Comparative performance of new, repaired, and remanufactured 48- by 40-inch GMA-style wood pallets

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Abstract

The pallet repair industry has been growing at significant rates in the United States. It has been estimated that the repair industry received 299 million pallets in 2001, and a majority went back into the marketplace as repaired or remanufactured pallets. Many question how well these pallets perform when compared to new pallets. The purpose of this research was to provide a benchmark for the relative performance (strength, stiffness, and durability) of new, repaired, and remanufactured 48- by 40-inch, three-stringer, partial four-way, flush, non-reversible, Grocery Manufacturers of America (GMA)-type pallets. GMA-type pallets were selected because they are the most common wood pallets repaired and remanufactured in the United States. The pallets in this study were sampled in 1995 from locations throughout the United States. Repaired pallets were separated into three grades. Performance tests showed differences between new, repaired, and remanufactured pallets. Bending strength and stiffness spanning pallet stringers declined and variation increased as repair quality decreased. This was expected because repair quality is segregated according to stringer repair level. There was little difference in the bending strength and stiffness of new and used GMA-style pallets spanning the deckboards. Stringer repair had a small effect on performance when spanning deckboards. Remanufactured pallets were less strong and stiff due to nail holes in many of the used parts. The new, remanufactured, and Grade A GMA-type wood pallets performed similarly when tested for structural durability and should have comparable service life in use. Greater standardization of repair practices would result in performance improvements of repaired wood pallets.

In 2001, an estimated 433 million new wood pallets were manufactured in the United States, consuming an estimated 6.6 billion board feet (BBF) of hardwood and softwood lumber, cants, and parts (Bejune et al. 2002). Subsequently, another industry has emerged that specializes in the repair and remanufacture of wood pallets. This rise of the wood pallet repair and remanufacture industry is in large part the result of increasing landfill fees, recycling mandates, and a perceived market opportunity. In 1999, pallet recyclers recovered an estimated 299 million wood pallets, or approximately 4.46 BBF of recovered pallet parts for repair (Bejune et al. 2002). Of the pallets received for repair, 66 percent were multiple-use grocery pallets, or so-called Grocery Manufacturers of America "(GMA)-type" 48- by 40-inch, three-stringer, non-reversible, partial four-way, flush pallets (Bejune et al. 2002). Standard grades and repair methods for repaired pallets are specified in the American Society of Mechanical Engineers (ASME) MH1-Part 3 Wood Pallets, but the performance of repaired pallets is undocumented (ASME 2000).

A previous study investigating the performance of pallet parts recovered from used wood pallets concluded that average flexural strength and stiffness of used pallet parts varies significantly, but is generally less than parts manufactured from new material when adjusted for moisture content. This lower strength and stiffness were due to the presence of nail holes (Clark et al. 2001). This study also indicated that the quality of

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used hardwood parts was better than that of used softwood parts, and that there is no significant difference in the grade characteristics of new and used hardwood and softwood pallet parts in general. However, the presence of significant variation in used pallet part deckboard thickness and stringer width indicates the need for dimension sorts prior to using salvaged parts. Also, due to the difficulty of separating parts on the basis of species, it is most practical to group parts into simple hardwood and softwood categories since further species separations would contribute little to pallet performance criteria (Clark et al. 2001).

The purpose of the present study is to benchmark the relative performance (strength, stiffness, and durability) of new, repaired, and remanufactured GMA-type pallets sampled from locations throughout the United States. The test specimens were sampled and tested during 1995 and 1996. Although this research was previously accepted for publication, the authors postponed resubmission until now to allow a similar study by Clark et al. to publish first (Clark et al. 2001). Changes in raw material and repair procedures may have occurred since the time of this study. Readers are cautioned when applying the results from this study to new and repaired pallets that differ from those tested. The pallets tested, however, were in compliance with current industry standards (ASME 2000).

Materials and methods

Pallets tested

All of the test pallets were GMA-type, 48- by 40-inch, three-stringer, partial four-way, flush, non-reversible designs. Three distinct groups – new, repaired, and remanufactured – were sampled. The description of each group is:

- New – pallets manufactured of new, unused lumber, cants, or parts.
- Repaired – "Used" pallets, or pallets that have supported at least one unit load, been recovered, repaired if necessary, and returned to the marketplace. Deckboards and stringers may have been renailed, repaired, or replaced. Repaired pallets were further differentiated into three quality grades, described later in the text.
- Remanufactured – pallets manufactured of parts salvaged from disassembled, used pallets.

New pallets were sampled from 11 locations in California, Florida, Missouri, New York, Ohio (two mills), Oregon, Pennsylvania, Texas, Virginia, and Wisconsin. Remanufactured pallets were obtained from nine locations in Arizona, California, Illinois, Minnesota, Missouri, Ohio, Texas, West Virginia, and Wisconsin. Repaired pallets were sampled from 13 locations in Arizona, California, Florida (two mills), Illinois, Minnesota, New Hampshire, Ohio, Pennsylvania, Tennessee, Texas, Virginia, and Wisconsin. Repaired pallets were typically differentiated by quality. Representative pallets of each repair quality or grade were sampled at each location. The two general types of pallet repair were deckboard repair and stringer repair. Deckboard repairs included replacement with new or used boards, or simply re-nailing a loose deckboard to stringer connection. Although deckboard repairs were more prevalent, the repair industry typically segregated pallet grades according to the type and number of stringer repairs. The stringer repairs observed in the test pallets were:

- *replaced stringer* – removal of damaged stringer and replacement with a full length new or used stringer. Top and bottom deckboards were nailed to replaced stringers.
- *full companion stringer* – full length (approx. 48 in) new or used stringer placed adjacent to the damaged stringer. Top and bottom deckboards were nailed to the companion stringer (**Fig. 1**).
- *half companion stringer* – half length (approx. 24 in) new or used stringer segment placed adjacent to the damaged stringer and connected by nailing the applicable top and bottom deckboards to the half stringer (**Fig. 2**).
- *plug companion* – any wood companion shorter than a half stringer or any unnotched block placed adjacent to the damaged stringer and connected by nailing the applicable top and bottom deckboards to the plug (**Fig. 3**).
- *metal plate* – similar to metal plates used in the roof and floor truss industry. Typically, a pair of plates were used, one on each side of a stringer split, and plate teeth were hydraulically pressed into the damaged stringer (**Fig. 4**).

Repair practices vary considerably. The number of repaired pallet grades used by manufacturers varied from 1 to 11. However, the most common number of grades was 3. The names assigned to pallet repair grades also varied considerably. Standard repair practices are lacking in commerce. Although stringer repair was the industry-accepted method of separating grades, the

Figure 1. — Example of full companion stringer repairs adjacent to center and outer stringers.

Figure 2. — Example of half companion stringer repair.

number and quality of repairs within a grade was not consistent between manufacturers, especially in the lower grades of repair. For example, one manufacturer's Grade B pallets may have similar stringer repairs to another manufacturer's Grade C repairs. To achieve the objectives of this research, it was necessary to develop a single set of repaired pallet groupings. These were called Grade A, Grade B, and Grade C. The repaired pallet grades used in this study are described as:

- *Grade A* – Samples contained pallets with stringer metal plate repairs, but no companion member repairs. Deckboard repairs were acceptable, but top and bottom leadboards were nominal 6 inches wide.
- *Grade B* – Samples contained at least some pallets with one full length or half-length companion member (stringer) per opening, and a maximum of two per pallet. Plugs were not acceptable. Metal plate repair and all deckboard repairs were acceptable.
- *Grade C* – Samples contained at least some pallets that did not meet the above criteria for Grade A and Grade B. All repairs, including plugs, were acceptable.

Flexural strength and stiffness tests

Pallets were subjected to flexural strength and stiffness tests simulating warehouse racked storage according the methods outlined in the American Society for Testing and Materials (ASTM) D 1185, Section 8.4 (ASTM 1994). The two bending test setups were:

1. pallets suspended or racked across the stringers (RAS) at a 44-inch free span and
2. racked across the deckboards (RAD) using a 36-inch free span.

These setups represent common modes of pallet support in warehouses. A full-coverage, uniformly distributed flexible load was applied until pallet failure or the machine capacity of 11,000 pounds was achieved (Mackes et al. 1995). Maximum load and initial stiffness were determined from force/deflection diagrams.

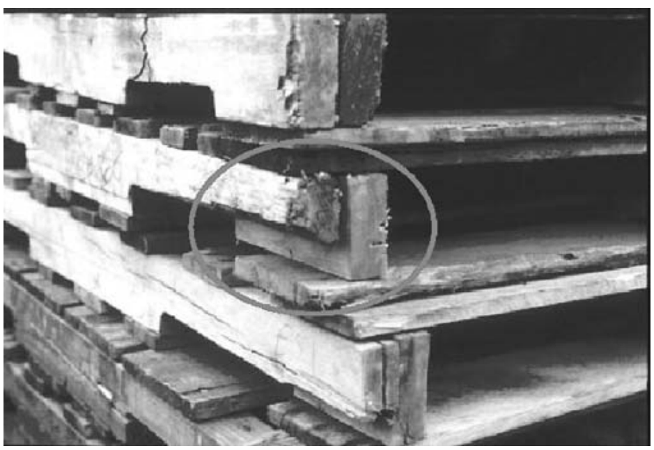

Figure 3. — Example of plug companion stringer repair.

Figure 4. — Example of metal plate stringer repairs.

Resistance to rough handling in the VPI FasTrack

The VPI FasTrack is a simulated grocery warehouse and shipping environment operated by the Pallet and Container Research Laboratory at Virginia Tech. The grocery industry, and likewise the VPI FasTrack, are considered relatively harsh pallet handling environments (Cao 1993). The test simulates idle pallet storage, palletizing, shipping, transport, receiving, and three types of storage: static rack, flow rack, and block stacking.

Pallets were handled in the FasTrack with a 3,000-pound capacity forklift and 4,000 pound capacity electric pallet jack. Each pallet supported a 1,500-pound, full-coverage, uniformly distributed, semi-flexible unit load. Each FasTrack cycle simulated a typical grocery pallet trip from manufacturing to retail, and included 13 handlings with the forklift or pallet jack. After every 10 cycles (130 handlings), the empty pallet was dropped from a 5-foot-high pallet stack. Records were kept after each cycle of any damages occurring to the pallet components. Several equipment operators were used during the course of testing.

The only repairs performed during the FasTrack tests were re-nailing loose deckboard/stringer joints. Damaged deckboards and stringers were not replaced with new components. When re-nailing loose joints no longer restored the pallet to a functional state in FasTrack, the pallet was considered no longer functional and testing was stopped.

Research results

Table 1 contains the physical properties of the test pallets. At the time of this study, the average new pallet sampled for the study contained thinner deckboards and less deckboard coverage than the average repaired or remanufactured pallet. This reflects a manufacturing trend that impacts the failure integrity of used GMA-type pallets in the industry. New pallets at any point in time become the raw material of used pallets in the future. Otherwise, the physical characteristics of the new, repaired, and remanufactured pallets were similar at time of testing.

Pallet bending strength and stiffness

Spanning the pallet stringers. — **Table 2** shows the measured static strength and stiffness of the new, remanufactured, and repaired pallets when tested in the RAS configuration. Typical failure is at the location of the notches. In general, the average new pallet was stronger and stiffer spanning the stringers than any grade of repaired or remanufactured pallets. The level of variation of strength and stiffness increased as grade or quality of repair decreased. Note that, within individual mills, variation was much lower for new pallets than repaired or remanufactured pallets. This increase in variation reflects the

Table 1. — Average physical properties of the new, remanufactured and repaired pallets sampled from the United States at the time of testing.[a]

Pallet grade	Replicates	Average							
		Weight	Moisture content	Stringer height	Stringer width	Deckboard thickness	Range of deckboard thickness within a pallet	Top deck coverage	Bottom deck coverage
		(lb)	(%)	(in.)				(%)	
New	332	48.6 (16%)	16.8 (73%)	3.588 (3%)	1.375 (5%)	0.614 (9%)	0.092 (56%)	60 (3%)	45 (3%)
Remanufactured	365	44.8 (14%)	10.8 (40%)	3.502 (4%)	1.367 (11%)	0.632 (15%)	0.192 (50%)	65 (18%)	43 (17%)
Grade A repaired	570	48.1 (14%)	11.6 (28%)	3.519 (4%)	1.391 (10%)	0.649 (11%)	0.147(63%)	66 (12%)	46 (7%)
Grade B repaired	239	50.3 (14%)	11.9 (25%)	3.516 (3%)	1.422 (9%)	0.657 (9%)	0.158 (61%)	65 (12%)	45 (8%)
Grade C repaired	353	46.4 (18%)	10.2 (26%)	3.51 (4%)	1.396 (11%)	0.642 (13%)	0.186 (55%)	65 (15%)	43 (13%)

[a] Numbers in parentheses are coefficients of variation (COV) in percent. All COV values represent between mill variations. Within mills, properties of new and remanufactured pallets experienced significantly less variability, while the variability of repaired pallets within mills was similar to between mill variability.

Table 2. — Relative flexural bending strength and stiffness of new, repaired, and remanufactured GMA-type pallets while spanning the stringers.

Pallet grade	Replicates	Average performance	Average COV[a] all mills	Average COV within mill	Fisher's pairwise comparisons[b]	5% LEL[c]	Performance of 5% LEL vs. new pallets
				Strength (lb)			
New	168	4,807	35%	20%	A	2,038	--
Remanufactured	143	4,103	35%	32%	B	1,759	–14%
Grade A repaired	212	4,399	38%	36%	B	1,650	–19%
Grade B repaired	84	4,433	41%	36%	B	1,454	–29%
Grade C repaired	132	3,767	45%	39%	C	995	–51%
				Stiffness (lb/in.)			
New	168	9,064	22%	--	A	5,790	--
Remanufactured	143	7,101	27%	--	B	3,721	–36%
Grade A repaired	212	7,326	34%	--	B	3,269	–44%
Grade B repaired	84	6,912	41%	--	B	2,211	–62%
Grade C repaired	132	6,166	42%	--	C	1,856	–68%

[a] COV is coefficient of variation.
[b] Fisher's pairwise comparison results significant at the 5% level.
[c] Lower exclusion limit (LEL) = average performance – (1.645 × standard deviation).

influence of multiple-site repairing of these pallets. Lower qualities of repaired pallets (Grade B, and to a greater extent, Grade C) were likely repaired more often and at different locations representing different repair methods.

Fisher's Least Significant Difference (LSD) pairwise comparison (5% significance level) was used to determine differences in average RAS strength and stiffness between the pallet groups. New pallets were statistically stronger and stiffer when loaded in the RAS orientation. Remanufactured, repaired Grade A, and repaired Grade B pallets were not significantly different in strength or stiffness suspended across the stringers. Grade C repaired pallets were the weakest and exhibited the lowest stiffness.

A comparison of performance based on average observations is misleading, however, because the level of performance variation differs among the grades of repair. In general, the properties of repaired and remanufactured pallets were much more variable than new pallets. A better measure of the relative performance capability of new and used or repaired pallets is the performance of the weakest 5 percent of samples, known as the 5th percent lower exclusion limit (5% LEL).

Table 2 shows 5 percent LEL for the new, remanufactured, and repaired pallet grades. Based on this measure, remanufactured, Grade A, B, and C repaired pallets were 14, 19, 29, and 51 percent weaker than the comparable new GMA "multiple-use" pallets when suspended in racks across the pallet stringers. These same pallets exhibited only 64, 56, 38, and 32 percent of the stiffness of the comparable new GMA pallets. These differences in performance are not surprising since stringer integrity will influence the strength and stiffness of pallets spanning stringers in warehouse racks and because the typical industry repair grades segregated pallets according to stringer repair.

Spanning the pallet deckboards. — **Table 3** contains the relative static strength and stiffness of the new, remanufactured, and repaired pallets when suspended in the RAD configuration. The typical failure mode was a bending failure of the top or bottom pallet deckboards at mid-span. This type of failure

Table 3. — Relative bending strength and stiffness of new, repaired, and remanufactured GMA-type pallets while spanning the pallet deckboards.

Pallet grade	Replicates	Average performance	Average COV[a] all mills	Average COV within mill	Fisher's pairwise comparisons[b]	5% LEL[c]	Performance of 5% LEL vs. new pallets
				Strength (lb)			
New	154	7,732	27%	18%	C	4291	--
Remanufactured	164	6,882	28%	19%	D	3671	–14%
Grade A repaired	195	8,490	26%	22%	B	4929	+15%
Grade B repaired	85	9,095	19%	19%	A	6315	+47%
Grade C repaired	119	7,746	29%	27%	C	4060	–5%
				Stiffness (lb/in.)			
New	154	4,529	26%	--	C	2571	--
Remanufactured	164	4,050	35%	--	D	1729	–33%
Grade A repaired	195	4,876	32%	--	B	2343	–9%
Grade B repaired	85	5,448	25%	--	A	3240	+26%
Grade C repaired	119	4,748	36%	--	B C	1910	–26%

[a] COV is coefficient of variation.
[b] Fisher's pairwise comparison results significant at the 5% level.
[c] Lower exclusion limit (LEL) = average performance – (1.645 × standard deviation).

Table 4. — Relative resistance of new, repaired, and remanufactured GMA-type wood pallets to rough handling in the VPI FasTrack.[a]

Pallet grade	Replicates	Average number of FasTrack handlings until first repair[b]	Average number of handlings until pallet no longer functional in FasTrack[c]	Percentage of pallets within a grade requiring the first repair at the following locations: Top leadboard	Bottom leadboard	Top interior board	Bottom interior board	Stringer end foot	Stringer between notches
				(%)					
New	150	31 (113%)	57 (129%)	30	5	1	0	57	7
Remanufactured	119	34 (110%)	70 (100%)	24	12	0	3	50	10
Grade A repaired	152	34 (129%)	64 (94%)	30	7	0	7	47	9
Grade B repaired	69	24 (80%)	52 (71%)	50	3	0	4	33	10
Grade C repaired	98	26 (157%)	46 (110%)	45	8	1	0	39	7

[a] FasTrack is a simulated grocery warehouse and shipping environment consisting of 13 handlings per cycle.
[b] FasTrack repair consists of renailing loose deckboards. No stringer repairs or new deckboards are used. The damage levels indicating repair used in the study are described in ASME MH1-Part 3 Wood Pallets.
[c] See footnote b. When these type repairs fail to restore the usability of the pallet in the FasTrack, testing is stopped. (i.e., if stringer end foot damage prevents racking, testing is stopped).

was the most common for all pallet quality levels, including new pallets. The average Grade B repaired pallets were the strongest and stiffest of the pallets tested.

Between sampling sites, the variation in stiffness, but not strength, increased from new to Grade C repaired pallets. Within sampling sites, however, the variation of strength and stiffness was significantly lower for new pallets. This reflects the increased variation when a mixture of pallets and lumber from various sources are combined during repair at multiple sites.

The average pallet strength and stiffness (RAD) was compared using a Fisher's pairwise analysis at the 5 percent significance level. The average Grade B repaired pallet was significantly stronger than the other pallets tested. Grade A repaired pallets were significantly stronger than new and Grade C pallets. Remanufactured pallets were the weakest. Grade B pallets were also the stiffest when suspended across the deckboards in bending. Grade A and Grade C pallets were comparable in stiffness, while the remanufactured pallets were again the lowest. It is likely the remanufactured pallets performed poorly due to the presence of nail holes in many of the used parts. This has been documented by Clarke et al. (2001).

The 5-percent LELs were calculated based on average values and the between mill or sampling site variation. From **Table 3** it is evident that the Grade A and B repaired pallets performed best. The reason the higher grades of repaired GMA pallets perform as well as or better than the new GMAs in this mode of support is primarily due to the fact that the repaired pallets were drier and contained 7 percent thicker deckboards and 10 percent more deckboard coverage than the new GMAs (**Table 1**). This again reflects that the "repaired" pallets at the time of this study contained components from "new" pallets that were produced at a time when thicker parts were more common.

Relative resistance to rough handling in the VPI FasTrack

Table 4 contains the results of testing the resistance of new, remanufactured, and repaired pallets to rough handling in the VPI FasTrack Unit-Load Material Handling Simulator. Because of the large performance variation, only trend analysis was feasible. Stresses imposed on pallets during handling are quite variable in magnitude and duration. The FasTrack simulator reflects this "real world" variation. Therefore, some of the variability in performance observed during these tests reflects the influence of the test method. The average Grade A pallet and remanufactured pallet survived a greater number of handlings than the new, Grade B, and Grade C repaired pallets.

Table 4 also includes the location of initial repairable damage. Cracking and breaking of top leadboards and splits occurring in the ends of the stringers constituted 75 to 85 percent of the initial damage. Damage to the bottom leadboards, top and bottom interior deckboards, and stringer notches occurred during testing, but typically followed damage to the stringer ends or top deck leadboards. As repaired pallet grade declined, the percentage of initial damage shifted from the stringers to the top leadboards. Assuming that the lower quality repaired pallets represented older pallets repaired more often, this trend is likely due to the increasing number of repaired top leadboards. An examination of the fasteners indicates that leadboards are repaired with lower quality fasteners than those found in unrepaired leadboards that still contain the fasteners used when the pallet was new. Repair fasteners were smaller, i.e., the nails used in repair were typically 12.5 gauge (approx. 0.099-in wire diameter), whereas original nails were 11.5 to 11 gauge (approx. 0.113 to 0.120-in wire diameter). These smaller repair nails drive more easily into the dry hardwood stringers when broken leadboards are replaced during repair. Unfortunately, such smaller nails also bend more easily. Subsequently, joints are less resistant to impacts by forklifts as they contact the lead edge of deckboards applying shear stresses on joint connections. Deckboards poorly attached to companion half stringers and plugs compounded this problem, further reducing resistance to failure.

Conclusions

- The remanufactured and Grades A, B, and C repaired pallets tested were not as strong or stiff as new GMA pallets when spanning pallet length in simulated warehouse racked storage.
- There was little difference in the bending strength and stiffness of new and used GMA-type pallets spanning the pallet deckboards.
- Remanufactured pallets were less strong and stiff due to nail holes in many of the used parts salvaged from previously nailed pallets.
- The new, remanufactured, and Grade A GMA-type wood pallets were similar in resistance to rough handling. These pallets should have a comparable service life when used in warehouse and shipping environments.
- Variation in strength, stiffness, and durability was greater in used pallets than in new pallets due to greater variation in component sizes and quality. Standardization of repair practices would result in performance improvements of repaired and remanufactured wood pallets.

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