Flexural properties of eastern hardwood pallet parts

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Abstract

Accurate estimates of the flexural properties of pallet parts are critical to the safe, yet efficient, design of wood pallets. To develop more accurate data for hardwood pallet parts, 840 stringers and 2,520 deckboards, representing 14 hardwood species, were sampled from 35 mills distributed throughout the Eastern United States. The parts were sorted by species, visually graded, and tested in bending to destruction. This article describes the methods used to conduct this research and presents summary statistics of the flexural properties for the species and sizes tested. The modulus of rupture and modulus of elasticity of nominal 6-inch-wide deckboards is consistently greater than that of 4-inch material. The visual stress grading procedure used in this study can segregate pallet parts into strength and stiffness classes. These data will now be incorporated into the CAD procedure for pallets known as the Pallet Design System, which aids designers in selecting wood pallets for use in material handling.

The wood pallet and container industry is the largest user of hardwood lumber in the United States. In 1989, an estimated 6.4 billion board feet (BBF) of hardwood lumber was used to construct over 400 million hardwood pallets (14). The wood pallet is literally and figuratively the base of the unit-load material-handling system by which most products are transported and stored. It is the principal interface between the rigors of the handling environment and the packaged product. The function of the pallet is to facilitate transport and storage of, as well as protect, the product. Because of the relatively large volume of wood required to manufacture pallets, and the role of the pallet in material handling, the design and selection of wood pallets impacts on 1) the availability of timber for alternative uses; 2) the cost to society of solid waste disposal; 3) the cost of consumer goods; 4) productivity and competitiveness of industry; and 5) human health and safety, which can be jeopardized by pallet failures.

Recent cooperative research efforts between Virginia Polytechnic Institute and State University (Virginia Tech), the USDA Forest Service, and the National Wooden Pallet and Container Association (NWPCA) resulted in a computerized, structural design procedure that significantly improves the design and selection process for wood pallets. This design procedure, known as the Pallet Design System (15), incorporates advanced structural analysis techniques and is rapidly becoming accepted by the material-handling industry as the standard procedure for designing and selecting wood pallets.

Accurate estimates of the flexural properties of the pallet parts are critical to the safe, yet efficient, design of pallets. Historically, estimates of lumber strength and stiffness have been based on results of tests of small clear specimens, with modifications to these small clear values to account for the effect of size and grade differences. However, a recent study showed that strength ratios used to account for the effect of defects in oak pallet parts resulted in conservative estimates of bending strength, particularly for lower grades with

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Figure 1. — Geographic location of pallet mills from which eastern hardwood pallet parts were sampled.

larger defects (12). The applicability of the traditional size factor has been questioned due to trends in the relative strength of pallet stringers versus deckboards (11). Much better estimates of lumber strength and stiffness can be obtained from tests of full-size pieces. The structural lumber industry has tested full-size members of each species and grade in order to develop more accurate design values (6). For pallet parts, however, only eastern oaks (10) and yellow-poplar (9) have been evaluated through full-size testing. Flexural property estimates for all other species are currently based on modified clearwood values.

In order to generate more accurate flexural strength and stiffness estimates for eastern hardwood pallet parts, a testing program was initiated. The resulting data will allow development of flexural property estimates for eastern hardwood pallet parts based on in-grade testing. In turn, performance estimates for hardwood pallets will be more accurate and reliable, and the hardwood resource can be used more efficiently. Heavy-demand species can be more efficiently utilized, while underutilized species can be substituted with confidence in predicted performance.

Data from this study can also be used to evaluate the relative quality of eastern hardwood pallet parts from the grade distributions. Historical changes in quality distribution can be monitored by comparison with previous studies (7). The effectiveness of the visual grading rules in segregating eastern hardwood pallet parts by strength and stiffness can be evaluated. Calibration studies used to set safety levels in the Pallet Design System (8) can also be improved using this new data. Finally, species groupings for eastern hardwoods will more accurately reflect similarities and differences in mechanical properties of pallet parts.

TABLE 1. – *Common and scientific names of wood species and species groups tested.*

Common name	Scientific name
Black locust	*Robinia pseudoacacia*
Hickory	*Carya* spp.
Ash	*Fraxinus* spp.
Hard maple	*Acer* spp.
American beech	*Fagus grandifolia*
Birch	*Betula* spp.
Black cherry	*Prunus serotina*
Sweetgum	*Liquidambar styraciflua*
Blackgum	*Nyssa* spp.
Soft maple	*Acer* spp.
Hackberry	*Celtis* spp.
Aspen	*Populus* spp.
Cottonwood	*Populus* spp.
Basswood	*Tilia* spp.

Objectives

The objectives of this research project were the following:

1. To determine modulus of rupture (MOR) and modulus of elasticity (MOE) of commonly used species of eastern hardwood pallet parts based on full-she tests of pieces of typical dimension and quality.

2. To evaluate the ability of a visual grading system to segregate eastern hardwood pallet parts by MOR and MOE.

3. To determine the proportions of currently produced eastern hardwood pallet parts that fall within each grade, or quality class.

4. To create an eastern hardwood pallet parts database for use in developing flexural design values and for use in calibrating the structural analysis methodology used in the Pallet Design System.

Materials and methods

Pallet parts were sampled from 35 pallet mills in 26 states throughout the eastern hardwood growing region. Pallet mills were selected primarily from the NWPCA membership list (13). The selection was based on willingness to participate in the study by donating material and allowing the research team to visit their site. Figure 1 shows the geographical location of each mill. Samples were randomly selected from inventory of cut-to-size pallet parts at the mills. A total of 8402- by 4- by 48-inch stringers, 1,3181- by 4- by 40-inch deckboards, and 1,202 1- by 6- by 40-inch deckboards were collected and tested. Species sampled were representative of the material at each mill at the time of sampling, except that no oak or yellow-poplar was selected. Each piece was identified as to genus and, if possible, species. Table 1 lists the common and scientific names of the species sampled. The samples collected at each mill were representative of the quality distribution before any segregation by grade or removal of cull pieces.

Hardwood pallet parts are produced from cants or lumber at green moisture content (MC). Typically, the material is assembled into pallets without drying, and the pallets are initially used while the material is still above fiber saturation. Currently, all Pallet Design

System performance estimates reflect this practice by using green material property values. It was desired in this study to test the material while above fiber saturation. Therefore, once the material was selected from a mill, it was wrapped in plastic to prevent change in MC. The material was then transported to William H. Sardo Jr. Pallet and Container Research Laboratory at Virginia Tech. Once at the laboratory, the material was stored submerged in water tanks to prevent drying and to prevent biological deterioration during the time required to test the material. Given the large sample size, some delay between time of sampling and time of testing was unavoidable. In order to minimize this delay, the sampling/testing process was divided into three phases. AU the material sampled during a particular phase was also tested before beginning the next phase, keeping the storage interval prior to testing under 60 days.

Cross-sectional dimensions were measured to the nearest 0.001 inch. Each piece was visually graded according to specifications developed by Sardo and Wallin (16). This is the same grading scheme used in the oak parts study (10). A summary of this grading scheme is shown in Tables 2 and 3. The parts were then tested to destruction in third-point bending using procedures outlined in ASTM D 198-84 (1). Deckboards were tested flatwise at a 36-inch span and stringers on edge at a 45-inch span, with the tension face randomly selected. Load and centerspan deflection were measured continuously throughout the test. Deviations from the ASTM standard were rate of unloaded crosshead travel, which was 1.1 and 3.2 inches per minute for stringers and deckboards, respectively. This was necessary in order to test the large number of samples in an economical time frame. Adjustments for pallet part MOR and MOE from this rate of loading to the ASTM standard test rate have been developed by McLeod (11). After testing, an MC and specific gravity (SG) sample was taken from every third piece. MOR and MOE were calculated as in ASTM D 198-84. Stringer MOE was corrected for shear effects using procedures in ASTM D 2915-84 (3).

Results and discussion

This study is an unbalanced factorial design with three factors: species, size, and grade. It is unbalanced because it was impractical to control the number of

TABLE 2. – *Grading criteria employed for stringers.*

Defect	Description	Grades of parts 2&BTR	3	4
Size of knot	Maximum portion of cross section affected	1/4 of cross section	l/3 of cross section	1/2 of cross section
Location of knots	Over notch or in end 6 in. of the stringer	1/2 in. max. diameter	1/4 of cross section	1/3 of cross section
Clusters of knots	Knots over 1/2 in. in diameter spaced 3 in. or less apart are measured as one defect	None	1/3 of cross section	1/2 of cross section
Type of knots	Knot holes, unsound or loose knots, and holes	1/8 of cross section	1/6 of cross section	1/4 of cross section
Cross grain	Slope of general cross grain	1 in. in 10 in.	1 in. in 8 in.	1 in. in 6 in.
	Maximum dimension of local cross grain	1/4 of cross section	1/3 of cross section	1/2 of cross section
Splits, checks, and shake	Maximum length singly or in combination Defects 3 in. or less are ignored	1/4 of length of part	1/2 of length of part	3/4 of length of part
Wane	Maximum portion of cross section	1/16 of cross section	1/8 of cross section	3/16 of cross section
	Portion of nail face width	3/16 efface	1/4 of face	5/16 of face
Decay	Maximum portion of cross section	None	1/8 of section	1/4 of section
Pith	Length in face	None	Full length	Full length
	Length boxed	None	1/3 length	Full length
Mismanufacture	Maximum portion of cross section, and maximum of 10 in. long	1/16 of cross section	1/8 of cross section	3/16 of cross section

TABLE 3. – *Grading criteria employed for deckboards.*

Defect	Description	Grades of parts 2&BTR	3	4
Size of knot	Maximum dimension across width of the board	1/4 of board width	1/3 of board width	1/2 of board width
Location of knots	Knots in the edges and end 3 in. of the boards	1/2 in. diameter	1/4 of board width	1/3 of board width
Clusters of knots	Knots over 1/2 in. in diameter spaced 3 in. or less apart are measured as one defect	1/4 of board width	1/3 of board width	1/2 of board width
Type of knots	Knot holes, unsound or loose knots, and holes	1/8 of board width	1/6 of board width	1/4 of board width
Cross grain	Slope of general cross grain	1 in. in 10 in.	1 in. in 8 in.	1 in. in 6 in.
	Maximum dimension of local cross grain	1/4 of board width	1/3 of board width	1/2 of board width
Splits, checks, and shake	Maximum length singly or in combination Defects 3 in. or less are ignored	1/4 of board length	1/2 of board length	3/4 of board length
Wane	Maximum portion of cross section affected at point of deepest penetration	1/16 of cross section	1/8 of cross section	3/16 of cross section
Decay	Cross section deepest penetration	None allowed	32 units	64 units
Pith	In face of board	None	Full length	Full length
	Boxed	None	1/3 length	Full length
Mismanufacture	Maximum 10 in. in length: and maximum cross section	1/16 of cross section	1/8 of cross section	1/2 of cross section

pieces sampled of a particular species and size. Instead, the number of pieces of each were representative of current production and inventory at each mill. Positive species identification and visual grading did not take place until the sampled material was at the laboratory. Larger sample sizes for certain species reflect greater volumes of use over a larger geographical area. The greater sample size for deckboards than stringers reflects the number of pieces of each required to construct a pallet. It was undesirable to control the number of pieces in each grade since quality distribution was a variable of interest in this study.

Mill or geographical area was not considered a factor in this study due to the variable number of pieces of any given species and size selected from each mill. The MC of all material tested was above fiber saturation. Since moisture level above fiber saturation is assumed not to affect flexural strength and stiffness MC is not a factor in this study.

The general linear model procedure of the Statistical Analysis System (17) was used to perform an analysis of variance to test for all main effects and interactions on MOR and MOE. Table 4 presents the results of this analysis. As expected, species, size, and grade had a significant effect on both MOR and MOE. All interactions between the three main factors were also significant with the exception of the size x grade interaction, which was not significant for MOE.

TABLE 4. – *Analysis of variance for modulus of rupture (MOW and modulus of elasticity* (MOE) *of eastern hardwood pallet parts.*

Factor	MOR	MOE
Species	$p < 0.0001$[a]	$p < 0.0001$
Size	$p = 0.0001$	$p = 0.0001$
Grade	$p < 0.0001$	$p = 0.0001$
Species x size	$p = 0.0001$	$p = 0.0001$
Species x grade	$p = 0.0001$	$p = 0.0001$
Size x grade	$p = 0.0062$	$p = 0.6410$
Species x size x grade	$p = 0.0108$	$p = 0.0046$

[a] The null hypothesis states there is no effect of the factor on MOR or MOE. These p-values represent the probability that if the null hypothesis was true, the differences In MOR and MOE would be observed.

Size effects

Table 5 contains MOR, MOE, SG, and MC data for each size class of pallet parts tested. Mean and nonparametric lower fifth percentile MOR and mean MOE were greatest for 6-inch deckboards, followed by 4-inch deckboards, and then stringers. A Duncan's multiple-range test ($\alpha = 0.0 1$) indicated the mean MOE of each size class was significantly different, while the mean MOR was not significantly different between the 4-inch and 6-inch deckboards.

Pallet deckboards are most commonly produced in two nominal size classifications: 1 inch thick by 4 inches wide or 1 inch thick by 6 inches wide. For hardwood pallet deckboards, the actual dimensions will vary widely and depend on manufacturer and minimum acceptable dimensions in a particular pallet specification. In the previous oak parts study (10), the mean MOR and MOE were significantly greater for 6-inch than 4-inch deckboards. Based on a statistical size-effect (19), 6-inch deckboards are more likely than 4-inch deckboards to contain a strength-reducing defect due to their greater volume. However, there maybe other rational reasons for differences in the flexural properties between 4-inch and 6-inch deckboards when production method is considered. Most hardwood pallet deckboards are resawn from 4 by 6 cants. It may be reasonable to expect that the average knot diameters might not differ between the two deckboard sizes in proportion to their width. Indeed, in the oak parts study the average knot diameters were 1.44 and 1.54 for the 4-inch and 6-inch deckboards, respectively (1 1). Knots of equivalent diameter will more severely reduce the flexural strength and stiffness of a 4-inch than a 6-inch deckboard.

Table 6 contains MOR, MOE, and SG data by individual species and size. For most of the species in this study, the average and nonparametric lower fifth percentile MOR and average MOE were greater for the 6-inch than 4-inch deckboards. The lack of statistical significance for the difference in mean MOR between 4-inch and 6-inch deckboards, as reported in Table 5, is likely due to the high variability given the number of different species. If species are considered separately, statistical t-tests show the difference in mean MOR, as well as mean MOE, to be significant for a majority of the species tested.

As indicated by McLain et al. (10), current pallet design procedures do not differentiate material properties between deckboard sizes. Only two size classes are considered, stringers and deckboards, with 4-inch and 6-inch deckboards combined. In the future, however, trends seen in this and previous studies may warrant differentiation of flexural properties between these two deckboard sizes, particularly given current

TABLE 5. – *Summary of properties of eastern hardwood pallet parts by size.*

Size	N	MOR 5th percentile[a]	MOR Mean	MOR COV[b]	MOR Duncan grouping[c]	MOE Mean	MOE COV	MOE Duncan grouping	N	SG	MC
		- - - - ($x10^3$ psi)	- - - -	(%)		($x10^6$ psi)	(%)			(OD wt./OD vol.)	(%)
Stringer	840	3.201	6.367	29.1	B	1.333	27.4	C	286	.613	65.2
4-in. deckboard	1,318	3.520	6.631	28.8	A	1.507	28.9	B	441	.621	68.3
6-in. deckboard	1,202	3.820	6.735	27.2	A	1.550	25.9	A	413	.612	69.2

[a] Nonparametric lower fifth percentile.
[b] COV - coefficient of variation.
[c] Duncan-s multiple range test. Means with the same capital letter are not significantly different at the a -0.01 level.

TABLE 6. – *Properties of eastern hardwood pallet parts by species and size.*

Species	Size	N	MOR 5th percentile[a]	MOR Mean	COV[b]	MOE Mean	MOE COV	N	SG
			- - - - (x10³ psi) - - - -		(%)	(x10⁶ psi)	(%)		(OD wt./OD vol.)
Black locust	4-in. deckboard	14	3.192	8.765	22.7	1.517	16.4	4	.660
Hickory	Stringer	59	4.844	7.964	26.0	1.538	18.0	23	.766
	4-in. deckboard	91	4.990	8.466	25.7	1.795	28,2	27	.735
	6-in. deckboard	140	5.290	8.642	23.6	1.804	26.5	48	.711
Ash	Stringer	98	2.654	6.595	34.4	1.340	28.4	32	.684
	4-in. deckboard	141	3.565	7.208	25.0	1.522	28.0	46	.674
	6-in. deckboard	113	3.243	6.693	28.2	1.487	24.9	36	.640
Hard maple	Stringer	193	3.875	7.018	26.0	1.456	27.5	67	.663
	4-in. deckboard	232	4.055	7.132	24.5	1.670	25.1	79	.656
	6-in. deckboard	180	4.724	7.672	20.3	1.689	21.1	66	.649
American beech	Stringer	77	3.614	5.951	22.0	1.244	21.4	24	.602
	4-in. deckboard	151	4.348	7.224	20.5	1.575	18.3	53	.692
	6-in. deckboard	111	4.891	7.108	20.9	1.649	19.6	37	.673
Birch	Stringer	62	3.673	6.335	22.3	1.327	24.9	24	.640
	4-in. deckboard	203	4.538	7.034	21.2	1.730	21.8	69	.632
	6-in. deckboard	135	3.298	5.738	28.4	1.476	25.9	47	.595
Black cherry	Stringer	50	1.731	5.984	30.7	1.274	28.8	16	.568
	4-in. deckboard	64	2.883	5.673	26.2	1.266	27.5	27	.631
	6-in. deckboard	103	3.898	6.656	22.3	1.424	23.7	34	.569
Sweetgum	Stringer	52	3.772	5.802	20.8	1.201	21.4	16	.548
	4-in. deckboard	177	2.905	5.295	27.7	1.193	27.3	54	.545
	6-in. deckboard	150	3.444	5.668	23.9	1.302	25.2	54	.545
Blackgum	Stringer	52	3.186	5.505	23.5	1.128	27.0	15	.585
	4-in. deckboard	110	3.193	5.638	25.4	1.252	31.3	39	.525
	6-in. deckboard	125	3.943	5.953	19.6	1.467	24.8	42	.514
Soft maple	Stringer	123	4.596	6.579	21,1	1.427	24.6	42	.576
	4-in. deckboard	55	4.130	6.161	18.4	1.439	25.0	16	.627
	6-in. deckboard	96	4.463	6.396	19.3	1.612	18.6	32	.579
Hackberry	4-in. deckboard	19	4.034	6.964	31.6	1.297	35.1	4	.593
	6-in. deckboard	7	3.014	5.420	52.5	1.472	61.2	1	.770
Aspen	Stringer	18	1.866	4.740	22.0	1.115	13.7	6	.402
	4-in. deckboard	46	2.515	4.707	24.8	1.379	19.8	16	.388
	6-in. deckboard	42	3.949	6.028	19.9	1.565	28.4	14	.443
Cottonwood	Stringer	34	2.214	4.430	27.7	1.041	29.0	13	.398
Basswood	Stringer	22	2.230	4.271	27.4	1.020	25.6	7	.377
	4-in. deckboard	15	1.296	3.283	33.8	0.835	27.8	7	.423

[a] Nonparametric lower fifth percentile.
[b] COV - coefficient of variation.

manufacturing practices for hardwood pallet deckboards. Six-inch deckboards have some advantages over 4-inch deckboards from a pallet performance standpoint; they have greater load-carrying capacity due to their greater section modulus, and they can provide greater joint rigidity because they can receive a greater number of fasteners per joint without splitting. If they also have superior flexural properties (independent of section modulus), this could affect future design trends and pallet manufacturing practice by favoring production and use of 6-inch over 4-inch deckboards.

As seen in Table 5, average and nonparametric lower fifth percentile MOR and average MOE were lower for stringers than deckboards. A lower MOR for stringers would be expected based on the traditional depth effect (5). MOR and MOE were also found to be lower for stringers than deckboards in previous studies of yellow-poplar (9) and red alder and bigleaf maple (4). In the oak parts study, stringer MOE was lower than deckboard MOE (10). However, stringer MOR was actually greater than deckboard MOR, opposite the trend expected based on difference in depth. It was postulated that any size effect may be species dependent since oak is quite different anatomically than yellow-poplar, alder, or maple. However, in this study, only soft maple and sweetgum stringer MOR was greater than the average MOR for deckboards. Ring-porous species such as ash and hickory, as well as all other species tested, had higher deckboard MOR compared to stringer MOR. Stringer MOE was lower than deckboard MOE for all the species tested. No definitive explanation can be offered for the higher stringer MOR in oak, soft maple, or sweetgum. However, it does not appear to be related to anatomical differences nor to differences in SG or MC. Sweetgum stringers did have a greater percentage of higher grade material compared to deckboards. In the oak parts study, the loading rates used resulted in a somewhat higher strain rate in stringers compared to deckboards, which would tend to increase the stringer MOR. Overall, the majority of species tested in this and previous studies tend to have lower MOR for stringers than deckboards, as expected.

Grade distributions

In this study, the grade distribution refers to the percentage of a population of pallet parts that falls within each of the grades defined by Sardo and Wallin (16). The grade distribution is useful for evaluating the relative quality of the material. Currently, most pallet manufacturers do not separate individual grades. Instead, only lower quality material is removed, resulting in a combined grade, such as 4&BTR or 3&BTR. The grade distribution can also be used in development of design values for these combined grades (11). Table 7 contains the grade distribution by size for the eastern hardwood pallet parts sampled in this study. There was a greater percentage of 4-inch deckboards of the highest grade compared to 6-inch deckboards. This might be expected based on Weibull's statistical size-effect theory (19) in which 6-inch deckboards are more likely than 4-inch deckboards to contain a strength-reducing defect due to their greater volume. However, there was also a slightly greater percentage of 4-inch deckboards of the lowest grades. A greater percentage of 6-inch deckboards were of mid-quality grade 3. This tends to support the previous discussion that based on current hardwood deckboard manufacturing practice, average knot sizes might not differ between 4-inch and 6-inch boards proportional to their size. Equivalent knot sizes would downgrade a 4-inch more than a 6-inch deckboard. Deckboards had a greater percentage of pieces in the highest grade and a smaller percentage of pieces in the lower two grades compared to stringers. Since stringers and deckboards are typically resawn from cants in a similar fashion, but with greater thickness for stringers, the difference in grade distribution between these two sizes may be due to the greater volume in stringers and therefore the greater likelihood of defects.

Table 7 contains two additional grade distributions measured in earlier studies. The first is from a quality distribution study of eastern hardwood deckboards published in 1974 (7). In 1985, McLeod (11) compiled all data sets of graded pallet parts to date and computed the weighted average grade distribution shown in Table 7. This average represents both stringers and deckboards, hardwoods and softwoods, and eastern and western U.S. species. Coincidentally, the percentages in these two grade distributions are identical (rounded to the nearest 0.5%). The grade distributions indicate that currently produced eastern hardwood pallet parts have a smaller proportion of very high quality pieces compared to pallet parts produced over the past 15 to 20 years. There was more of a decrease in the percentage of high grade parts for stringers compared to deckboards.

Pallet parts are typically produced from low quality timber resources. Nevertheless, current as well as previous studies have found that the majority of pieces produced meet the higher quality pallet part grades, with a smaller proportion falling into the lower grades. This indicates the wood pallet industry's ability to utilize and even upgrade a low quality resource through remanufacture. A notable exception to this trend was the eastern oak parts study (10), which had nearly

TABLE 7. – *Comparison of grade or quality distribution for eastern hardwood pallet parts sampled in this study with similar distributions measured in previous studies.*

	Grade distribution				
	N	2&BTR	3	4	CULL
		(%)			
Stringers	840	38.5	32.5	20.5	8.5
4-in. deckboards	1,318	47.5	30.5	14.0	8.0
6-in. deckboards	1,202	42.0	38.5	13.0	6.5
Previous study of eastern hardwood deckboards[a]	17,817	48.0	31.0	13.0	8.0
Average for all available data sets of graded pallet parts[b]	43,513	48.0	31.0	13.0	8.0

[a] Species include maple. beech, birch, oak, and gum (7).
[b] Includes deckboards and stringers, hardwoods and softwoods, eastern and western U.S. species (11).

TABLE 8. – *Flexural properties of eastern hardwood pallet parts by size and grade.*

			MOR				MOE		
Size	Grade	N	L5EL[a]	Mean	COV[b]	Duncan grouping[c]	Mean	COV	Duncan grouping
			($\times 10^3$ psi)		(%)		($\times 10^6$ psi)	(%)	
Stringer	2&BTR	324	4,691	7.176	23.6	A	1.475	26.0	A
	3	273	3.826	6.307	25.7	B	1.315	25.4	B
	4	171	3.063	5.637	28.3	C	1.200	22.7	C
	CULL	72	1.692	4.684	44.4	D	1.077	30.5	D
4-in. deckboard	2&BTR	624	4.209	7.305	25.0	A	1.647	27.2	A
	3	401	3.556	6.228	26.0	B	1.422	25.6	B
	4	187	2.611	5.706	32.8	C	1.313	28.8	C
	CULL	106	2.255	5.821	35.0	C	1.341	32.4	C
6-in. deckboard	2&BTR	507	4.561	7.294	23.9	A	1.670	22.9	A
	3	462	3.712	6.391	26.3	B	1.489	25.0	B
	4	156	3.481	6.335	28.8	B	1.437	24.7	BC
	CULL	77	1.899	5.930	38.8	C	1,359	39.4	C

[a] Nonparametric lower fifth percentile.
[b] COV - coefficient of variation.
[c] Duncan's multiple range test. Means with the same capital letter are not significantly different at the a -0.01 level.

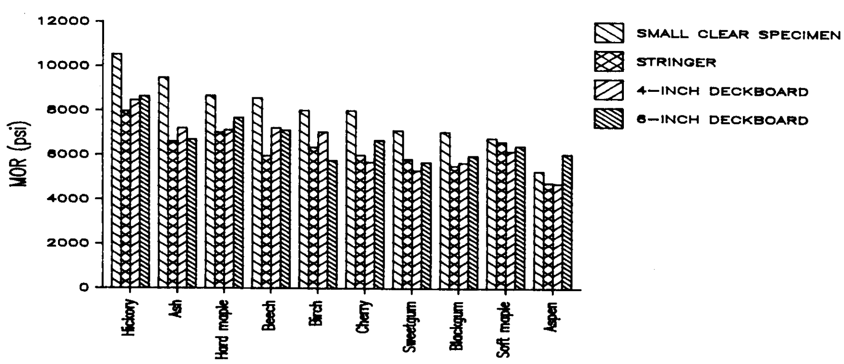

Figure 2. — Comparison of MOR of eastern hardwood pallet parts by species. Small clear specimen values are from ASTM D 2555-81 (2) except for cherry, which is from the Wood Handbook (18). Small clear value for hickory is the average for pecan, water, mockernut, pignut, shagbark, shellbark, bitternut, and nutmeg; for ash, the average is for green and white; for hard maple, it is for sugar and black; for birch, it is for paper, sweet, and yellow; for soft maple, it is for red and silver; and for aspen, it is for bigtooth and quaking aspen.

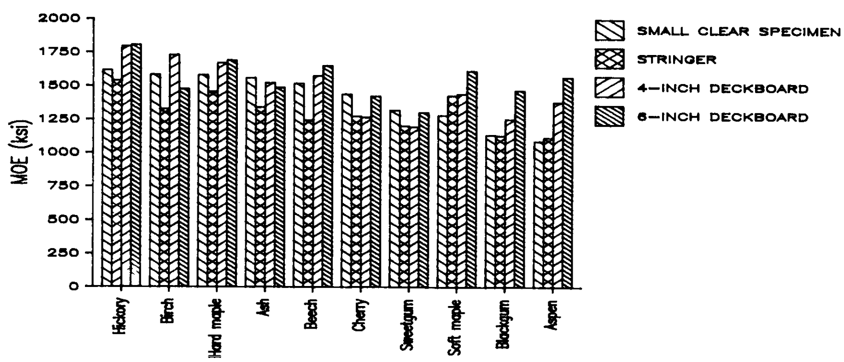

Figure 3. — Comparison of MOE of eastern hardwood pallet parts by species. Refer to Figure 2 for an explanation of the small clear specimen values.

equal percentages in each grade. As noted by the authors of that study, this may have been due to heavy demand for oak by the furniture industry at the time, reducing the overall quality of material available to the pallet industry for remanufacture into pallet parts. While the grade distribution for each species in the current study was slightly different, most were reasonably close to the averages shown in Table 7.

Effectiveness of visual grading

The primary purpose of the pallet part grades used in this study, which have specific limits on size and location of knots, slope of grain, and other defects, is to segregate material by flexural strength and stiffness. Table 8 provides MOR and MOE data by size and grade. The lower fifth percentile and average MOR and average MOE decreased for both stringers and deckboards with decreasing grade. Four-inch deckboards of grade Cull were the only exception, having slightly higher average MOR and MOE than grade 4. However, the lower fifth percentile MOR was lower for grade Cull. The coefficient of variation of the flexural properties tended to increase with decreasing grade. These trends are as expected and indicate that the grading specifications allow separation of material with differing flexural properties on a visual basis. To determine which grades had statistics.lly significant differences, a Duncan's multiple-range test was performed ($\alpha = 0.05$). Results of this test, as given in Table 8, indicate the mean MOR and MOE are significantly different between each grade of stringers. For 4-inch deckboards, the mean MOR and MOE were significantly different between grades 2&BTR, 3, and 4. For 6-inch deckboards, the mean MOR and MOE were significantly different between grades 2&BTR, 3, and Cull.

Effect of species on flexural strength and stiffness

Figures 2 and 3 allow a visual comparison of the MOR and MOE, respectively, for the species tested in this study. While data for all species tested are contained in Table 6, only those with the largest sample sizes are shown in Figures 2 and 3. Within each figure, the average experimentally determined MOR and MOE are shown separately for stringers, 4-inch, and 6-inch deckboards of each species group. The average MOR and MOE values determined from tests of small clear specimens at green MC and published in ASTM D 2555-81 (2) are also shown. These small clear values represent expected trends between species, which are shown in decreasing order of small clear value.

As indicated in Figure 2, the relative ranking of species groups by experimentally determined MOR generally followed the ranking by small clear value. The average MOR for stringers and deckboards was typically less than the small clear value, as would be expected given the presence of defects and differences in size. Exceptions include soft maple stringers and deckboards and 6-inch aspen deckboards, which had higher MOR values than expected. It should be noted that the increased loading rate used to test the stringers and deckboards in this study probably increased the average MOR between 5 and 10 percent compared to the standard ASTM loading rate (11). The effect of size on MOR, as previously discussed, is evident with higher 6-inch than 4-inch deckboard MOR and higher deckboard than stringer MOR for most species.

As indicated in Figure 3, the relative ranking of species groups by experimentally determined MOE did not follow the ranking by small clear value particularly well. Stringer MOE was typically less than clearwood MOE, as would be expected due to the presence of defects. Deckboard MOE was typically higher than stringer MOE, and 6-inch deckboard MOE was typically higher than 4-inch deckboard MOE. Deckboard MOE was also much higher than clear wood MOE for most species. Soft maple, blackgum, and aspen had higher MOE than expected. The increased loading rate used to test the material in this study probably resulted in a 3 to 8 percent increase in MOE compared to the standard ASTM loading rate (11). The substantially different span-to-depth ratio for the deckboard tests versus the stringer and small clear specimen tests may also have affected relative MOE, although a correction for shear effects was made to the stringer and small clear data. The trend observed in previous studies of higher deckboard than stringer MOE was previously discussed. McLeod (11) also found deckboard MOE to be higher than small clear specimen MOE in tests of oak and yellow-poplar.

Summary and conclusions

Eight-hundred forty pallet stringers and 2,520 pallet deckboards of eastern hardwood species were sampled from 35 mills in 26 states. The parts were identified as to genus and (if practical) species, visually graded, and tested to destruction in bending. The resulting flexural property data were used to create a database for eastern hardwood pallet parts. This database can be used to develop accurate and reliable flexural property estimates for use in structural design of hardwood pallets.

Six-inch-wide deckboards were found to have higher average flexural strength and stiffness than 4-inch deckboards for most species, although the differences were not always statistically significant. Deckboards did exhibit significantly higher flexural strength and stiffness properties than stringers, as might be expected based on the difference in depth. In developing design values for pallet parts, consideration should be given to differentiating flexural properties between 4-inch and 6-inch deckboards, as well as between deckboards and stringers.

Compared with the average for data collected over the past 15 to 20 years, the eastern hardwood pallet parts sampled in this study had a slightly lower percentage of pieces in the highest quality grade, although the percentage in grade Cull was unchanged. A greater percentage of the stringers in this study were of lower grade than deckboards. A greater percentage of 4-inch deckboards were of the lowest grades compared to 6-inch deckboards.

Visual grading was found to be effective in segregating eastern hardwood pallet parts by flexural strength and stiffness. Higher quality grades had significantly greater average MOR and MOE as well as lower variability. Nonparametric lower fifth percentile MOR decreased with decreasing grade.

The relative ranking of the species groups by stringer and deckboard MOR followed expected trends. However, a similar ranking by MOE did not follow the expected pattern as well.

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