Evaluation of metal connector plates for repair of wood pallet stringers

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Abstract

Repair of damaged pallets with metal connector plates (MCPs or plates) may reduce woodwaste while providing high quality, economical pallets. This study evaluated some effects of MCP repair on the performance of pallet components and some provisions of a preliminary standard for MCP repair of pallets. Whole pallet stringers and notched segments of stringers were tested in static bending: end feet were tested for resistance to fork tine impact. After repair at notch corners, stringers 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. Practical differences in the performance of these plate styles may exist 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. Component testing may be a practical means of assessing the effect of repair techniques on pallet performance.

Of the 560 million wood pallets produced in the United States in 1992 (9), approximately half were designated as expendable and usually were discarded after a single use due to damage, or simply for convenience. Stronger nonexpendable pallets, the other half of production, are designed and built for repeated uses and longer life. These also may 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 disposal costs.

Traditional pallet repair uses additional wood members nailed in place of, or adjacent to, the damaged stringers (7). 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 replaced more easily and economically than stringers.

Common failures in notched pallet stringers may be grouped into three general categories (Fig. 1). 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 end-foot failures are generally localized splits along the grain; more typical bending-type failures are found in the above-notch region. MCPs can be used to strengthen the damaged stringer by restoring continuity in the stringer and transferring tension or shear forces across the fracture region.

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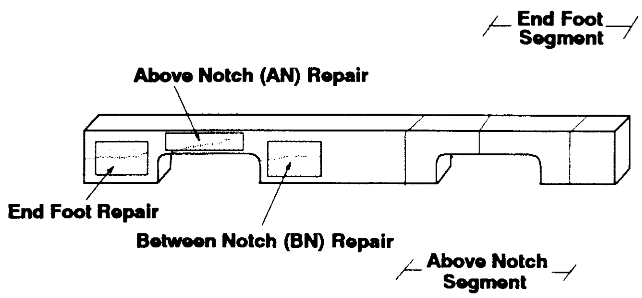

Figure 1. — Pallet stringer illustrating repair areas and test segments.

Equipment manufacturers and pallet repair specialists have developed applications equipment and techniques to effectively repair pallets with minimum cost and maximum benefit. There is concern, however, over a lack of minimum standards for MCP repair, as inadequate standards will result in reduced consumer acceptance of repaired wood pallets.

In 1991, the National Wooden Pallet and Container Association (NWPCA) issued *Interim Guidelines for the Use of Pallet Metal Connector Plates* (8) to address some immediate needs of consumers and the pallet repair industry. But development of a comprehensive standard requires abetter understanding of the effects that plate design, application procedures, and other factors have on the performance of MCP-repaired pallets. In addition, standard test procedures and performance criteria are needed to enable the user to rationally compare competing repair products and procedures. This paper describes a preliminary study of some effects of pallet repair. A companion study, described in a different paper, evaluated the potential for reinforcement of new wood pallets with MCPs.

The objectives of this study were to: 1) evaluate the effectiveness of different styles of 20-gauge pallet repair MCPs for restoring the bending strength, stiffness, and impact resistance of broken stringers; and 2) evaluate some provisions of the NWPCA interim guidelines for repairing stringer-class pallets with MCPs.

Background

MCPs 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. 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 historically is 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 (11,12). Standardized tests by the Truss Plate Institute have been established to evaluate MCPs in tension and shear (11,12). These tests, however, do not directly simulate the expected loads on MCPs used to repair pallet stringers.

MCPs were first used to repair wood pallets in the early 1970s (5). At that time, pallets were viewed as low-cost, disposable units, and not worth the cost of plating for extended use. Today, however, wood raw materials are increasing in cost, and society is more concerned with waste and recycling.

Several pallet and metal plate manufacturers have conducted proprietary test programs to demonstrate the effectiveness of plating for stringer repair. In general, the results of these tests suggest that 1) there may be some effect of plate style, size, placement, and application method on performance: and 2) bending strength, but not bending stiffness, can be restored in most notched stringers, although the subsequent failure is often not at the plate location.

We are not aware of any significant studies on the effectiveness of MCP repair of stringer ends, although some attention has been paid to stringer end reinforcement.

In this study, tests were conducted to assess: 1) the static flexural strength and stiffness of repaired stringers, and 2) the impact resistance of repaired stringer ends (called feet). In general, new undamaged components were tested to failure, repaired with MCPs, then tested again. Properties before and after repair were compared.

Materials

Pallet components

Test pallet stringers were either 1-1/2 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 1/2-inch fillet radii. Notched stringer segments were cut from the notch area of stringers as shown in Figure 1. Segments were 14 inches long, with the 9-inch notch centered in the 14-inch length. End feet, 12 inches long, with 6 inches of actual foot and 6 inches of above-notch area, were cut from the ends of stringers.

Two species groups of wood components were tested, mixed eastern oak (*Quercus* spp.) and southern yellow pine (*Pinus* spp.). All stringers met or exceeded Pallet Design System Grade 3 (6), or the equivalent NWPCA Grade 4 (10). Notched segments and end feet conformed to the applicable parts of these grade rules. All components were donated by Virginia pallet manufacturers. Oak samples were obtained in the green condition; the pine was approximately 20 percent moisture content (MC). All wood samples were air-dried to equilibrium at approximately 12 percent MC before any testing or plating. This MC represents a practical level for pallets after some time in service.

TABLE 1. — *Description of 20-gauge metal connector plates.*

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
BN2	3 by 4	0.336	4.3	4-tooth, round-plug type
BN3	3 and 2 by 6[b]	0.333	4.2	2-tooth, in-line-slot type
BN4	3 by 4	0.344	4.0	4-tooth, x-shaped-plug type
BN5	3 by 4	0.327	7.9	2-tooth, semistaggered-slot type
BN6	3 by 4	0.330	5.2	5-tooth. round-plug type
ANl	2 by 6	0.349	7.0	2-tooth, staggered-slot type
AN2	2 by 6	0.356	4.2	4-tooth, round-plug type
AN3	3 and 2 by 13[b]	0.333	4.2	2-tooth, in-line-slot type
AN4	2 by 6	0.341	3.9	4-tooth, x-shaped-plug type
AN5	2 by 6	0.329	5.1	5-tooth, round-plug type

[a]Plate names indicate use: BN = between the notches: AN = above the notches.
[b]Custom geometry, plate shape conforms to stringer notch.

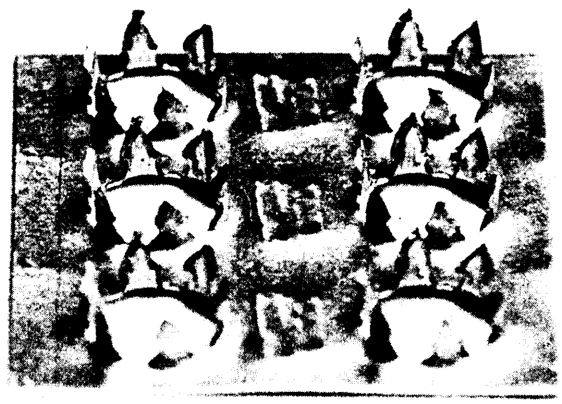

Figure 2. — Round-plug type plate.

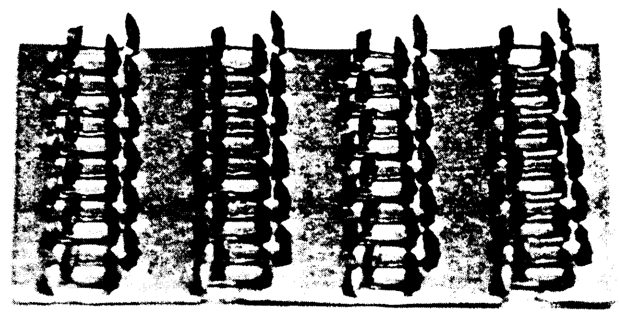

Figure 3. — Semistaggered-slot type plate.

Metal connector plates

Samples of all known MCPs used for pallet repair were obtained from suppliers or manufacturers. From these samples, 11 test MCP styles (Table 1) were selected to represent the various designs. There were three categories of plate design: slot-tooth, plug, and special. Representatives of these categories are shown in Figures 2 to 4. Plates for repair of between-notch fractures were assigned the letters "BN," and plates for above-notch fractures were assigned "AN." Some BN plates were also used for the repair of end feet. All plates had a thickness that fell within the range of 0.037 to 0.043 inch.

Plate application

The plates were applied to pallet components with a portable hydraulic 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 was closed by pressure (100 psi) from the air cylinder. A plate was placed over the closed fracture and pressed in with the hydraulic ram (hydraulic pressure 2,500 psi). The sample was then turned over and the process repeated.

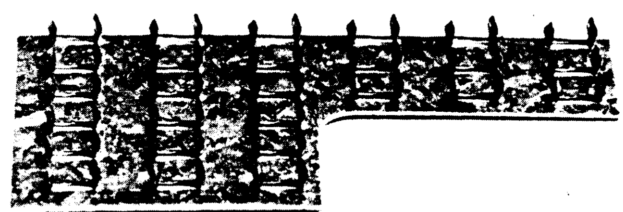

Figure 4. — Custom pallet plate.

The interim guidelines published by the NWPCA (8) 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 1 inch from the impact end.

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 (Fig. 5) using the procedures and fixtures that generally conformed to ASTM D 198 (1), except that the rate of deformation was 1 in./min. Almost always, a BN failure resulted where a crack along the grain initiated at an inner notch fillet.

Failures may occur above the notch, but were rare in our whole-stringer tests. To better understand AN failures, we also tested notched stringer segments cut from the full stringer in centerpoint bending. The segments were supported over a 12-inch span and loaded at the centerpoint with a deformation rate of 1 in./min.

The properties measured for stringers and notched segments were the static bending strength (lb.) and the static bending stiffness (lb./in.). New, unbroken samples were tested to failure to determine the original properties, then repaired with plates and retested in static bending to determine the repaired performance.

Dynamic impact tests

An inclined-impact tester, described in ASTM D 880 (2), was used for impact tests of stringer end feet. The setup, shown in Figure 6, consisted of a four-wheel dolly on parallel rails inclined at a 10-degree angle from the floor. ASTM D 1185 (3) contains a description of an impact test with this inclined tester for pallets. Testing of full-size pallets was not feasible due to the number of needed replicates, and the test method was modified to include end-foot segments. Typically, an 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 (and thus, impact force) was 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 2-1/2-inch-wide oak samples, which required a 12-inch travel distance. Original, unbroken end feet were impacted repeatedly until failure, repaired with plates, then impacted again at a location 1/2 inch above the original impacts (Fig. 7) 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 taken as the number of tine impacts required to cause end-foot failure.

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

Figure 6. — Test setup for determining the impact resistance of new and repaired stringer end feet.

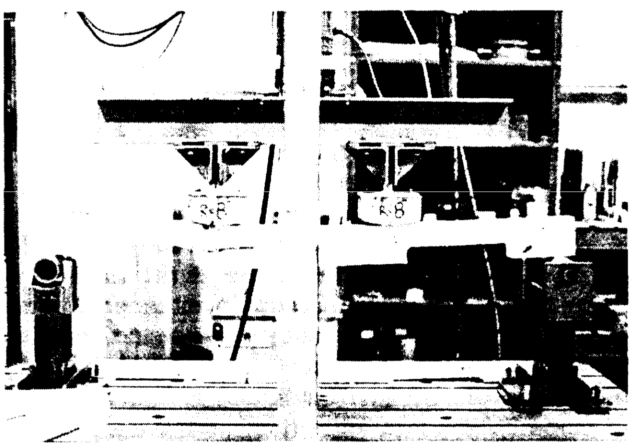

Figure 5. — Test setup for determining the bending strength and stiffness of new and repaired stringers.

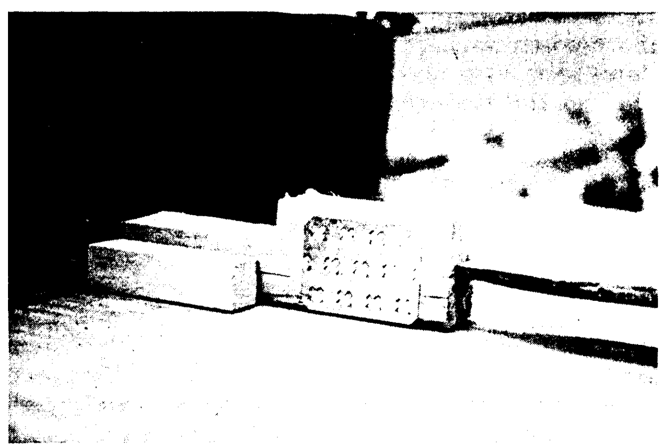

Figure 7. — Impact location used to test the effectiveness of repair of stringer ends with MCPs.

TABLE 2. — *Effect of MCP design on the bending performance of repaired notched oak stringers.*

Plate design	Replicates	Average initial	Average repaired	Univariate p-value	Repaired performance[a]	LSD comparison[b]
Maximum strength		----------(lb.)----------				
BN1	30	1,315 (7)[c]	1,528 (16)	.0001	1.16	A
BN2	30	1,315 (7)	1,573 (19)	.0001	1.20	A
BN3	30	1,313 (7)	1,668 (15)	.0001	1.27	A
BN4	30	1,312 (7)	1,597 (23)	.0001	1.22	A
BN5	30	1,311 (7)	1,658 (21)	.0001	1.26	A
BN6	30	1,310 (7)	1,605 (19)	.0001	1.23	A
ANOVA p-value	--	0.9999	--	--	0.4216	
Stiffness		---------(lb./in.)---------				
BN1	30	3,023 (16)	2,626 (17)	.0001	0.87	B
BN2	30	3,002 (13)	2,729 (15)	.0001	0.91	B
BN3	30	3,025 (15)	2,973 (15)	.0828	0.98	A
BN4	30	3.073 (11)	2,760 (12)	.0001	0.90	B
BN5	30	3,097 (15)	2,804 (20)	.0001	0.91	B
BN6	30	3,043 (13)	2,740 (16)	.0004	0.90	B
ANOVA p-value	--	0.9266	--	--	0.0001	

[a]Repaired performance (RP) is a ratio of the repaired value divided by the initial value.
[b]Least Significant Difference comparison method for means. RP values with the same letter are statistically similar.
[c]Numbers in parentheses are coefficients of variation in percent.

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 tested 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 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), which is defined as:

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

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

Analysis of variance determined if differences existed between the mean properties of treatment groups, Univariate analyses, or paired t-tests, were used to make comparisons within a treatment group. Univariate analysis determined if the repaired properties of a single treatment group were equal to the initial properties of that same group.

Results and discussion

Repair of BN fractures

Effect of plate design. — Six different BN plates (Table 1) were evaluated for their ability to repair fractured 1-1/2-inch-wide oak stringers. Six groups of 30 samples each were assembled so that there was no significant difference between the groups before plate application with respect to strength, stiffness, or fracture lengths.

The results, given in Table 2, indicate that 1) MCP repair of a stringer, fractured at the notch, results in a repaired strength that exceeds the original strength; and 2) except for plate BN3, the bending stiffness could not be restored to repaired stringers. Strength is perceived to be a more important property than stiffness for pallets, except where excessive deflection may cause product damage or interfere with handling equipment.

For restoring strength, no practical difference was found between the performances of the six different plates. This does not mean that all plates are equivalent for all applications. For example, reasonable care was taken in this study 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 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 (Fig. 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 AN area. Plate BN1, the 3-inch by 3-inch plate, exhibited the most plate tooth withdrawal.

Effect of fracture length — Four groups of 1-1/2-inch-wide oak stringers, each containing incrementally longer BN fractures, were repaired with BN1 plates. Plate BN1 was the smallest of the study plates and has a common tooth design. Stringers in all groups were repaired with one pair of plates, located at the fracture origin, instead of the NWPCA recommended (8) two pair of plates for fractures longer than 8 inches.

Figure 9 shows results for stringers repaired with one pair of plates. The repaired strength for fracture lengths up to one-half the length of the middle foot (9.0 in.) was greater than that of the original strength. With longer fracture lengths, repaired strength equaled original strength. Stiffness could not be returned to the original level with a single pair of plates, regardless of 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. However, no change in the NWPCA guidelines (8) is recommended for the following reasons: 1) measuring the actual crack length in used pallets maybe difficult; 2) field placement of repair plates may vary: and 3) stiffness cannot be successfully restored for any fracture length.

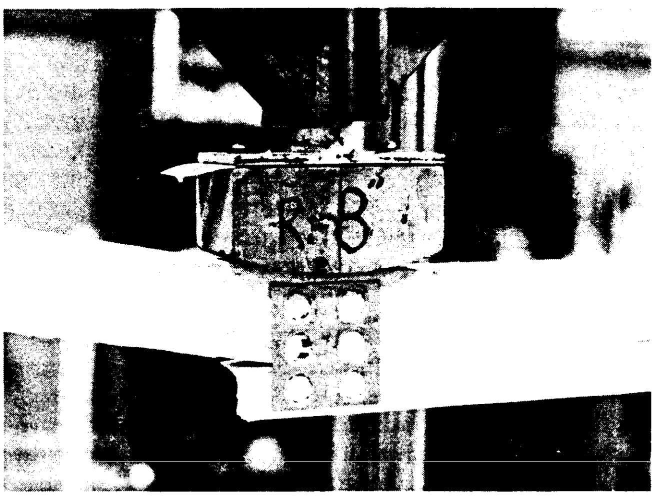

Figure 8.— Plated notch failure mode in repaired stringers tested in bending.

Effect of stringer species and width — This subset included groups of 1-1/2-inch- and 2-1/2-inch-wide stringers of both oak and pine with all repairs made with BN1 plates following the NWPCA interim guidelines (8).

The results, shown in Table 3, indicate that 1) species differences affect strength and stiffness more than width differences; and 2) 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.

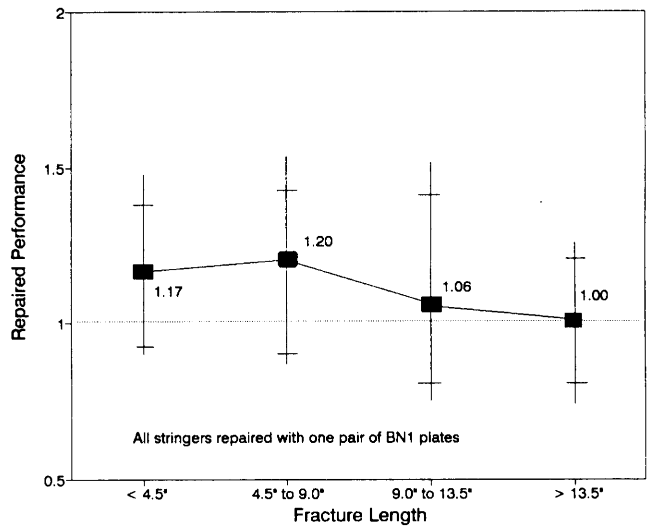

Figure 9. — Effect of fracture length on the repaired performance for stringers repaired with one pair of plates (original strength =1).

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[a]	LSD comparison[b]
Maximum strength		----------(lb.)----------				
1-1/2-in. oak	30	1,315 (7)[c]	1,528 (16)	.0001	1.16	B
2-1/2-in. oak	30	1,951 (21)	2,579 (23)	.0001	1.32	A
1-1/2-in. pine	40	781 (25)	916 (27)	.0001	1.17	B
2-1/2-in. pine	40	1,285 (21)	1,402 (25)	.0001	1.09	B
ANOVA p-value	--	--	--	--	0.0089	--
Stiffness		---------(lb./in.)---------				
1-1/2-in. oak	30	3,023 (16)	2,626 (17)	.0001	0.87	B
2-1/2-in. oak	30	4,906 (13)	3,916 (16)	.0001	0.80	B
1-1/2-in. pine	40	2,018 (25)	2,105 (26)	.3381	1.04	A
2-1/2-in. pine	40	2,876 (27)	2,879 (23)	.9741	1.00	A
ANOVA p-value	--	--	--	--	0.0001	--

[a]Repaired performance (RP) is a ratio of the repaired value divided by the initial value.
[b]Least Significant Difference comparison method for means. RP values with the same letter are statistically equal.
[c]Numbers in parentheses are coefficients of variation in percent.

TABLE 4. — *Effect of plate design on the bending performance of repaired oak notched segments.*

Plate design	Replicates	Average initial	Average repaired	Univariate p-value	Repaired performance[a]	LSD comparison[b]
Maximum strength		------------(lb.)------------				
ANl	30	5,458 (15)[c]	4,332 (15)	.0001	0.79	A
AN2	30	5,550 (15)	3,714 (23)	.0001	0.67	A
AN3	30	5,501 (16)	3,855 (22)	.0001	0.70	A
AN4	30	5,593 (9)	3,972 (20)	.0001	0.71	A
AN5	30	5,613 (10)	3,960 (21)	.0001	0.71	A
ANOVA p-value	--	0.9191	--	--	0.2091	--
Stiffness		---------(lbs./in.)---------				
ANl	30	30,074 (12)	29,079 (14)	.1383	0.97	A
AN2	30	30,721 (17)	26,139 (17)	.0001	0.85	B
AN3	30	30,140 (18)	27,660 (20)	.0220	0.92	A
AN4	30	30,245 (10)	28,904 (13)	.0356	0.96	A
AN5	30	30,658 (8)	28,809 (14)	.0043	0.94	A
ANOVA p-value	--	0.9494	--	--	0.0084	

[a]Repaired performance (RP) is a ratio of the repaired value divided by the initial value.
[b]Least Significant Difference comparison method for means. RP values with the same letter are statistically equal.
[c]Numbers in parentheses are coefficients of variation in percent.

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[a]	Univariate p-value	Repaired performance[b]	LSD comparison[c]
BN4	20	3.25 (30)[d]	10.4 (37)	.0001	3.20	A[d]
BN5	20	3.20 (31)	14.8 (35)	.0001	4.63	A
ANOVA p-values	--	0.8735	--	--	0.0785	

[a]Half of the end feet repaired with Plate BN5 did not fail within 20 impacts: all of the feet plated with plate BN4 failed.
[b]Repaired performance (RP) is a ratio of the repaired value divided by the initial value.
[c]Least Significant Difference comparison method for means. RP values with the same letter are statistically similar.
[d]Number; in parentheses are coefficients of variation in percent.

Repair of AN fractures

Effect of plate design. — Five different AN plates were applied to groups of fractured 1-1/2-inch-wide oak segments. The initial groups were statistically equivalent with respect to strength, stiffness, and fracture lengths before plate application.

The results, given in Table 4, indicate that 1) MCP repair of a fractured notched segment does not restore original strength; 2) with respect to strength, there was no practical difference between the five study plates; and 3) some, but not all, plates may restore original stiffness. The low strength performance of repaired segments, however, does not mean that an AN repair of a stringer is ineffective. Unless there are serious defects in the AN region, a notched stringer is weakest between the notches. A comparison of the moment to cause failure in new and repaired oak stringers with AN and BN fractures indicates that only 35 to 50 percent of the original AN strength must be restored before BN strength will govern the behavior of the stringer.

Repair of end-foot fractures

Effect of plate design. — Plates BN4 and BN5 were each used to repair 1-1/2-inch-wide oak end-foot segments. These plates were selected to represent different tooth styles: an X-shaped plug and a slot-type tooth. With both plates, as shown in Table 5, the repaired ends were more resistant to failure than the original unplated ends, but the statistical significance of any difference in repaired performance between the two groups is marginal (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 abetter performance would be expected with 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 1-1/2-inch-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 previously.

The results, detailed in Clarke's master's thesis (4), 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 percent 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 (7) 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 the laboratory and both original pieces could be reasonably realigned and repaired. That may not be practical in production.

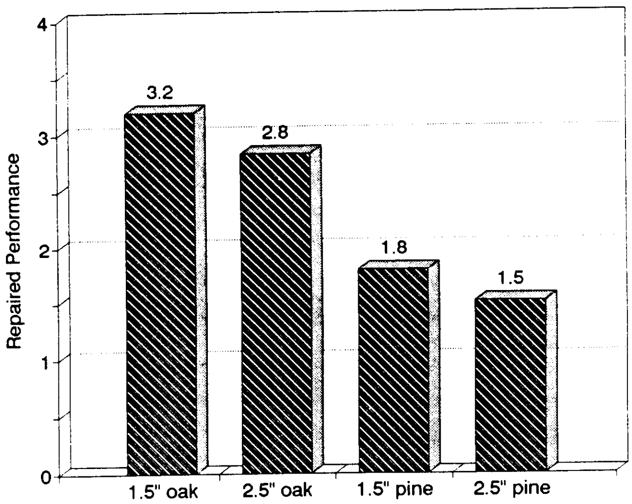

Figure 10. — Repaired performance for oak and pine end feet repaired with BN4 plates.

Effect of end-foot species and width. — End feet of two widths, 1-1/2 inch and 2-1/2 inch, and two species, oak and pine, were tested. Plate BN4 was used for all repairs because it was considered the lower performer from the plate design study described previously.

The results, given in Figure 10, indicate that the impact resistance of all repaired test samples was greater than the original impact resistance. Oak end feet benefitted more from MCP repair than pine end feet. Pine is more brittle and less dense than oak, resulting in more wood splits and plate tooth withdrawal in the pine. For the test samples, species was a more significant factor on the performance of repaired end feet than was stringer width.

Conclusions

The average bending strength of MCP-repaired stringers loaded at the third-points was greater than that of the original stringers for six plate designs tested. No significant differences were found between the strength of stringers repaired with the six test plate designs. In general, MCPs could not restore original stringer stiffness but, for most applications, pallet strength is the more important property. The results, limited to the six BN plate designs tested, suggest that if plates are properly applied in an actual repair environment, plate design is not a significant issue. Other factors related to repair production, however, may influence the selection of the most effective plate design. It is recommended that two pairs of plates be used to repair fractures longer than 8 inches. More testing with stringers or pallets damaged in-service is needed before any changes in the NWPCA interim repair guidelines can be proposed.

In general, MCP repair could not restore the original strength or stiffness to notched segments. The AN repairs were effective enough, however, to restore whole-notched stringer strength to original levels. No differences were found between the mean strengths of segments repaired with the five different test plates.

MCP-repaired end feet had greater impact resistance than did the original undamaged end feet. Both plug and slot-type plates restored original impact 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.

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