Reinforcement of wood pallets with metal connector plates

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Abstract

Reinforcement of the damage-prone areas of wood pallet stringers with metal connector plates (MCPs) may increase useful pallet life or permit use of less desirable wood species. This will improve the utilization of our timber resources and landfill space. Whole pallets and individual stringers, reinforced at the inner notches, were tested in static bending. Stringer end segments, reinforced on the sides, were tested for resistance to fork tine impact. Reinforced stringers had greater strength, and in some cases greater stiffness, than unreinforced stringers. Reinforced end feet withstood a greater number of tine impacts to failure than did unreinforced end feet. Wood species had a greater influence on MCP reinforcement performance than did stringer width for all components. In general, tests of whole pallets, after accelerated handling, supported the results from component tests. This suggests that component testing may be a practical means of assessing the effect of reinforcement on pallet performance.

Over 560 million wood pallets were manufactured in the United States in 1992 (8), making pallets second only to the housing industry in lumber consumption (13). Properly designed pallets will withstand many load cycles, but over time, damage may occur. As society becomes more concerned with waste, and restrictions on landfill space increase, disposal of these damaged pallets will become more difficult and costly.

Methods of repairing damaged pallets with metal connector plates (MCPs or plates) were investigated and reported in another article (5). MCPs applied to damage-prone areas of the pallet during manufacture, however, may also prevent or delay the initial damage. This reinforcement has the potential to extend the service life of wood pallets or improve service performance. Reinforcement may also allow the substitution of stringers made from underutilized, weaker species for more traditional, but costlier, woods.

Although many parts of a pallet maybe damaged, this research examined only notched stringers in stringer-class pallets. Deckboards are damaged more frequently, but replaced more easily than stringers (10). Currently, MCPs are not used for deckboard reinforcement.

With notched pallet stringers, the most common damage is cracking at the interior notches. Typically, two notches are cut in stringers to satisfy a common requirement for forklift tine entry from any side of the pallet. These notches create stress risers, causing a notched-stringer pallet to have much less strength than an equivalent pallet with unnotched stringers. Pallets are commonly used in a racked-across-stringer (RAS) storage mode, where the stringers can fail at the

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notches, resulting in potential personal injury or damage to products. Stringer-class pallets, both notched and unnotched, also commonly fail at the stringer end (or foot) due to forklift tine impacts during entry or sluing (turning) of the pallet with the forklift. MCPs, applied at the notches and ends of stringers, might reduce the possibility of failure and extend the useful life of the pallet.

The National Wooden Pallet and Container Association (NWPCA), recognizing the importance of quality assurance in the use of MCPs for pallet repair and reinforcement, issued *Interim Guidelines for the Use of Pallet Metal Connector Plates* (7). The development of a comprehensive standard, however, requires better knowledge of the possible benefits that MCP reps.irand reinforcement might have with different pallet and plate application variables. Additionally, standard test procedures and performance criteria are needed to enable the user to rationally compare competing MCP products and procedures.

Virginia Tech recently completed a preliminary study designed to provide technical support to this development issue. This paper describes the portion of this study that evaluated reinforcement of new, undamaged notched stringers with MCPs.

Background

A review of literature did not find any significant, nonproprietary studies on the effectiveness of MCPs for reinforcing stringer notches, although some attention has been paid to stringer end foot reinforcement. Smith (11) conducted impact tests of stringer end feet reinforced with MCPs pressed into the end grain of Australian hardwoods and Douglas-fir. Reinforced and unreinforced stringer ends were impacted with a simulated forklift tine attached to a pendulum arrangement. Studies were conducted to determine the best plate profile and comparisons were made between plated and unplated samples. On a basis of energy absorbed and relative plate cost, a 1.2-mm- (0.047 -in.) thick plate was identified as the best performer. The plate was 44 mm wide by 88 mm long (1.73 in. by 3.46 in.) and had 9-mm- (0.354 in.) long teeth. Stringers reinforced with this plate absorbed tine impacts of 50 percent greater velocity than those absorbed by unreinforced samples. This is equivalent to a 125 percent increase in absorbed energy. Smith (11) also found that tests where tine impact was random over the depth of the stringer end gave results (on a ratio basis) similar to tests where impact was consistently at mid-depth. Smith relates anecdotal evidence that stringer end grain plating has extended average pallet service life threefold, and reduced pallet maintenance by 70 percent.

Methods and materials

Because the strength and stiffness of stringer-class pallets depends directly on the properties of stringers, tests were conducted to assess: 1) the static flexural strength and stiffness of reinforced notched stringers; and 2) the impact resistance of reinforced stringer ends (called end feet). In general, new undamaged components (stringers or ends) of a given species and width were separated into two groups. One group was reinforced with MCPs and the other was left unplated as a control. Both groups were tested to failure. Properties of reinforced components were compared with the equivalent control groups to determine the influence of reinforcement.

Any performance increase due to reinforcing stringers should approximate the expected increased performance of reinforced whole pallets in service. To explore this hypothesis, reinforced and control pallets were subjected to an accelerated field service history and then tested in bending.

Materials

Pallets and pallet components. — For this paper, a stringer refers to a notched pallet stringer, either 1-1/2 inches or 2-1/2 inches wide, 3-1/2 inches in height, and 48 inches long. Each stringer had two notches, located 6 inches from each end, 1-1/2 inches deep, and 9 inches long with a 1/2-inch fillet radii. End foot segments, 12 inches long, with 6 inches of actual foot and 6 inches of above-notch area, were cut from the ends of stringers. Test pallets were 48 by 40 inches, stringer-class, flush, nonreversible, with partial four-way entry. Each contained three 1-1/2-inch-wide stringers, as described previously, with seven top and five bottom deckboards, all 5/8 inch thick. A common deckboard and nailing specification was used. Details may be found in Clarke (4).

All test pallets and components were donated by Virginia pallet manufacturers. Stringer lumber met or exceeded Pallet Design System Grade 3 (6) or the equivalent NWPCA Grade 4 (9). End feet conformed to the applicable parts of these grade rules.

Three species groups of wood components were tested, mixed eastern oak *(Quercus* spp.), southern yellow pine *(Pinus* spp.), and yellow-poplar *(Liriodendron tulipifera).* Oak and poplar samples were obtained in the green condition; the pine was approximately 20 percent MC. Components were reinforced after procurement, then dried to 12 percent MC to maximize any wood shrinkage-plate withdrawal problems that might occur in used reinforced pallets. This moisture content, 12 percent, represents a practical average level for pallets after some time in service.

Metal connector plates

Various MCP designs for pallets were evaluated in the earlier repair study (5). For repaired notched stringers tested in static bending, no practical differences were found among competing plate designs. Therefore, a 3-inch by 3-inch, 6-tooth, round plug-type plate was selected (Table 1) for this part of the study. This plate, designated BN1, was designed for application between notch areas but was also used here for the side reinforcement of end feet.

Two end grain plates (EG1 and EG2), specifically designed for end foot reinforcement, were also evaluated in this study. Plate EG1, with relatively short teeth, was designed for hardwoods, whereas EG2, with

TABLE 1. — *Description of 20-gauge metal connector plates used to reinforce pallet stringers.*

Plate[a]	Size	Tooth length	Teeth per square inch	Tooth style
	------------(in.)------------			
BN1	3 by 3	0.374	4.4	6-tooth. round-plug type
EG1	1-1/4 by 3-l/4	0.360	10.3	2-tooth, staggered-slot type
EG2	1-1/4 by 3-l/4	0.455	8.1	2-tooth, staggered-slot type

[a]Plate names indicate use: BN = between the notches; EG = stringer end grain.

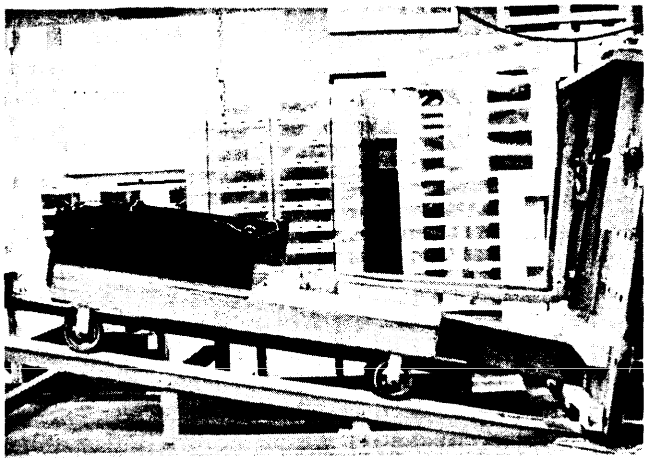

Figure 1. — Test setup for determining the impact resistance of reinforced and unreinforced stringer end feet.

longer teeth, is marketed for softwoods. These plates are described in Table 1.

Plate application

All BN1 plates were applied to pallet components with a modified portable hydraulic truss-chord plater. End grain plates were applied to whole stringers with a hydraulic press by the plate manufacturer. For whole pallets, MCPs were applied at a commercial pallet facility with a scissors-jaw type plater.

Stringers were reinforced with a pair of BN1 plates at each interior notch, for a total of four plates per stringer. End feet designated for side reinforcement were plated with one pair of BN1 plates, located 1 inch from the impact end. End feet designated for end grain reinforcement had one plate pressed into each end of a stringer. Whole pallets had 4 BN1 plates per stringer, as described previously, for a total of 12 plates per pallet. No end grain plates were used in the pallets.

Test methods

Static bending tests. — An MTS servo-hydraulic test machine under stroke control was used for all static bending tests. Stringers were supported over a span of 45 inches and loaded at third-points using a procedure and fixtures that generally conformed to ASTM D 198 (1) with a rate of deformation of 1 in./min. Additional details can be found in Clarke's thesis (4).

The properties measured for stringers were the static bending strength (lb.) and the static bending stiffness (lb./in.). Reinforced and unreinforced samples were tested to failure in the same manner and the properties were then compared to determine the benefit of reinforcement.

Dynamic impact tests. — An inclined-impact tester, described in ASTM D 880 (2), was used for impact tests of stringer end feet. The setup consisted of a four-wheel dolly on parallel rails inclined at a 10-degree angle from the floor (Fig. 1). ASTM D 1185 (3), Sections 43-48, outlines an impact test with this inclined tester for end feet of stringers in whole pallets. Testing of full-size pallets was not feasible due to a large number of replicates, and the test method was modified to accommodate end-foot segments. Typically, the end-foot specimen was placed top down on the dolly and supported at the sides and rear to prevent lateral movement at impact. The dolly weight was 250 pounds. Impact force was adjusted by moving the distance that the dolly traveled prior to end foot impact with the fork tine.

preliminary tests indicated the optimum travel distance for reinforced and unreinforced end feet was 6 inches, except that 2-1/2-inch-wide oak end feet required a 12-inch travel distance (4). This optimum point was selected to require multiple impacts to failure but also to complete testing in a reasonable time frame. Reinforced and unreinforced end feet were repeatedly impacted at the same point on the stringer end until failure. Failure occurred when the forklift tine split the foot, or when the MCP curled or exhibited tooth withdrawal greater than 1/4 inch from the wood surface. Impact resistance was defined as the number of tine impacts required to cause failure.

Pallet tests. — Whole pallets were subjected to an accelerated rough handling program and static bending test to failure. RAS static bending tests were conducted with an inflatable air-bag tester using procedures outlined in ASTM D 1185 (3), Sections 8-13. The air-bag tester applied a uniformly distributed load over the top surface of the pallet, which was supported over a span of 45 inches.

Two pallets were obtained for each test species. One pallet was designated for between-notch reinforcement and the second pallet was designated as a control. No end-foot reinforcement was used. Each pallet was loaded nondestructively with 1,000 pounds on the RAS air-bag tester to determine the initial stiffness.

All pallets were then subjected to an accelerated material handling test protocol (4) to simulate service exposure. Each cycle included 1) palletizing; 2) sluing; 3) loading and unloading from a trailer; 4) pallet jack and forklift movement; 5) RAS storage; 6) stacked

TABLE 2. — *Effect of species and width on the bending performance of notched stringers reinforced with 3-inch by 3-inch BN1 plates.*

Stringer width and species	No. of replicates[a]	Average unreinforced	Average reinforced	ANOVA p-value	SRF[b]	LSD[c] comparison
Maximum strength (lb.)						
l-1/2-in. oak	30/30	1,315 (7)[d]	2,286 (9)	0.0001	1.74	B
2-1/2-in. oak	30/30	1,951 (21)	2,416 (16)	0.0001	1.24	C
l-1/2-in, pine	40/40	781 (25)	1,540 (27)	0.0001	1.97	AB
2-1/2-in. pine	40/40	1,285 (21)	2,671 (25)	0.0001	2.08	A
1-1/2-in. poplar	30/30	1,295 (22)	1,745 (14)	0.0001	1.35	C
Stiffness (lb./in.)						
l-1/2-in. oak	30/30	3,023 (16)	4,247 (14)	0.0001	1.40	C
2-1/2-in. oak	30/30	4,906 (13)	5,211 (17)	0.2096	1.06	D
1-1/2-in. pine	40/40	2,018 (25)	3,795 (27)	0.0001	1.88	B
2-l/2-in. pine	40/40	2,876 (27)	6,571 (20)	0.0001	2.28	A
1-1/2-in. poplar	30/30	3,959 (12)	3,945 (14)	0.9150	1.00	D

[a]Unreinforced replicates/reinforced replicates.
[b]SRF = stringer reinforcement factor, which is a ratio of the reinforced value divided by the unreinforced value.
[c]Mean SRF values with the same capital letter are statistically similar (95% confidence).
[d]Numbers in parentheses are coefficients of variation in percent.

storage; 7) rolling on a conveyor; and 8) depalletizing. Each test cycle was designed to simulate one pallet trip (cycle) typical of that experienced by pallets in the dry grocery industry. Pallets for this study were cycled 30 times. It was assumed that the average pallet cycled six times per year, and this test was equivalent to 5 years of simulated pallet use.

After accelerated handling, pallets were tested to failure in static bending, as described previously, to determine their strength and stiffness.

Experimental design

The performance of reinforced stringers compared to unreinforced stringers was studied for various species and widths of stringers, end foot segments, and whole pallets. These are described in more detail in the results and discussion section.

In most substudies, two groups of samples with equal properties were desired. Random assignment was used rather than distribution using a nondestructive property such as stiffness because of poor correlation between notched stringer strength and stiffness. One sample group was reinforced with MCPs, and the other was left unplated as a control.

The effectiveness of plate reinforcement was expressed as a stringer reinforcement factor (SRF), calculated as:

$$SRF = \frac{Average\ Reinforced\ Property}{Average\ Unreinforced\ Property}$$

To justify the expense of reinforcement, one or more properties should have an SRF greater than 1. Minimum effective reinforcement must be an economic and practical decision, however, and is beyond the scope of this paper.

Results and discussion

Reinforcement between stringer notches

Effect of species and width. — Three species (oak, pine, and poplar) of 1-1/2-inch-wide stringers and two species of 2-1/2-inch-wide stringers (oak and pine) were evaluated. A group of reinforced and unreinforced samples was tested for each species and width. Results are given in Table 2.

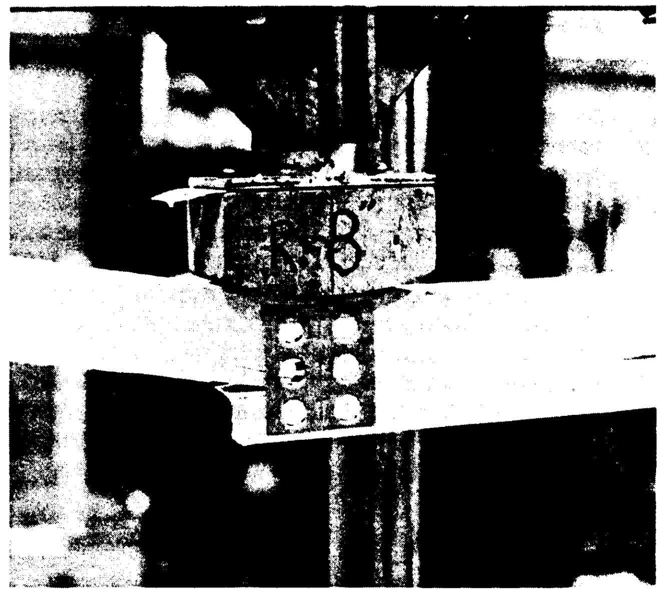

Figure 2. — Plated notch failure mode in reinforced stringers tested in bending.

The strength of reinforced stringers was greater than that of the unreinforced stringers for all species and widths tested. Reinforced stiffness was significantly greater in all groups except for 1-1/2-inch-wide poplar and 2-1/2-inch-wide oak, where there was no significant improvement with reinforcement. In general, strength is a more important property than stiffness with regard to satisfactory performance of pallets.

However, there are times when excessive deflection may cause product damage or slow the handling system.

Least Significant Difference (LSD) comparisons indicate that pine stringers were enhanced more by

MCP reinforcement than oak or poplar stringers, possibly because unreinforced pine failures were brittle, and MCP reinforcement reduced this brittleness. The 2-1/2-inch-wide oak and 1-1/2-inch-wide poplar gained the least from reinforcement. As width increased, the SRF values stayed the same or increased for pine but decreased for oak.

Most unreinforced stringers failed between the notches, with the crack beginning at an inner notch fillet. With reinforced stringers, this failure mode was restricted by the plates located at each inner notch. In over 75 percent of the tests, failure in reinforced stringers was associated with vertical cracks at a plated notch (Fig. 2). Tooth cutting by the plates contributed to this failure by reducing the net section and causing stress concentrations. Nevertheless, reinforced stringers failed at levels above those at which unreinforced stringers failed. About 10 percent of the pine stringers exhibited failure above the notch, usually caused by knots. Tooth withdrawal of plates was noted in about one quarter of the reinforced poplar stringers.

Note that these observations apply only to reinforcement with the 3-inch by 3-inch BN1 plate. However, in the companion study of pallet repair using six competing designs, the observed failure modes suggest that similar vertical crack failures could be expected with other rectangular plates.

Table 3 highlights some potential opportunities for species substitution. The average strength and stiffness of reinforced pine stringers was greater than that of the unreinforced oak stringers for both 1-1/2-inch and 2-1/2-inch widths. Reinforced, 1-1/2-inch-wide poplar stringers were stronger and stiffer than unreinforced oak stringers. This means that MCP reinforcement may permit substitution of notched Class B stringers (pine and poplar) for notched Class C stringers (oak) with respect to bending strength and stiffness. However, there could be other untested factors related to life expectancy and damage potential that may bear on potential substitution. Future research is needed.

Reinforcement of stringer end feet

Preliminary tests of 1-1/2-inch-wide stringer end feet reinforced with EG1 (oak) and EG2 (pine) indicated that forklift tine impacts caused the plates to curl, leaving teeth and sharp metal exposed (Fig. 3).

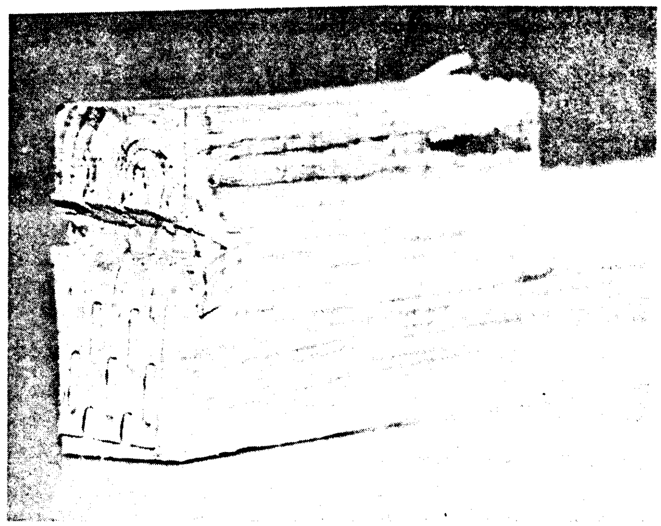

Figure 3. — Typical plate curling failure on end-grain MCP-reinforced foot after forklift tine impact testing.

TABLE 3. — *Potential for substituting MCP-reinforced pine or poplar stringers for unreinforced oak stringers based on bending performance.*

Group	Average maximum strength	Average stiffness
	(lb.)	(lb./in.)
1-1/2-in. oak — unreinforced	1,315 (7)[a]	3,023 (16)
1-1/2-in. pine — reinforced	1,540 (27)	3,795 (27)
1-1/2-in. poplar — reinforced	1,745 (14)	3,945 (14)
2-1/2-in. oak — unreinforced	1,951 (21)	4,906 (13)
2-1/2-in. pine — reinforced	2,671 (25)	6,571 (20)

[a]Numbers in parentheses are coefficients of variation in percent.

TABLE 4. — *Effect of species and width on the impact resistance of end feet from stringers reinforced with 3-inch by 3-inch BN1 plates.*

Stringer width and species	No. of replicates[a]	Impact resistance: Average no. of impacts before failure — Unreinforced	Reinforced	ANOVA p-values	SRF[b]	LSD[c] comparison
1-1/2-in. oak	20/20	3.25 (30)[d]	6.60 (37)	0.0009	2.03	A
2-1/2-in. oak	20/20	1.45 (35)	3.15 (33)	0.0001	2.17	- -[e]
1-1/2-in. pine	20/20	2.00 (28)	2.80 (34)	0.0064	1.40	B
2-1/2-in. pine	20/20	3.05 (36)	4.10 (27)	0.0048	1.34	B
1-1/2-in. poplar	20/20	2.10 (26)	4.45 (27)	0.0001	2.12	A

[a]20 unreinforced replicates; 20 reinforced replicates.
[b]SRF = stringer reinforcement factor, which is a ratio of the reinforced value divided by the unreinforced value.
[c]Mean SRF values with the same capital letter are statistically similar (95% confidence).
[d]Numbers in parentheses are coefficients of variation in percent.
[e]2-1/2-inch-wide oak was not included in the statistical analysis.

TABLE 5. — *Potential for substituting MCP-reinforced pine or poplar stringers for unreinforced oak stringers based on impact resistance of end feet.*

Group[a]	Average no. of impacts before failure
1-1/2-in. oak — unreinforced	3.25(30)[b]
1-1/2-in. pine — reinforced	2.80(34)
1-1/2-in. poplar — reinforced	4.45(27)

[a]2-1/2-inch-wide oak was tested at a different travel distance than 2-1/2-inch-pine, and no comparison between the two was made.
[b]Numbers in parentheses are coefficients of variation in percent.

After consulting with industry advisors, we concluded that this failure mode may be more dangerous to products or personnel than a damaged end foot. Test results also indicated that the end grain plate began to curl with fewer impacts than needed to cause end foot failure in an unreinforced foot. Therefore, further testing with end grain plates was suspended. Details of these tests are found in Clarke's thesis (4).

Three species (oak, pine, and poplar) of 1- 1/2-inch-wide end feet and two species (oak and pine) of 2-1/2-inch-wide end feet were evaluated. Two groups, one reinforced with plate BN1 and the other unreinforced, were tested for each species and width.

The results, shown in Table 4, indicate that plate reinforcement increased the impact resistance of all test end foot groups by 34 to 112 percent. Wood species influenced the SRF values more than did stringer width, with oak and poplar end feet gaining the most from reinforcement. Side plating the ends of stringers may have less practical value with pine than with other species, because pine end feet tended to split more easily when impacted by the tine and, even when reinforced, pine split between the plates.

The predominant failure mode for unreinforced feet was a straight split with the crack extending from one wide face of the stringer to the other. Side plate reinforcement prevented this failure. For reinforced oak and pine end feet, the predominant failure was still wood splits, but the splits extended between the narrow faces of the stringer and between the plates. Plates were still firmly attached to the wood. If deckboards had been nailed to the narrow face of the stringers, it is likely that nailing would exacerbate the vertical splitting.

For poplar reinforced feet, the predominant failure was plate tooth withdrawal. Tooth withdrawal was also a frequent failure mode with reinforced poplar stringers in bending, which suggests that a different plate design may be better suited for reinforcement of poplar. The tooth withdrawal is associated with the low density of poplar compared to oak. Fine stringers and feet, which had density similar to poplar in these tests, were brittle and the wood failed before plate teeth could pull out.

Reinforced 1-1/2-inch-wide poplar end feet withstood a greater number of impacts before failure than did the unreinforced 1-1/2-inch-wide oak end feet. The reinforced 1-1/2-inch-wide pine feet were equivalent in impact performance to the unreinforced 1-1/2-inch oak feet (Table 5). This suggests that MCP reinforcement of end feet might increase utilization of some Class B species (pine and poplar) when the impact resistance of a Class C species (oak) is sought. The impact performance of reinforced low-density species must be assessed in a service environment before specific conclusions can be drawn because damage to stringers also results from side impacts. Future testing of end foot reinforcement should include side impacts.

Reinforcement of pallets

Six pallets, two each of three species (oak, pine, and poplar) were used to test the effects of stringer reinforcement on pallet performance. One pallet of each species was randomly selected for reinforcement and the other was designated as an unplated control. The results are limited by the one sample for each species and treatment method (reinforced or control), but this initial investigation did yield some valuable observations.

After nondestructive testing in RAS bending, all six pallets were subjected to the accelerated handling protocol. No significant differences in damage levels were found between the reinforced and control pallets within a species. There were differences between species, but for all pallets, most damage was related to deckboards, which were not a focus of this study. Some end foot splitting was found, but no pallets were reinforced in this area. No between-notch cracks were found in any control or reinforced pallets. Further details are given in Clarke's thesis (4).

After accelerated handling, the RAS bending strength of reinforced pallets was greater than that of the unreinforced pallets for all three species. The opportunity for species substitution, which was supported by component tests, could not be confirmed with the limited pallet tests. The unreinforced oak pallet was stronger than the reinforced poplar pallet, and the unreinforced poplar pallet was stronger than the reinforced pine pallet. Further testing with adequate sample sizes of pallets is needed to determine if species substitution is practical.

The RAS bending stiffness of both reinforced and unreinforced pallets declined after the accelerated-handling tests. This was expected, as no new members or plates were added after the initial nondestructive tests. Although there was no visible stringer damage in the reinforcement area, the reinforced pallets retained less of the original stiffness than did the control pallets. This suggests that MCP reinforcement may cause degrade in stiffness after handling, possibly due to net section reduction of stringers from plate teeth.

Common failure modes in the pallets, after testing to failure in RAS bending, were between the notch fractures for unreinforced pallets and vertical fractures at a plated notch for reinforced pallets. These failures are similar to the failure modes found in component stringers.

Conclusions

In general, the average bending properties of reinforced stringers and impact resistance of end feet were greater than those of the equivalent unreinforced components. Bending strength, considered to be the most important flexural property, was increased 24 to 108 percent by reinforcement. Bending stiffness, however, was not increased in all cases. Impacts by a forklift tine on stringer ends reinforced with end grain MCPs resulted in curling of the plates with fewer impacts than needed to cause failure in an unreinforced foot. Plate curling was judged to be unacceptable in service. Wood species influenced reinforcement potential more than did stringer width.

MCP reinforcement creates potential opportunities for substitution of underutilized wood species for more traditional, but costlier, species. This potential for species substitution will need to be confirmed with tests and observations of pallets in a service environment.

In general, the results of pallet testing support the results from component tests. For all three species, MCP reinforcement of pallets increased strength but decreased stiffness. This suggests that component testing offers a practical method of measuring MCP effects on pallet performance. Further study of whole pallets, exposed to service conditions, is needed to verify the trends found with these component tests.

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