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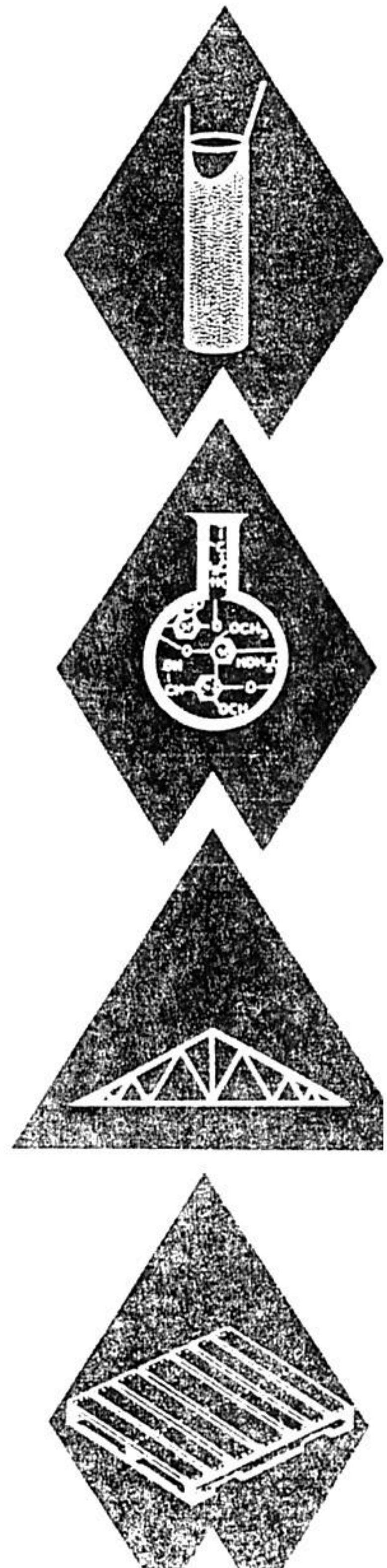

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by

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EVALUATION OF METAL CONNECTOR PLATES FOR REPAIR OF WOOD PALLETS

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Abstract

Repair of damaged pallets with metal connector plates (MCPs or plates) may reduce wood waste while providing quality, economical pallets. This study evaluated some of the effects of MCP repair on expected pallet performance as well as elements of a preliminary standard for repair of pallets with MCPs. Whole pallets, stringers, and notched segments of stringers were tested in static bending; end feet were tested for resistance to fork tine impact. Stringers, after repair at notch corners, had greater strength, but less stiffness, than originally. MCP repair of above-notch failures could not restore the original strength or stiffness of notched segments. However, these repairs may be satisfactory in stringers, since only half the original above notch strength is needed before the average stringer will fail between the notches. No differences were found in performance of different plate styles used to repair stringers and notched segments. Differences between plate styles may exist, however, under industrial conditions or with species other than oak. Repaired end feet had greater impact resistance than originally. Wood species, rather than stringer width, had a greater influence on MCP repair performance 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 repair techniques on pallet performance.

Introduction

Of the 500 million wood pallets produced in the US in 1990 (NWPCA 1991), approximately half were designated as expendable, usually discarded after a single use due to damage or simply for convenience. Stronger non-expendable pallets, the other half of production, are designed and built for repeated uses and longer life. These may also fail after extended use or due to inherent design weaknesses such as notches in stringers. As timber prices and disposal costs increase, discarded pallets will become more expensive to the user and ultimately the consumer. Pallet repair has the potential to extend the life of damaged pallets, thus reducing life cycle and disposal costs.

Traditional pallet repair uses additional wood members nailed in place of, or adjacent to, the damaged stringers (NWPCA 1985). Recently, interest in the use of metal connector plates (MCPs or plates) for repair of damaged stringers has increased. Although pallet deckboards are also frequently damaged, they are more easily replaced than stringers and MCP repair is not currently economical or practical for deckboard repair.

Common failures in notched pallet stringers may be grouped into three general categories. Failures of the notched stringer ends (or feet) result from an impact load by a forklift tine to the end of a stringer. Between-notch (BN) and above-notch (AN) failures are generally caused by bending loads on the stringers resulting from storage or transportation of the loaded pallet. BN and

The objectives of this study were to:

a) Evaluate the effectiveness of different styles of 20 gauge pallet repair MCPs for restoring the bending strength, stiffness, and impact resistance of broken stringers.

b) Evaluate some provisions of the NWPCA interim guidelines for repairing stringer-class pallets with metal connector plates.

Background

Metal connector plates consist of a flat piece of sheet steel with punched teeth. The teeth are integral projections formed perpendicular to the plate during the stamping process (TPI 1988). These teeth enable the plate to grip wood when pressed into the fiber, and they are designed to transmit lateral loads, primarily in tension and shear. MCPs are manufactured in various sizes and tooth shapes, and their use is historically associated with light-frame wood truss systems.

During manufacture and subsequent in-use loading, stress concentrations form in MCPs around holes, teeth, plugs, etc. Because of these stress concentrations and the difficulty of predicting the path of failure, design values for plates must be based on tests rather than analytical methods (TPI 1988). Standardized tests by the Truss Plate Institute, TPI (1988), have been established to evaluate MCPs in tension and shear. These tests, however, do

In general, new undamaged components were tested to failure, repaired with MCPs, then tested again. Properties before and after repair were compared.

The performance of individual repaired stringers should approximate the in-service performance of repaired stringer-class pallets. To explore this hypothesis, repaired pallets were subjected to a program of accelerated handling and then tested to failure.

Materials

Pallets and Pallet Components

Test pallet stringers were either 1½" or 2½" wide, 3½" in height, and 48" long. Each stringer had two notches, located 6" from each end, 1½" deep, and 9" long with ½" fillet radii. Notched stringer segments were cut from the notch area of stringers, as shown in Figure 1. Segments were 14" long, with the 9" notch centered in the 14" length. End feet, 12" long, with 6" of actual foot and 6" of above notch area, were cut from the ends of stringers.

Test pallets were 48x40", stringer-class, flush, non-reversible, with partial 4-way entry. Each contained three 1½" stringers, as described above, with 7 top and 5 bottom deckboards, all 5/8" thick. A common deckboard and nailing specification was used. Details may be found in Clarke (1992).

Two species groups of wood components were tested, mixed eastern oak (*Quercus* spp., called oak) and southern yellow pine (*Pinus* spp., called truss-chord plater. Though not designed for whole pallet repair, this press was acceptable for installing MCPs on pallet components, and was modified with an air cylinder to close notch fractures. Typically, a sample was laid flat on the press table and the fracture closed by pressure from the air cylinder. A plate was placed over the closed fracture and pressed in with the hydraulic ram. The sample was then turned over and the process repeated. For whole pallets, MCPs were applied at a commercial pallet repair facility with a scissors-jaw type plater.

The interim guidelines published by the NWPCA (1991) were used to determine the number of plates used in each repair. Stringers with BN fractures were repaired with one pair of plates, located at the notch where the fracture originated and on opposite sides of the stringer. For fractures longer than 8 inches, a second pair of plates was located at the fracture end, except for stringers in one substudy described later. All notch segments and end feet were repaired with one pair of plates. Plates for notched segments were centered on the fracture. Plates for end feet were located one inch from the impact end.

Test Methods

Static Bending Tests

A MTS servo-hydraulic test machine under stroke control was used for all static bending tests. Stringers were supported over a span of 45" and floor. ASTM D 1185 (1989), contains a description of an impact test with this inclined tester for pallets. Due to the number of replicates needed, testing of full-size pallets was not feasible, and the test method was modified to include 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. The impact force was adjusted by moving the distance that the dolly traveled prior to impact with the forklift tine.

Travel distance (i.e. impact force) was arbitrarily adjusted to result in a practical number of impacts to failure, more than 3 but less than 20. This distance was 6 inches for all new and repaired segments, except for 2½" wide oak samples, which required a 12" travel distance. Original, unbroken end feet were repeatedly impacted until failure, repaired with plates, then again impacted at a location ½" above the original impacts (Figure 7) until failure. Failure occurred when the forklift tine split the foot, or when the MCP curled or exhibited tooth withdrawal greater than ¼" from the wood surface. Impact resistance, or the number of tine impacts required to cause end foot failure, was measured.

An accelerometer was attached to the samples to measure velocity at impact. The velocity for a 6" travel was approximately 2.2 mph, while at 12" the velocity was 3.1 mph. These speeds are achieved by a forklift in service.

<u>Pallet Tests</u>

New and repaired pallets were subjected to both static bending tests and

Experimental Design

There were several substudies conducted as a part of this research. These included the effect of plate design, mechanical fracture closing, fracture length, species, and stringer width on the performance of repaired stringers.

For most substudies, it was necessary to create groups of equivalent samples. This grouping was based on the initial strength and a visual assessment of the fracture. Individual stringers were segregated into groups by ranking them from low to high strength, and then serially distributing them to treatment groups. The means of each group were tested using analysis of variance, ANOVA, to ensure equality.

Repair Performance Measures

Restoring original pallet properties through repair may be required if the expected performance of a repaired pallet is the same or near that of an undamaged pallet. Pallets not restored to full original properties, however, may still be useful for certain applications. Therefore, no specific performance criteria for effective repair of pallets or pallet components were set for this study. Effectiveness of repairs was expressed as the Repaired Performance (RP), defined as:

$$RP = \frac{\text{Average Repaired Property}}{\text{Average Original Property}}$$

If the repaired properties were equal to the initial properties, then RP = 1.

performance of the six different plates. This does not mean that all plates are equivalent for all applications. For example, in this study, reasonable care was taken to locate the repair plates on the fractures and to insure a consistent level of pressing quality. In a production setting, with used pallets, it may be that some external factor such as pressing equipment, pallet style, labor skill, or production rate may tangibly favor the use of one plate over another.

There were two predominant failure modes for MCP repaired stringers, BN cracks at the unplated notch or vertical cracks near plate teeth at a plated notch (see Figure 8). The vertical cracks are a result of the plate teeth cutting wood fibers and reducing the bending net section in the repair area. An exception, plate BN3, caused no vertical cracks but, due to its unique shape, forced more failures to the above notch area. Plate BN1, the 3"x3" plate, exhibited the most plate tooth withdrawal.

Effect of Mechanical Fracture Closing

To straighten a broken stringer and create a good connection, stringer fractures are often closed before repair with hand pressure or by mechanical means. The effect of hand or mechanical closing was evaluated for three different plates (BN1,BN4,BN5) applied to equal groups of 1½" wide oak stringers. These plates were chosen to represent a variety of tooth styles. For each plate type, one stringer group had fractures mechanically closed before plate application, while fractures in the other group were closed by hand.

Details of results are given in Clarke (1992) but, in general, there was no fracture length. In most cases, failure in the repaired stringers occurred at the unplated notch, regardless of fracture length.

These results indicate that, if strength is the principal criterion, the 8 inch limit could be relaxed somewhat. However, given that measuring the actual crack length in used pallets may be difficult, that field placement of repair plates may vary, and that stiffness cannot be successfully restored for any fracture length, no change is recommended in the NWPCA guidelines (1991) for fracture length.

Effect of Stringer Species and Width

This subset included groups of 1½" and 2½" wide stringers of both oak and pine. As with the above substudy, all fractures were repaired with BN1 plates, following the NWPCA interim guidelines (1991).

The results, shown in Table 3, indicate that, a) species differences affect strength and stiffness more than width differences, and b) the stiffness of pine stringers, unlike oak stringers, can be returned to the original levels with BN1 plates. Pine stringers had more vertical failures at the plated notch, while oak failed more often at an unplated notch.

We speculate that there is some interaction between plate design and species. It is possible that different plate designs will yield different modes of failure and perhaps, different performance levels with various species.

the repaired ends were more resistant to failure than the original unplated ends, but the statistical significance of any difference in RP between the two groups is marginal (ANOVA P-value close to 0.05). However, the fact that half of the feet repaired with BN5 plates did not fail within the upper limit of 20 impacts, whereas all feet repaired with plate BN4 did fail, suggests a better expected performance for plate BN5. When feet did fail, the typical failure modes were wood splits and curling of the plate edges.

Effect of Fracture Type

Two different groups of 1½" wide oak end feet were assembled from tested specimens. Both groups had the same mean initial number of impacts to failure, one group had fractures that split the foot but left it in one piece, while in the other group the feet were split into two pieces. All fractures were repaired with BN4 plates, considered the lower performer from the plate design study described above.

The results, detailed in Clarke (1992), indicate that the fracture type had little influence on the repair performance, and that both groups of repaired end feet exhibit impact resistance about 34% greater than the original. This suggests that the test MCP, if properly applied, can satisfactorily repair both one-piece and two-piece end foot failures.

The NWPCA recommendation (1991) against repair of two-piece failures at the end foot area, however, should not be changed without further tests of pallets damaged in service. Two-piece failures for this study were created in for each species and repair method, and the fact that initial stringer fractures before repair were not equivalent in all cases. Although additional tests of pallets are required, this preliminary study does reveal some important observations.

The pallet test results are combined in Table 6 to better contrast the three repair methods. The table results suggest that a) all repair methods restored original strength, b) full companion repair results in the greatest increase in performance over original strength, and c) strength is more easily restored by repair than is stiffness. Repaired performance values for plate repaired pallets, in general, are lower than the equivalent RP values for pallet components. This may reflect the effect of accelerated handling and/or a different quality of whole pallet repair than laboratory repair of components.

One pallet stringer, repaired above the notch with AN2 plates, withstood the accelerated handling test and then fractured between the notches when later tested to failure in RAS bending. This supports the notion that AN repair may be effective for whole stringers.

Repair with companion stringers, as expected, resulted in a better RP than repair with MCPs. However, both repair methods are successful. The added weight (about 5 lbs for each stringer, 1 lb for 12 plates) of additional members and reduced space for fork tine entry may make plates more efficient for some applications. Further studies, especially considering repair costs, are needed to reach definitive conclusions with regard to overall repair efficiency.

resistance, but there were differences in the performance of the two plates. Wood species was a more significant factor than stringer width on MCP repair performance, implying that to achieve equivalent performance, different plate designs may be needed for different wood species. Two-piece end foot fractures, where the original pieces are present and easily pressed together, may be effectively repaired with plates.

In general, the results of pallet testing support the conclusions from stringer and end foot component testing. If properly applied, MCPs can effectively restore pallet bending strength, but not stiffness. Full stringer repair may be more efficient than MCP repair in terms of bending strength, but both methods can restore bending strength to their original levels. Advantages to MCP repair, however, are lower repaired pallet weight and no reduction of space for tine entry.

Table 1: Description of 20 Gauge Metal Connector Plates

Plate[1]	Size (in.)	Tooth Length (in.)	Teeth per square inch	Tooth style
BN1	3x3	0.374	4.4	6-tooth, round plug type
BN2	3x4	0.336	4.3	4-tooth, round plug type
BN3	3&2x6[2]	0.333	4.2	2-tooth, in-line slot type
BN4	3x4	0.344	4.0	4-tooth, X-shaped plug type
BN5	3x4	0.327	7.9	2-tooth, semi-staggered slot type
BN6	3x4	0.330	5.2	5-tooth, round plug type
AN1	2x6	0.349	7.0	2-tooth, staggered slot type
AN2	2x6	0.356	4.2	4-tooth, round plug type
AN3	3&2x13[2]	0.333	4.2	2-tooth, in-line slot type
AN4	2x6	0.341	3.9	4-tooth, X-shaped plug type
AN5	2x6	0.329	5.1	5-tooth, round plug type

[1] Plate names indicate use: BN = between the notches, AN = above the notches.

[2] Custom geometry, plate shape conforms to stringer notch.

Table 3: Effect of Species and Width on the Bending Performance of Notched Stringers Repaired with Plate BN1

Species and Width	Replicates	Average Initial	Average Repaired	Univariate P-value	Repaired Performance[1]	LSD Comparison[2]
		a) Maximum Strength - lbs				
1½" oak	30	1315(7)	1528(16)	.0001	1.16	B
2½" oak	30	1951(21)	2579(23)	.0001	1.32	A
1½" pine	40	781(25)	916(27)	.0001	1.17	B
2½" pine	40	1285(21)	1402(25)	.0001	1.09	B
ANOVA P-value	-	-	-	-	0.0089	-
		b) Stiffness - lbs/in				
1½" oak	30	3023(16)	2626(17)	.0001	0.87	B
2½" oak	30	4906(13)	3916(16)	.0001	0.80	B
1½" pine	40	2018(25)	2105(26)	.3381	1.04	A
2½" pine	40	2876(27)	2879(23)	.9741	1.00	A
ANOVA P-value	-	-	-	-	0.0001	-

Note: numbers in parenthesis are coefficients of variation in percent.

[1] Repaired performance (RP) is a ratio of the repaired value divided by the initial value.

[2] Least Significant Difference comparison method for means. RP values with the same letter are statistically equal.

Table 5: Effect of Plate Design on the Impact Resistance of Repaired End Feet from Oak Stringers

Plate Design	Replicates	Average Number of Impacts Before Repair	Average Number of Impacts After Repair	Univariate P-values	Repaired Performance[2]	LSD Comparison[3]
BN4	20	3.25(30)[1]	10.4(37)	.0001	3.20	A[4]
BN5	20	3.20(31)	14.8(35)	.0001	4.63	A
ANOVA P-values	-	0.8735	-	-	0.0785	

[1] numbers in parenthesis are coefficients of variation in percent.

[2] Repaired performance (RP) is a ratio of the repaired value divided by the initial value.

[3] Least Significant Difference comparison method for means. RP values with the same letter are statistically similar.

[4] Half of the end feet repaired with Plate BN5 did not fail within 20 impacts; all of the feet plated with plate BN4 failed.

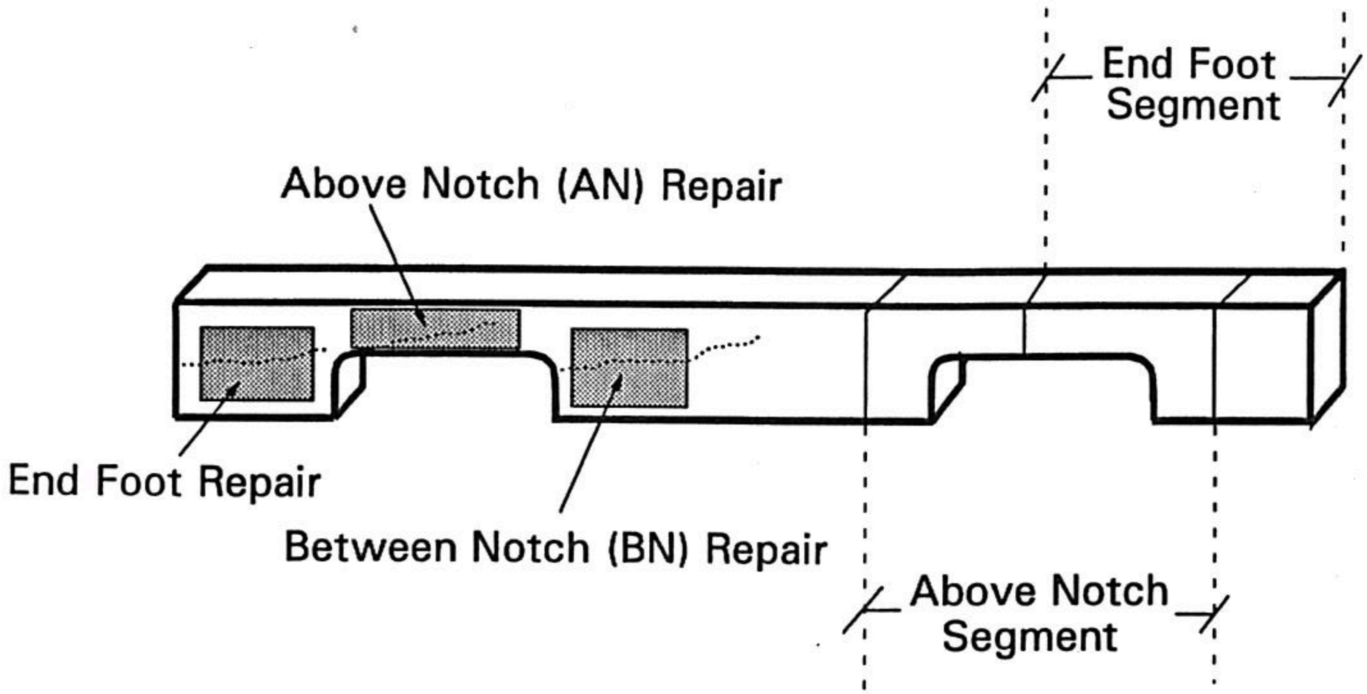


Figure 1: Pallet Stringer illustrating Repair Areas and Test Segments

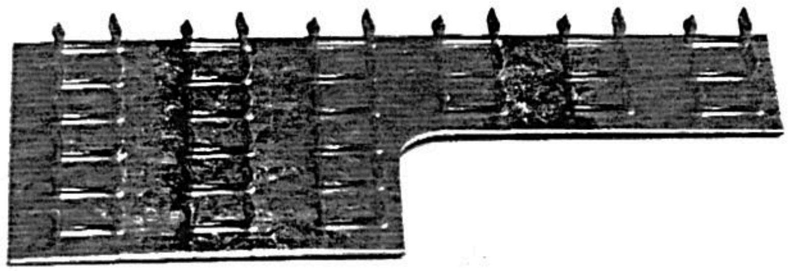


Figure 4. Custom pallet plate

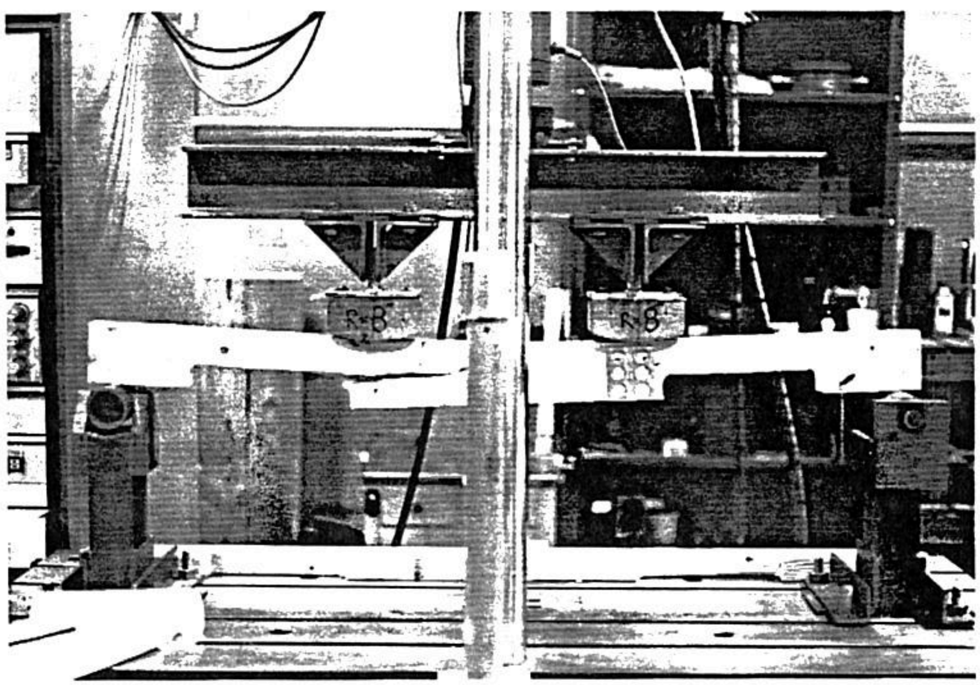


Figure 5. Test setup for determining the bending strength and stiffness of new and repaired stringers

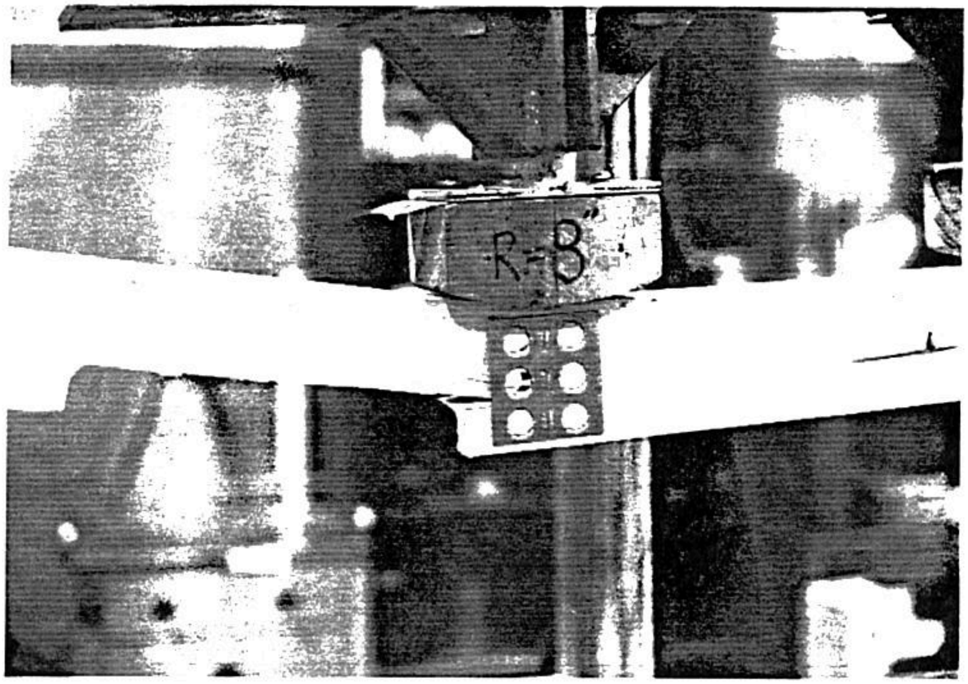
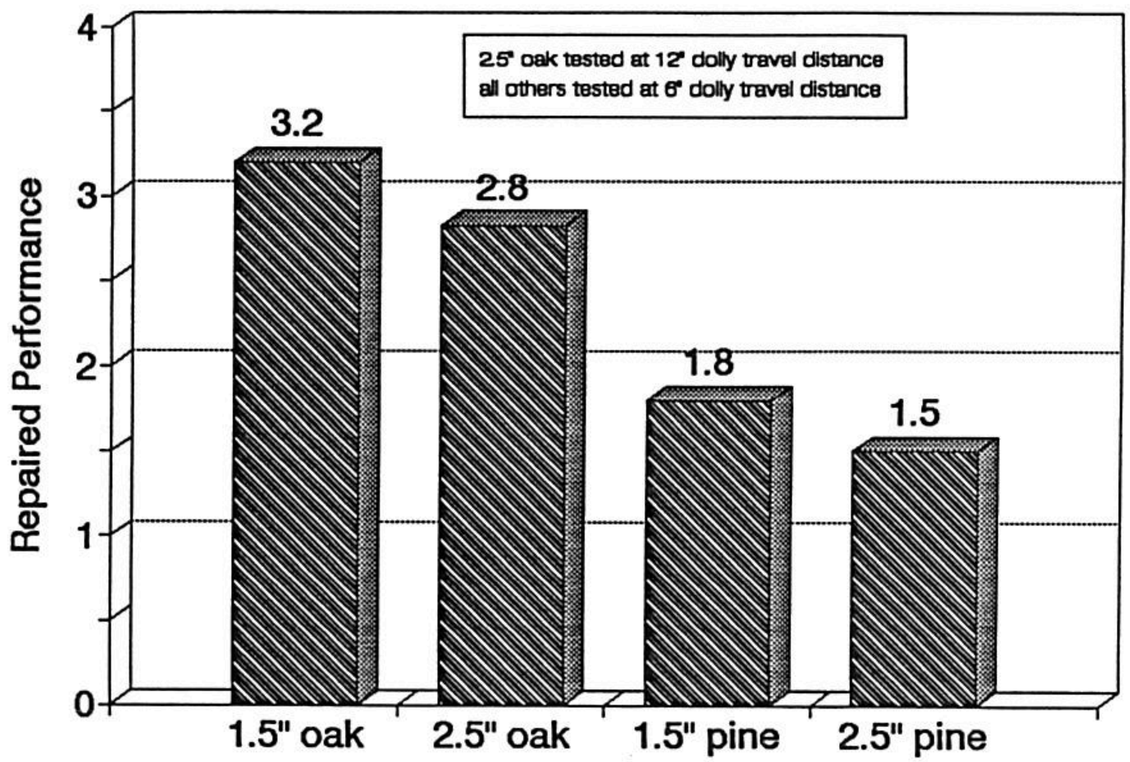


Figure 8. Plated notch failure mode in repaired stringers tested in bending

Figure 10:Effect of Species & Width on the Repaired Performance of End Feet



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.

Introduction

Over 500 million wood pallets were manufactured in the US in 1990 (NWPCA 1991), making pallets second only to the housing industry in lumber consumption (White and McLeod 1988). While properly designed pallets will withstand many load cycles, 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 an earlier article (Clarke et al 199_). 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 may be damaged, this research examined only notched stringers in stringer-class pallets. Deckboards are more frequently damaged, but more easily replaced than stringers (Schulte 1992). MCPs are not currently used for deckboard reinforcement.

With notched pallet stringers, the most common damage is cracking at the interior notches. Two notches are typically cut in stringers to satisfy a common requirement for 4-way forklift tine entry. These notches create stress

Background

A review of literature did not find any significant, non-proprietary studies on the effectiveness of MCPs for reinforcing stringer notches, although some attention has been paid to stringer end foot reinforcement. Smith (1992) 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 1.2mm (0.047 in.) thick plate was identified as the best performer. The plate was 44mm wide x 88mm long (1.73" x 3.46"), and had 9mm (0.354") long teeth. Stringers reinforced with this plate adsorbed tine impacts with 50% greater velocity than that absorbed by unreinforced samples, equivalent to a 225% increase in absorbed energy. They also found that tests where tine impact was random over the depth of the stringer end gave similar results (on a ratio basis) 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%.

segments, 12" long, with 6" of actual foot and 6" of above notch area, were cut from the ends of stringers. Test pallets were 48x40", stringer-class, flush, non-reversible, with partial 4-way entry. Each contained three 1½" wide stringers, as described above, with 7 top and 5 bottom deckboards, all 5/8" thick. A common deckboard and nailing specification was used. Details may be found in Clarke (1992).

All test pallets and components were donated by Virginia pallet manufacturers. Stringer lumber met or exceeded Pallet Design System Grade 3 (McLain 1988), or the equivalent NWPCA Grade 4 (Sardo and Wallin 1985). End feet conformed to the applicable parts of these grade rules.

Three species groups of wood components were tested, mixed eastern oak (*Quercus* spp., called oak), southern yellow pine (*Pinus* spp., called pine), and yellow-poplar (*Liriodendron tulipifera*, called poplar). Oak and poplar samples were obtained in the green condition; the pine was approximately 20% MC. Components were reinforced after procurement, then dried to 12% MC to maximize any wood shrinkage-plate withdrawal problems that might occur in used reinforced pallets. This moisture content, 12%, 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 (Clarke et al 199_). For repaired notched stringers tested in static bending, no

Test Methods

Static Bending Tests

A MTS servo-hydraulic test machine under stroke control was used for all static bending tests. Stringers were supported over a span of 45" and loaded at third-points using a procedure and fixtures that generally conformed to ASTM D 198 (1984) with a rate of deformation of 1 inch/minute. See Clarke (1992) for additional details.

The properties measured for stringers were the static bending strength (lbs.) and the static bending stiffness (lbs./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 (1986), was used for impact tests of stringer end feet. The setup, shown in Figure 1, consisted of a four-wheel dolly on parallel rails inclined at a 10 degree angle from the floor. ASTM D 1185 (1989), Sections 43-48, outlines an impact test with this inclined tester for end feet of stringers in whole pallets. Due to the large number of replicates, testing of full-size pallets was not feasible, 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 in ASTM D 1185 (1989), 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".

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 nondestructively loaded with 1000 lbs. on the RAS air-bag tester to determine the initial stiffness.

All pallets were then subjected to an accelerated material handling test protocol (Clarke 1992) to simulate service exposure. Each cycle included palletizing, sluing, loading and unloading from a trailer, pallet jack and forklift movement, RAS storage, stacked storage, rolling on a conveyor, and 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 6 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 above, to determine the strength and stiffness.

Experimental Design

The performance of reinforced stringers compared to unreinforced

reinforced and unreinforced samples was tested for each species and width with results given in Table 2.

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 1½" wide poplar and 2½" wide oak, where there was no significant improvement with reinforcement. In general, strength is a more important property than stiffness with regards to satisfactory performance of pallets. There are exceptions, however, 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 2½" wide oak and 1½" 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% of the tests, failure in reinforced stringers was associated with vertical cracks at a plated notch (see Figure 3). 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 the impact resistance of all test end foot groups by 34-112%. Wood species influenced the SRF 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 in the wide face of the stringer. Side plate reinforcement prevented this failure. For reinforced oak and pine end feet, the predominant failure was still wood splits, but the splits were in the narrow face 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 reinforced poplar feet, the predominant failure was plate tooth withdrawal. Tooth withdrawal was also a frequent failure mode with reinforced poplar stringers in bending, which suggests other plate designs may be better suited for reinforcement of poplar. The tooth withdrawal is associated with the low density of poplar compared to oak. Pine stringers and feet, with similar density to poplar (in these tests), were brittle and the wood failed before plate teeth could pull out.

Reinforced 1½" wide poplar end feet withstood a greater number of impacts before failure than the unreinforced 1½" wide oak end feet, while notch cracks were found in any control or reinforced pallets. Further details are given in Clarke (1992).

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. This is similar to the failure modes found in component stringers.

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Table 1: Description of 20 gauge Metal Connector Plates Used to Reinforce Pallet Stringers

Plate[1]	Size (in.)	Tooth Length (in.)	Teeth per square inch	Tooth style
BN1	3x3	0.374	4.4	6-tooth, round plug type
EG1	1¼x3¼	0.360	10.3	2-tooth, staggered slot type
EG2	1¼x3¼	0.455	8.1	2-tooth, staggered slot type

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

Table 3: Potential for Substituting MCP-Reinforced Pine or Poplar Stringers for Unreinforced Oak Stringers based on Bending Performance

Group	Average Maximum Strength (lbs)[1]	Average Stiffness (lb/in)[1]
1 ½" oak - Unreinforced	1315(7)	3023(16)
1 ½" pine - Reinforced	1540(27)	3795(27)
1 ½" poplar - Reinforced	1745(14)	3945(14)
2 ½" oak - Unreinforced	1951(21)	4906(13)
2 ½" pine - Reinforced	2671(25)	6571(20)

[1] numbers in parenthesis are coefficients of variation in percent.

Table 5: Potential for Substituting MCP-Reinforced Pine or Poplar Stringers for Unreinforced Oak Stringers based on Impact Resistance of End Feet

Group[1]	Average Number of Impacts Before Failure[2]
1 ½" oak - Unreinforced	3.25(30)
1 ½" pine - Reinforced	2.80(34)
1 ½" poplar - Reinforced	4.45(27)

[1] 2½" wide oak was tested at a different travel distance than 2½" pine, and no comparison between the two was made.

[2] numbers in parenthesis are coefficients of variation in percent.

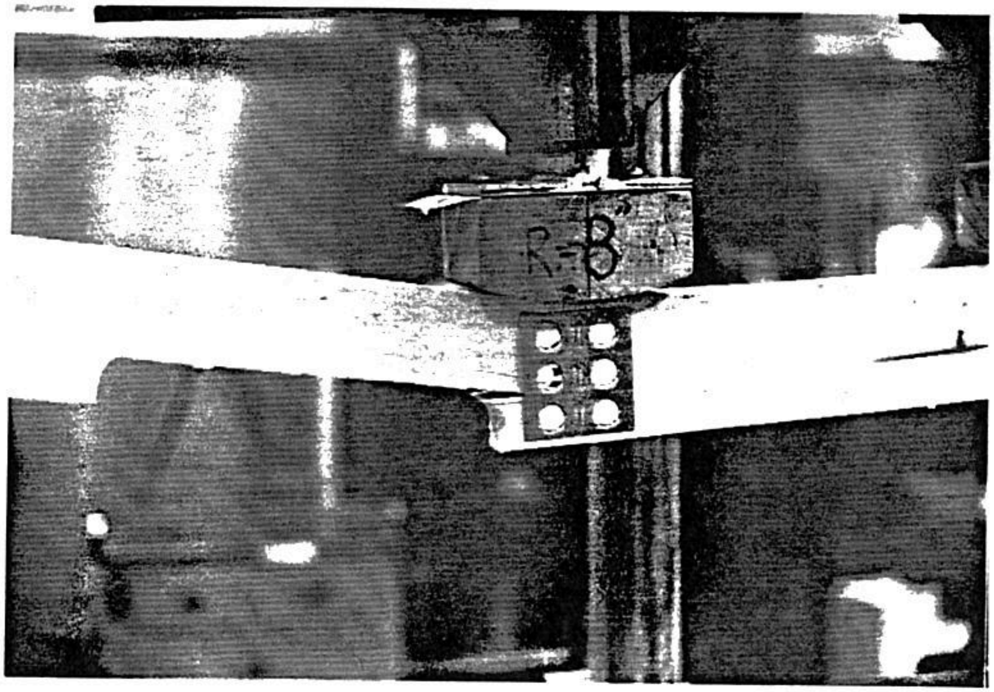

Figure 3. Plated notch failure mode in reinforced stringers tested in bending