32 units of the cross section area.
Decay	At the point of deepest penetration, decay may not exceed 32 units (one-eighth) of the cross section area of the part.
Pith	May occur in one face of the part, and/or may be boxed in less than one-third of the length.
Mismanufacture	Mismanufacture resulting in scant dimensions over sections less than 10 inches in length may not reduce the cross section dimension by more than 32 units.

Quality Class Specifications for Deckboards Continued

Class 3 Quality Deckboards

Size of knots	Maximum dimension in the width dimension of the part is one-half of the width of the board.
Location of knots	Knots located in the edges or in the end 3 inches may not exceed one-third of the width dimension of the part.
Number of knots	When two or more knots--over 1/2-inch in diameter--occur within 3 inches of each other, their respective dimensions shall be summed and the defects treated as one defect.
Type of knots	Unsound knots, loose knots, knot holes, and other holes, either singly or in combination, may not occupy more than one-fourth of the width dimension of the board.
Cross grain	General cross grain may have a slope of grain over at least a 10-inch portion of the length of the part not to exceed 1:6. Localized cross grain may not occupy more than one-half of the cross section area of the board.
Splits, Check, Shake	Singly or in combination, may not exceed in the aggregate three-fourths of the length of the board. Defects less than 3 inches long are ignored.
Wane	At the point of deepest penetration, wane may not exceed 48 units of the cross section area of the board.
Decay	At the point of deepest penetration, decay may not exceed one-fourth of the cross section area--64 units.
Pith	May occur boxed for the full length of the part.
Mismanufacture	Mismanufacture which reduces the cross section area of the board, and which does not extend over more than a 10-inch portion of the length of the part, may not occupy more than one-half of the cross section area--128 units.

Appendix 4

Listing of Defect Codes

Listing of Defect Codes

first two digits--relation to load points and supports

00 - tension side between load points
01 - compression side between load points
02 - tension side between support and load point
03 - compression side between support and load point
06 - compression side at load point
07 - tension side at load point
08 - tension and compression sides between load points
09 - tension and compression sides between support and load point
10 - tension and compression sides at load point

third and fourth digits defect type	fifth and sixth digits defect size
10 - clear wood	
11 - narrow face or spiked knot intergrown	
12 - narrow face or spiked knot encased	diameter
13 - narrow face or spiked knot unsound	
14 - wide face knot, center line intergrown	
15 - wide face knot, center line encased	knot size by diameter ($\pm$ 1/8 in.)
16 - wide face knot, center line unsound	
17 - wide face knot, at edge intergrown	
18 - wide face knot, at edge encased	knot size by diameter ($\pm$ 1/8 in.)
19 - wide face knot, at edge unsound	
21 - hole--use knot code for size and location; sue hole code in comment column	
22 - pin holes	
23 - grub or terido holes	thickness
24 - wide face knot, elsewhere* intergrown	
25 - wide face knot, elsewhere encased	diameter
26 - wide face knot, elsewhere unsound	

*An elsewhere knot is any knot whose arc does not intersect the center line or the edge on the wide face.

Listing of Defect Codes Continued

third and fourth digits defect type	fifth and sixth digits defect size
32 - honeycomb	percent cross section
33 - unsound wood or peck	
34 - distorted grain or burl	knot size by diameter ($\pm$ 1/8 in.)
41 - pitch or bark pockets	maximum thickness
42 - shake	01 for light, not through 02 for medium, not through 03 for others, not through 11 for light, through 12 for medium, through 13 for medium, through
43 - seasoning or roller check	01 for surface 02 for small, through 03 for medium, through 04 for large, through
44 - splits	$\pm$ 1" length in inches
45 - skip	01 for light 02 for medium 03 for heavy
46 - warp	00 for 1/2 of medium (SPIB, #1) 01 for light 02 for medium 03 for heavy
47 - manufacturing (rabbeted edge and machined edge)	Strength Ratio = 95
48 - excess moisture	over 19 percent (record if $\leq$ 30 pct)
49 - crossbreak	percent displacement cross section
50 - saw cut	01 saw cut through edge 02 all other saw cuts
51 - slope of grain	run of slope
52 - wane	first digit is number of fourths of width; second is fourths of thickness
53 - timber break	01, 1/3 or less of width 02, 1/3 - 2/3 of width 03, 2/3 or more of width

Listing of Defect Codes Continued

third and fourth digits defect type	fifth and sixth digits defect size
60 - local grain deviation (failure initiated in locally severe grain deviation)	run of slope (use 00 if less than 1 in 1)
61 - thickness mismanufacture	00
62 - pith	01, face 02, boxed
63 - sound edge knot cluster	
64 - sound center knot cluster	maximum diameter $\pm$ 1/8"
65 - sound elsewhere knot cluster	
66 - unsound edge knot cluster	
67 - unsound center knot cluster	maximum diameter $\pm$ 1/8"
68 - unsound elsewhere knot cluster	
75 - grade controlling defect = maximum strength reducing defect	00
90 - multiple small knots in notch area	number of knots
91 - insufficient spacing between knots	spacing (in.)
92 - multiple small knots in end area	number of knots

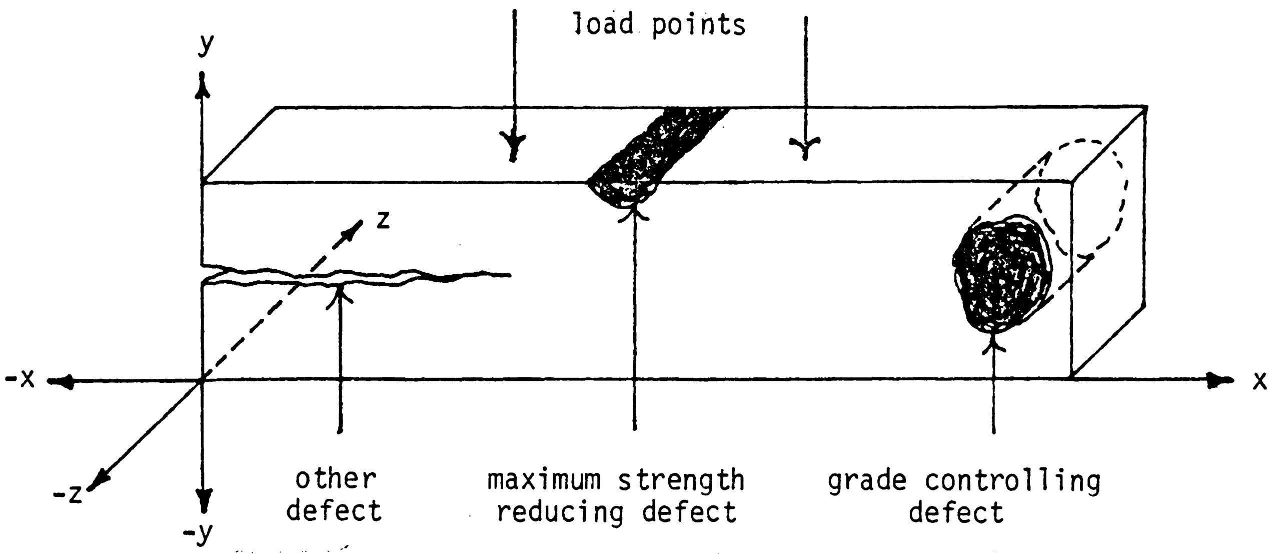
final digit--relationship between defect, faces, and edges

1 - defect intersects 1 edge, 0 faces
2 - defect intersects 2 edges, 0 faces
3 - defect intersects 0 edges, 1 face
4 - defect intersects 1 edge, 1 face
5 - defect intersects 2 edges, 1 face
6 - defect intersects 0 edges, 2 faces
7 - defect intersects 1 edge, 2 faces
8 - defect intersects 2 edges, 2 faces

Appendix 5

Example of Defect Mapping Procedure

Example of Defect Mapping Procedure



Mapping the defects on this deckboard would produce the following codes:

Maximum Strength Reducing Defect

code = 617117 182 34 80

6 = location with respect to load points = tension and compression between load points

17 = defect type = sound edge knot

11 = defect size = one inch, one eighth inches

7 = number of edges and faces intersected = 2 faces, one edge

182 = x coordinate = eighteen inches, two eighth inches

34 = y coordinate = three inches, two eighth inches

80 = 2 coordinate = full thickness

Grade Controlling Defect

code = 914266

9 = location in relation to load points = tension and compression between load and support

14 = defect type = wide face center line knot

26 = defect size = two inches, six eighths

6 = number of edges and faces intersected = two edges no faces

Other Defect

code = 104156

10 = location with respect to load points = tension and compression at load point

44 = defect type = split

15 = defect size = fifteen inches

6 = number of edges and faces intersected = two faces, zero edges

Appendix 6

Frequency of Strength Reducing
Defect Types by Percent

Frequency of strength reducting defect types by percent.

defect type	percent total
spike knots	9.6
center-line wide face knots	10.8
edge wide face knots	18.7
other wide face knots	15.6
splits, shake and checks	3.2
slope of grain	27.0
other	15.1

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