New PDS Will Predict Performance Of Pallets Made with Used Parts

By John W. Clarke
Marshall S. White
Philip A. Araman

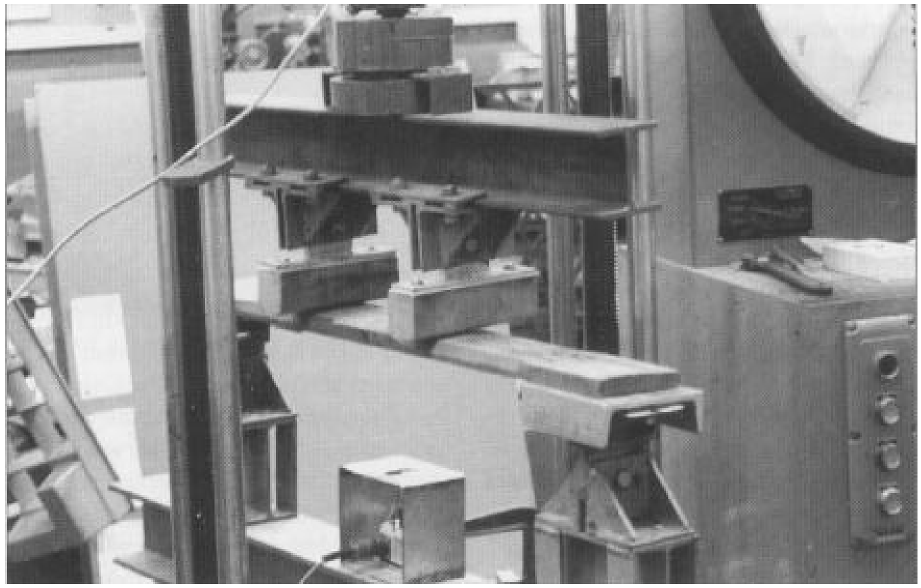

Figure 1: Test set-up to measure flexural strength and stiffness of used pallet parts.

The Pallet Design System (PDS) is a computer design program developed by Virginia Tech, the National Wooden Pallet & Container Association, and the U.S. Forest Service to quickly and accurately predict the performance of new wood pallets. PDS has been upgraded annually since its original version in 1984. All of the previous upgrades, however, have continued to improve the accuracy of new pallet performance.

So far, PDS has not been able to help pallet recyclers as they design and market used pallets. This will change with the 2002 version of PDS, which will predict the performance of pallets manufactured with used parts recovered from recycled pallets.

The pallet recycling industry continues to experience rapid growth. In 1999, an estimated 299 million pallets were received by pallet recyclers for repair, reuse, or recycling — up from 171 million in 1995.

One of the products of pallet recyclers is used pallet parts recovered from the disassembly of used pallets. These recovered parts can be used to make remanufactured pallets or combination (or 'combo') pallets. Remanufactured pallets are assembled entirely from recycled pallet parts. Combo pallets are assembled with a mixture of new and recycled parts. Remanufactured and combo pallets are environmentally friendly and are an efficient use of our wood resource.

Surveys of PDS users have indicated that the ability to design these pallets and specify used parts with PDS would improve their marketing and design efforts. First, however, the physical and mechanical properties, species groupings, and grade mixes of used pallet parts had to be determined.

The objectives of this study were to determine the physical and mechanical properties of used wood pallet parts. These material properties were used to recommend practical groupings of used pallet parts for use in PDS to predict the performance of remanufactured and combo pallets.

Test Materials and Methods

Used pallet stringers and deck boards were sampled from 10 pallet repair facilities throughout the U.S. Mills were selected and sampled based on concentrations of the pallet recycling industry within geographic areas. Parts were randomly selected from inventory of the sample mills. The number and size of parts varied at each location due to availability. A total of 255 nominal 2x4 48-inch stringers, 246 nominal 1x4 40-inch deck boards, and 221 nominal 1x6 40-inch deck boards were collected and tested.

Parts were shipped to the Virginia Tech Pallet and Container Research Laboratory for inspection and evaluation. Pallet parts were graded and measured for width and thickness. All parts were then tested to failure in third-point bending to determine strength (Modulus of Rupture) and stiffness (Modulus of Elasticity). The test set-up is shown in Figure 1. After testing, samples were cut from each board to determine moisture content and density.

RESULTS

Species of Used Wood Pallet Parts

We analyzed the percentage of each wood species or species group of the used pallet parts sampled. The combined

Table 4: The variation of used pallet part dimensions sampled from 10 locations throughout the US.

Pallet Part Nominal Size	Number	Dimension	Average dimension (in.)	Coefficient of variation (%)	Range of measured dimensions (in.)
1 x 4" deckboards	246	Width	3.601	6.3	2.398-4.411
		Thickness	0.649	15.5	0.361-0.954
1 x 6" deckboards	221	Width	5.565	5.0	4.188-6.086
		Thickness	0.639	15.4	0.375-1.079
2 x 4" stringers	255	Width	1.360	9.8	0.928-1.709
		Height	3.488	3.5	3.116-3.875

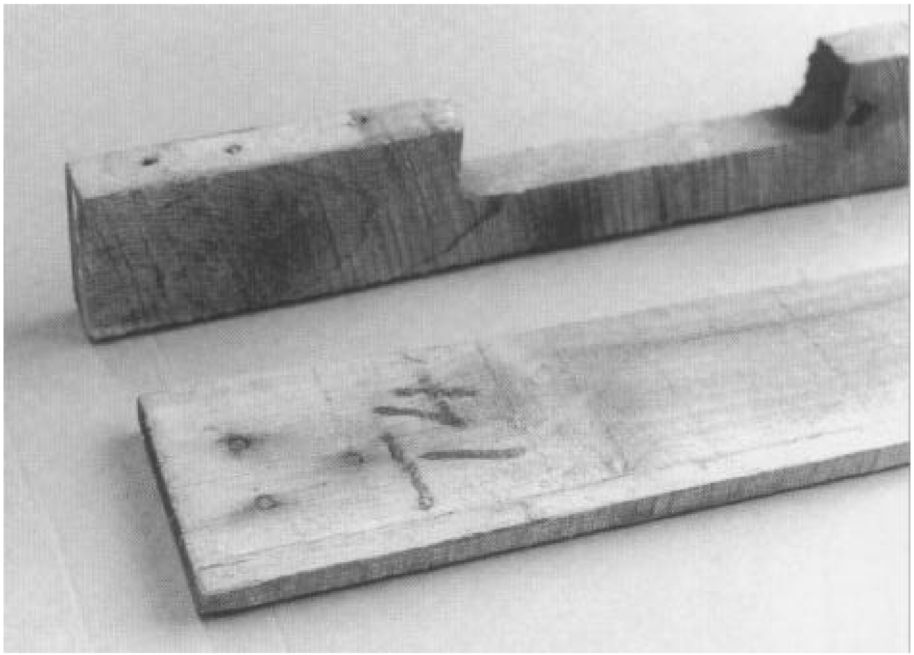

Figure 2: Typical nail holes and nail stubs in used deck boards and stringers.

red and white oaks (Quercus spp.) were the most common species, representing more than one-third of the used parts collected. The southern yellow pines (Pinus spp.), the hard maples (Acer spp.) and the spruces (Picea spp.) represented 15.9%, 14%, and 6.2%, respectively, of the parts collected. No other species represented more than 5% of the sampled used parts. A small percentage of parts was listed as "other" and were likely not indigenous to North America. Seventy-four (74%) of the parts sampled were hardwoods (non-coniferous) and 26% softwoods (coniferous).

Note: An independent 1995 study conducted by the Virginia Tech Center for Forest Products Marketing and Management determined that mixed Eastern oaks were the most common new parts used by the pallet and container industry. That study found that 72% of new pallet lumber was hardwood and 28% was softwood. This corresponds closely with the 74% hardwood and 26% softwood found in the used parts collected.

Used Pallet Part Species Distribution Between Sampling Sites

New wood pallet parts are grouped into PDS species classes. Each class includes species that exhibit similar strength, stiffness, and density. For example, the Eastern red and white oaks are grouped in one class while another class is comprised of aspen, catalpa, buckeye, butternut, American basswood and cottonwood. Red alder and yellow poplar are classes by themselves while another hardwood class contains 17 species.

New pallets are typically manufac-

Table 1: Average Flexural Strength and Stiffness of New * and Used Eastern Oak Pallet Parts

Pallet Part Condition	Replicates	Moisture Content (%)		Modulus of Rupture (psi)			Modulus of Elasticity (million psi)		
		Average	COV (%)	Average	COV (%)	Tukey's ** Distribution	Average	COV (%)	Tukey's ** Distribution
Used Oak deckboards	147	11	21	9606	31	A	1.695	39	A
New Oak Deckboards – Air dry	105	18	7	8499	23	B	1.679	26	A
New Oak Deckboards – Green	110	61	20	6516	23	C	1.374	29	B
New Oak Deckboards - 11% moisture content (predicted)***				11086			2.052		
Used Oak stringers	57	12	22	8464	45	A	1.428	36	A
New Oak Stringer – Air Dry	52	17	6	7988	36	A,B	1.276	25	A,B
New Oak Stringers – Green	50	71	12	6804	29	B	1.108	26	B
New Oak Deckboards - 11% moisture content (predicted)***				8830			1.399		

* New oak parts were previously tested (7)
** Average observations with the same letter A, B, or C are not statistically different.
*** These are predicted values based on adjustments of the new air dry measurements to the equivalent moisture content of the corresponding used parts using the procedures described in the Wood Handbook, Chapter 4 (14).

tured of species found within the region that the pallets are manufactured. New pallet manufacturers in the Eastern U.S. commonly use wood species in seven different classes — five classes of hardwoods and two of softwoods. In the Western U.S., four species classes — all softwoods — are more commonly used for pallet manufacture.

The percentage of used pallet parts within each PDS species classes was examined for each of the 10 repair mills sampled. For nine of the 10 mills sampled, the combined dense hardwoods and mixed Eastern oaks (Classes

1 and 21) were the majority of the parts sampled. The Pennsylvania mill was the exception, using a large percentage of Southern yellow pine (Class 22) on the day that we collected samples. All 10 mills sampled contained more hardwood parts (Classes 1,3,6,7,21,29) than softwood parts (Classes 11,13,22). The predominance of dense hardwoods was even true for mills located in the Western U.S., far from the source of these species of timber. This reflects the transcontinental shipment of pallets. The regional species
influences that we see in new pallet lumber were not evident with used parts.

Variation of Used Pallet Part Sizes

New pallet parts are sawn to a variety of target dimensions, depending on the new pallet specification. Within a new pallet, however, we typically do not see more than 1/16-inch (plus or minus) component size variation. The used parts sampled during this study reflect the wide variation of target dimensions produced by new pallet manufacturers. Table 4 shows the results of measuring the used pallet parts in the sample.

Typical bending failure of a used deck board is often at the location of the middle set of nail holes. The nail holes along the top and bottom edge of the used stringers contain stubs and do not seem to significantly affect average bending strength and stiffness.

In general, deck boards ranged from 3/8-inch to 1-inch in thickness. Stringers ranged from 15/16-inch to 1¾-inches in width and 3.1 to 3.9 inches in height. Without sortation, used part dimensions within a pallet would be much more variable than the 1/16-inch (plus or minus) typical of new parts.

Also, accurately predicting pallet performance using PDS will be difficult without size sortation. Size variation also leads to material handling and packaging inefficiencies. Uneven stringer heights leads to uneven pallet decks. Excessive variation of deck board thickness within a pallet deck creates stress concentrations for products supported by the uneven surface. The recommended maximum difference in deck board thickness for a pallet deck is 0.25 inches (ASME MH1, Part 10). Manufacturers of remanufactured and combo pallets would be encouraged to sort used parts by size on order to gain maximum benefit from the PDS program and to improve material handling efficiency.

Comparative Flexural Strength and Stiffness of Used and New Pallet Parts

The physical and mechanical properties of new (green and air dried) and used Eastern oak pallet parts are shown in Table 1. The new, green and air-dried, oak pallet parts were evaluated in previous studies in 1986 and 1998.

Surprisingly, used oak parts were stronger and stiffer than new oak parts!

Table 2: Average Flexural Properties for Various Groupings of Used Pallet Deckboards.

Grouping	% of sample	Modulus of Rupture		Modulus of Elasticity		Specific Gravity	
		Average (psi)	Tukey's** Distribution	Average (million psi)	Tukey's** Distribution	Average	Tukey's** Distribution
All species	100%	8721 (38%)*	--	1.582 (41%)	--	0.603 (20%)	--
AU Hardwoods	76%	9388 (34%)	A	1.646 (38%)	A	0.640 (17%)	A
softwood	24%	6662 (42%)	B	1.393 (35%)	B	0.488 (19%)	B
Oak	33%	9606 (31%)	A	1.695 (39%)	A	0.702 (9%)	A
All other hardwood species	42%	9223 (36%)	A	1.606 (37%)	A	0.593 (18%)	B
Softwood	24%	6662 (42%)	B	1.393 (35%)	B	0.488 (19%)	C

* Numbers in parentheses are the Coefficient of Variation.
** Average observations with the same letter A, B, or C are not statistically different.

This was primarily due to the differences in moisture content. The strength and stiffness of lumber increases as it dries below the fiber saturation point (25% to 30% moisture content). Most new parts are green and above 25-30% MC. The average moisture content of the wood in used pallet parts was only 11-12%. New air dried parts in the previous studies had been carefully conditioned to a target 17-18% moisture content, which simulates a typical air dried pallet at initial sale.

Note that if new parts are dried to 11-12% moisture content, they will be slightly stronger and stiffer than used parts. This difference is likely due to the consistent presence of two or three nail holes in the middle of each used deck board. These holes in the middle of the used deck boards appear to act as defects, and this is the region of maximum bending moment during testing.

Typical bending failure of a used deck board is often at the location of the middle set of nail holes. Figure 2 shows typical nail holes in both used stringers and deck boards. The nail holes along the top and bottom edge of the used stringers contain stubs and do not seem to significantly affect average bending strength and stiffness.

The flexural properties of used oak parts were much more variable than that of both green and air dried new oak parts. The greater variation within used parts may also be a result of holes from pallet fasteners, primarily nails.

Grouping Used Pallet Parts for Use in the PDS Program

We stated earlier that species selection is a major factor in designing new wood pallets. Used components, however, are comprised of parts from throughout the country. Most recyclers do not segregate by species. Some companies do separate softwood from hardwood, or oak from other hardwoods, but further species segregation is difficult to economically achieve. Therefore, we wanted to determine what level of segregation we should attempt in order to optimize the performance of pallets manufactured from used parts.

Tables 2 and 3 list the material properties for several such potential segregations for potential use in a future version of the Pallet Design System. The used part groups evaluated were "All Species," "Hardwoods versus Softwoods," and "Oak versus Other Hardwoods versus Softwoods."

For both deck boards and stringers, the mean MOR (strength), MOE (stiffness), and specific gravity of mixed hardwoods were significantly greater than that of softwoods. Oak parts were also

Table 3: Average Flexural Properties for Various Groupings of Used Pallet Stringers

Grouping	% of sample	Modulus of Rupture		Modulus of Elasticity		Specific Gravity	
		Average (psi)	Tukey's** Distribution	Average (million psi)	Tukey's** Distribution	Average	Tukey's** Distribution
AU species	100%	7253 (48%)*	—	1.149 (43%)	--	0.596 (24%)	—
Hardwood	65%	8159 (46%)	A	1.363 (36%)	A	0.647 (19%)	A
Softwood	35%	6337 (46%)	B	0.906 (49%)	B	0.458 (20%)	B
Oak	35%	8464 (45%)	A	1.428 (36%)	A	0.691 (10%)	A
All other hardwood species	30%	7765 (48%)	A,B	1.283 (36%)	A	0.589 (25%)	B
Softwood	35%	6337 (46%)	B	0.906 (49%)	B	0.458 (20%)	C

* Numbers in parentheses are the Coefficient of Variation.
** Average observations with the same letter A, B, or C are not statistically different.

significantly better than softwoods, but the average flexural properties of oak were not significantly different from the other mixed hardwoods. This suggests that recyclers could more accurately predict the performance of remanufactured pallets by sorting hardwoods from softwoods, but other sorts — such as oak from the other hardwoods — is of little practical value. Sortation by component size is also necessary.

Research Conclusions

- The species mix of used pallet parts was very similar to the mix and volume of species used to assemble new pallets.
- Used pallet parts sampled from any given region of the country contain species from all regions, reflecting the transcontinental movement of pallets.
- The variation of used pallet part thickness and width is many times that of new parts in assembled pallets. Dimension sorts will improve the design and performance predictions of pallets manufactured with used parts.
- The average flexural strength and stiffness of used pallet parts (at 11-12% moisture content) is better than new air dried parts at 17-18% moisture content and is greater than new green parts due to the differences in moisture content. When adjusted to the same moisture content, new deck boards are stronger and stiffer than used parts due to the presence of nail holes in the used parts. Because of these nail holes, the flexural strength and stiffness of used deck boards and stringers varies more than new deck boards and stringers.
- The most practical and effective grouping of used parts, by species, will be the separation of hardwood parts from softwood parts. Sorting used parts by species is difficult, and given the relative differences in flexural properties, would not significantly improve pallet performance prediction estimates.
- Performance estimates of pallets containing used parts should reflect the higher levels of variation of component flexural strength, stiffness, and dimensions.

(Editor's Note: John Clarke is a research associate at Virginia Tech, where he is also director of the Center for Unit Load Design. Marshall White is a professor at Virginia Tech and also is director of the pallet and container research laboratory. Phil Araman is a project leader for the U.S. Forest Service Southern Research Station at Virginia Tech. For a copy of the fill article as published in the Forest Products Journal, please call John Clarke at (540) 231-5370.)