

1. INTRODUCTION

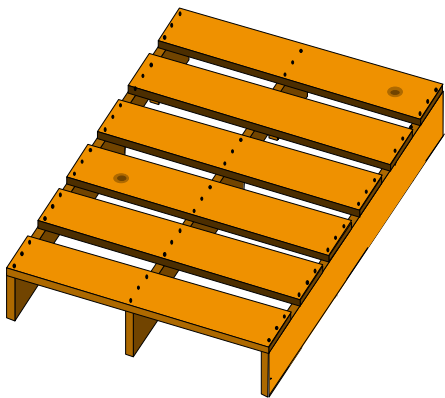
1.1 Overview

The pallet is a load-bearing device for shipping and stacking unit loads, and usually is made of wood, plastic, cardboard, steel, or aluminum. The wood pallet has become one of the principal forest products in the United States, providing an efficient and convenient method of moving other products with forklift trucks. Since the first pallet was put into use in 1930's, demand has been increasing steadily and pallet manufacturing has developed into one of the largest forest products industries. In 1995, the industry manufactured approximately 411 million new pallets, and approximately 6.32 billion board feet of solid wood lumber, cants, parts, and shooks was used by the pallet industry⁽²³⁾. This figure includes approximately 4.53 billion bft. of solid hardwood (including 1.22 billion bft. of oak and 379.5 million bft. of yellow-poplar) and 1.79 billion bft. of softwood materials (including 730.6 million bft. of southern pine). The pallet and container industry used an estimated 208 million square feet of softwood plywood and OSB in 1995 ⁽²³⁾.

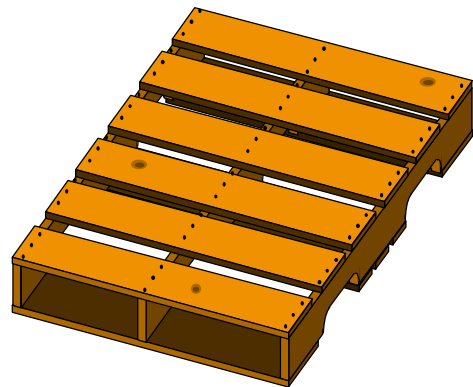
According to the usage, wood pallets are classified as reusable, expendable, general-purpose, and special-purpose pallets. Expendable, low cost pallets are designed to ship and store many different products for a single trip or a limited number of shipping cycles. Reusable on multiple-use pallets are designed to repeatedly support many different load types in various ways. All pallets are repairable. Stringer pallets are either

two-way (**Figure 1.1 a**) or partial four-way designs which permit fork entry into all four sides (**Figure 1.1 b**). Multiple-use general-purpose wood pallets are the most common designs. Special-purpose pallets are designed to support a limited and specified load under limited and specified conditions of handling. Special-purpose pallets vary significantly in design and size.

According to the construction, wood pallets can be classified as single-faced with one deck on top (**Figure 1.1 a**), or double-faced with both top and bottom decks (**Figure 1.1 b**). Double-faced pallets can be either reversible or non-reversible.



(a) single-faced two-way entry



(b) double-faced partial four-way entry

Figure 1.1 Typical non-reversible, flush, 48-by 40-inch wooden pallets

Currently the principal sizes of pallets used (specified by length x width) are 48' x 40", 42" x 42", 40" x 48", 48" x 42", 48" x 48", 36" x 36", and 40" x 40". The size 48" x 40" in 1980, 1985 and 1990 was the most frequently produced. Approximately 90% of pallet firms produce pallets of this size ⁽¹⁹⁾.

In 1995, approximately 171.1 million used pallets were received for recycling with about 150 million returned to the market as repaired pallets ⁽⁸⁾. Many contained damaged stringers. There is great potential for salvaging damaged stringers by cutting off damaged sections and splicing pieces into full-length stringers. These pieces would come from pallets that are disassembled and contain partially damaged or short stringers. Clarke, *et al* ⁽¹⁰⁾ has shown that using metal connector plates (MCPs) can successfully reinforce or repair stringers with cracks at the notches. However, 125.3 million bdf. of wood pallets or pallet parts were shredded in the U. S. in 1995 ⁽⁸⁾. Many of the non-repairable stringers that are shredded contain half-useable segments. These stringer segments could be reprocessed into higher valued full-length stringers instead of fiber products. This would reduce the need for new wood from standing timber. Stringer splicing is already being performed on a limited scale but, until now, no formal research has been conducted to determine if MCPs are effective for splicing together two completely separated stringer segments. This work is needed to help verify and provide guidelines for stringer splicing.

1.2 Research Objectives

The overall objectives of this research were to:

- a) Evaluate the effectiveness of splicing two notched pallet stringer segments with metal connector plates;
- b) Determine the relative effectiveness of different stringer splicing methods and under what condition the process is or is not effective.

2. LITERATURE REVIEW

2.1 Pallet Stringer Failure

Stringer pallet failures mostly occur at stringers and end deck boards during use. Most of stringer damages are longitudinal splits. In general, wood pallet stringers usually fail at three locations: between the notch (BN), above the notch (AN), and in the end foot (EF) (**Figure 2.1**). AN and BN failures are caused by bending stresses. Impacts by forklift tines usually cause damage to the end foot of the stringer. All of these failures leave at least a ½ stringer segment intact. Research at Virginia Tech has shown that some damaged stringers can be repaired with MCPs⁽¹⁰⁾. It may be feasible to splice two stringer segments that come from non-repairable stringers with plates.

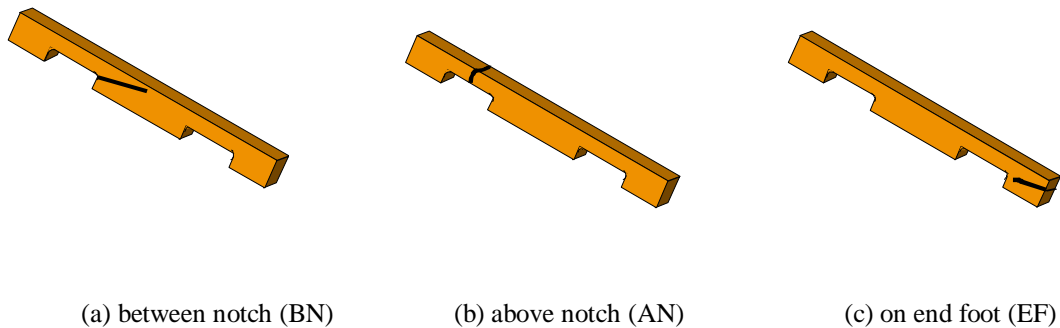


Figure 2.1 Three common failures in wood pallet stringers

2.2 Metal Connector Pallets

Metal connector plates (MCPs, metal plates, or plates) are made of sheet steel with punched teeth. The teeth are integral metal projections of the plate formed perpendicular to the plate during the stamping process. When pressed into the fiber of wood, these teeth can transmit lateral loads. Plates are manufactured using ASTM A653 A446, A591, A792, or A167 structural quality steel protected with zinc or zinc-aluminum alloy coatings or a stainless steel equivalent ⁽¹¹⁾.

The MCP resembles a smooth, clean patch on a wooden member, making the wood member safe to use. Each plate design resists forces based on: 1) the design of the tooth, individual tooth length, and angle of load to tooth; 2) the behavior of the teeth when processing into the wood; 3) the gauge and the net area of the structural steel left in the plate after the punch presses pierce the plate to form the teeth (the residual strength of the unpunched portion is applied to transferring forces through the connected wooden member). Standardized tests by the Truss Plate Institute (TPI) (1995) ⁽²⁶⁾ have been established to describe stress and force impressed of MCPs in tension and shear. These tests, however, are not directly applied to spliced stringers of pallets or pallets with spliced stringer(s).

MCPs manufactured to various dimensions are often touted as the most significant breakthrough in the light-frame wood building system. Plates promote flexibility from an architectural and engineering perspective, which significantly reduces costs of roof and floor framing.

2.3 Studies of Wood Structures with Metal Connector Plates

Masami Noguchi derived an equation for ultimate resisting moment of butt joints with plate connectors stressed in pure bending to calculate the maximum bending moment (M) of a butted joint with a connector plate ⁽²⁰⁾:

$$M = 2Pa - (2P^2/b\sigma) - wP$$

Where,

M = maximum bending moment, kNmm ;

P = the maximum tensile load of a connector plate used, kN;

a = the distance from compressive face of wood members to extreme tensile edge of plate, mm;

w = the width of a plate, mm;

b = is the thickness of wood members, mm;

σ = a compressive strength of wood members, kN/mm²;

Comparing theory and the experiment, he pointed out that the effect of wood member strength (the second term in the right-hand of the equation) on maximum bending moment is negligible compared with that of the plate location (a) when the using the same wood species. In other words, the strength of the connector plate and its location determine the maximum bending strength of a butted joint. The strength of both

pieces of wood segments has little effect. Masami Noguchi showed that the strength of the butted joint is an increasing linear function of distance (a).

Leslie Groom and Anton Polensek ⁽¹²⁾ studied nonlinear modeling of truss-plate joints. They concluded that teeth face bearing on end grain failed by tooth withdrawal or plate tensile failure; teeth edge bearing on end grain failed by plate peel back, and teeth bearing on grain failed in wood perpendicular to grain.

Kirk et al ⁽¹⁶⁾ studied the effect of gap size on axially loaded compression splices. They found that plate buckling could occur at loads less than the reported design load for 20-gauge (0.91-mm-thick) plates with 0.0625-inch. (1.59-mm) and 0.125-inch. (3.18-mm-thick) gaps, but 16-gauge (1.47-mm) plates did not buckle until the reported design load was exceeded. They pointed out that design of compression joints should not be solely based only on plate properties derived from tensile tests. Wolfe ⁽²⁸⁾ and Gupta ⁽¹³⁾ found that joint load eccentricity would significantly reduce axial load capacities that are based on a concentric load test.

The results are not directly applicable to this study because spliced stringers in this research are notched-stringers. The notches result in significant differences in the point of stress concentration and strength of the stringer.

2.4 Preliminary Bending Tests of Spliced Stringers

During October of 1995, the author conducted preliminary bending tests on several MCP spliced 48” notched stringers. Testing observations are summarized in Table 2.1.

Table 2.1 Results of the preliminary flexural strength tests of spliced 48” oak stringers

| SAMPLE | SPLICING TYPE ¹ | MAX. LOAD (LB.) | SIZE OF STRINGER (L” x W” x H”) | FAILURE LOCATION ² |
|--------|----------------------------|-----------------|-----------------------------------|-------------------------------|
| 1 | VS | 1020 | 48 x 1.63 x 3.75 | BN |
| 2 | VS | 1580 | 48 x 1.50 x 3.38 | PF |
| 3 | VS | 920 | 48 x 1.63 x 3.50 | PF |
| 4 | VS | 900 | 48 x 1.25 x 3.50 | BN |
| 5 | AS | 1000 | 48 x 1.25 x 3.50 | BN |
| 6 | AS | 1480 | 48 x 1.25 x 3.75 | BN |
| 7 | AS | 1690 | 48 x 1.25 x 3.75 | PF |
| 8 | AS | 790 | 48 x 1.25 x 3.50 | AN (knot) |
| 9 | VSG | 1020 | 48 x 1.38 x 3.75 | PF |
| 10 | VSG | 800 | 48 x 1.25 x 3.50 | PF |

Notes: 1) VS = Vertical Splice; AS = Angled Splice; VSG = Vertical Splice with Gap (see Figure 3.7).
2) BN designates a failure has occurred between both notches (Fig. 2.1); AN indicates a failure has occurred above notches (Fig. 2.1); PF denotes a failure has occurred at the metal connector plate and at least one of the two plates is failed.

Each spliced segment was processed from the same used stringer in order to avoid defects, such as, cup, bow, twist, and different widths of the used stringer segments, which would weaken the joint. The metal connector plate used was a 3” x 4” truss plate.

Ten observations were made on three different splice types and several different widths of stringers. Although the sample size was small, the results indicated that spliced stringers could support significant loads in pallets. The average ultimate bending strength of new notched stringers are 1,315 lbs. (1½”x3 ½”, oak), 1,951 lbs. (2 ½”x3 ½”, oak), 781 lbs. (1½”x3 ½”, pine), 1,285 lbs. (2 ½”x3 ½”, pine), and 1,295 lbs. (1½”x3 ½”,

poplar) (Clarke 1993 thesis). Strengths of the spliced stringers reported in Table 2.1 are similar to those of whole new-notched stringers. No tooth withdrawal failures occurred, indicating that increasing tooth capacity will not significantly improve the splice. Some failures occurred at the notches, and some in the joint area, indicating the strength of the plate may be important.

Manufacturers produce various types of MCPs. Approximately 13 MCPs are available commercially. Some examples of these are shown in Appendix A. Clarke, *et. al* reported no significant differences in the performance of the different types of plates tested in static bending ⁽¹⁰⁾. In other words, the selection of MCPs does not influence the results of repairing pallet stringers.

3. METHODS AND MATERIALS

3.1 Overview

The following tests were performed to assess mechanical the behavior of spliced stringers and pallets: 1) static bending tests of stringers, to determine the relative stiffness and flexural strength of spliced stringers; and 2) static uniform bending tests of pallets, to determine the flexural strength and stiffness of assembled pallets with spliced stringers. In order to limit experimental variation, new stringer segments were primarily used in the study. Spliced stringers made from used stringer segments were an experimental variable in static stringer bending tests. New stringers were used as control specimens to evaluate splice method effects on performance. All stringers and stringer segments contained a standard notch, 1½ inches deep, 9 inches long and 6” inches from the end of the stringer.

Because oak, yellow-poplar, and southern pine are major pallet wood species, these and the species combinations shown in Table 3.3 were tested. The grade of stringer segments and deck boards exceeded the minimum in Pallet Design System (PDS) grade 3. All specimens were fabricated and tested after conditioning to 12% EMC.

3.2 Apparatus

A pneumatic plater was used to press the plates into the wooden segment (see **Figure 3.1**).

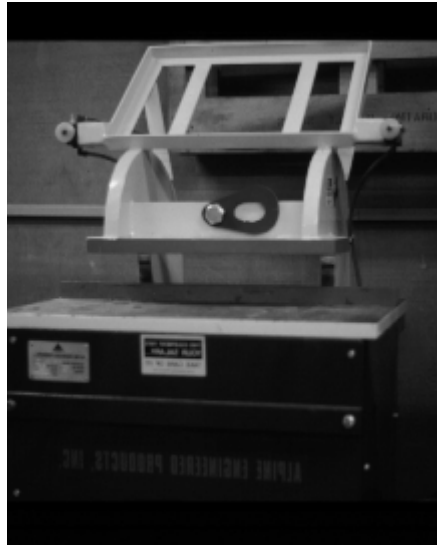


Figure.3.1 Pneumatic plater used to splice stringer segments with metal connector plates

The Tinius Olsen 12000 pound electromatic universal testing machine was used for the static bending tests of stringers (see **Figure 3.2**). The deformation rate during testing was 1.0 inch/min..

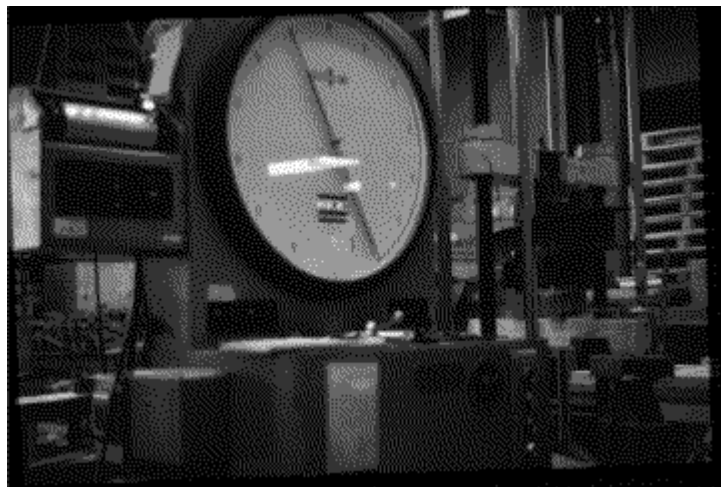


Figure3.2 Tinius Olsen electromatic universal testing machine used for stringer bending tests

The Tinius Olsen Deflectometer shown in **Figure 3.3** was used to measure the deflection at the center of a tested stringer. The deflection measurement range is 0 to 10.0 inches.



Figure 3.3 Tinius Olsen Deflectometer used to measure the deflection during bending tests of spliced stringer

A pneumatic pressure bag (airbag) testing machine (**Figure 3.4**) had been built by researchers at Virginia Polytechnic Institute and State University. It can be used for uniform loading any geometry of panel products and pallets in the range of 26 to 50 in. (0.66 to 1.27 m) wide and 38 to 62 in. (0.97 to 1.58 m) long. The airbag load application is a Uniroyal PE-D-2243 inflatable dunnage bag, 4-ft. (1.22 m) by 5-ft. (1.52 m), fabricated with tough neoprene rubber and woven nylon fabric. The airbag's maximum allowable unrestricted pressure is 6 psi (4.137 E + 03 Pa), therefore the maximum applied load is 14400 lb. (64.05 kn) to a 48 in. by 40 in. (1.22 m by 1.02 m) pallet. The range of loading rate, that is computer controlled by a servovalve and observed with a flow

indicator, can reach 0.006 to 0.250 in./min (0.152 to 6.35 mm/min). During testing, the air bag was filled at a rate of 18 liters/min.. Five Schaevitz Linear Variable Displacement Transformers (LVDTs) are mounted to the test machine for measuring deflection at ranges of ± 2 -in. (0.051 m).

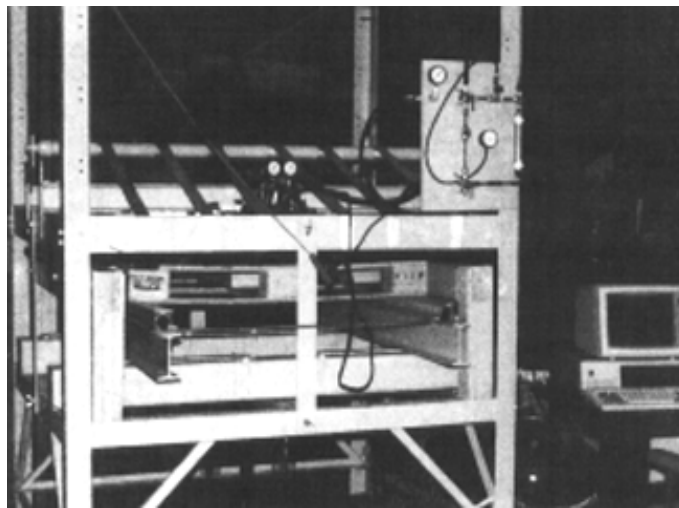


Figure 3.4 The airbag testing machine used to conduct pallet bending tests

3.3 Metal Connector Plate Selection

Four kinds of metal connector plates, 3 x 4-inch, 3 x 6-inch truss plates, and a 3 x 4-inch plug plate were selected in this study (see **Figure 3.5**). Table 3.1 contains some characteristics of these plates. Since the plates of 1.25 x 6-inch, were not available at the test time, 3 x 6-inch plates were used instead. All tested plates are zinc-iron alloy coating steel, SS Grd 50 [340]⁽⁷⁾.

TABLE 3.1 Description of test metal connector plates

| Characteristics | Plate types | | | |
|---|---------------|---------------|--------------------|------------------|
| | truss | plug | truss | truss |
| Plate size (in.) | <u>3 by 4</u> | <u>3 by 6</u> | <u>3 by 4</u> | <u>1.25 by 6</u> |
| Plate thickness (in.) | 0.036 | 0.036 | 0.036 | 0.036 |
| Tooth density (teeth/in ²) | 8 | 8 | 4.3 | 8 |
| Slot width (in.) | 0.130 | 0.127 | 0.685 ^a | 0.127 |
| Tooth length | 0.257 | 0.357 | 0.302 | 0.357 |
| Teeth configuration | | | | |
| Direction of plate width | staggered | staggered | round | staggered |
| Direction of plate length | in-line | in-line | round | in-line |

^aThe slot of plug plate is round, so slot is the diameter of the circle.

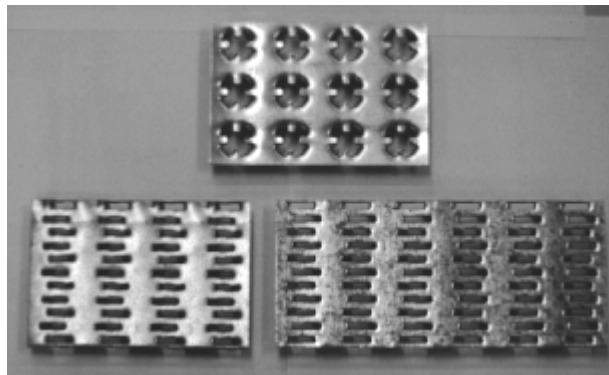


Figure 3.5 Photograph of the test metal connector plates used in this splicing study

(From top to right bottom: 3 x 4-in plug plate, 3 x 4-in. and 3 x 6-in truss plates.)

3.4 Splice Designs and Plating Method

Three splice designs were tested. Vertical splice (VS) type -- both spliced ends are tightly connected and the spliced plane is perpendicular the spliced stringer longitudinal axis (shown as **Figure 3.6 a**). Angle splice (AS) type -- both spliced ends are tightly connected and the spliced plane forms on angle (45°) with the spliced stringer longitudinal axis (shown as **Figure 3.6 b**). Vertical splice with gap (VSG) type -- VS splice with a gap, of 0.25 inches between the segments (shown as **Figure 3.6 c**). Figure 3.7 shows a photograph of the three splices tested.

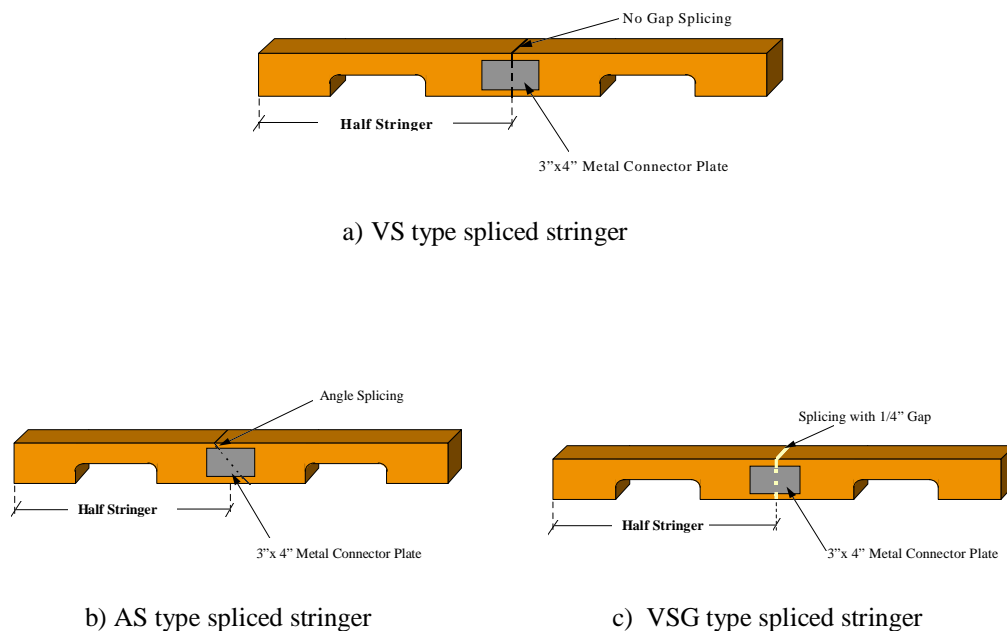


Figure 3.6 Types of splices tested

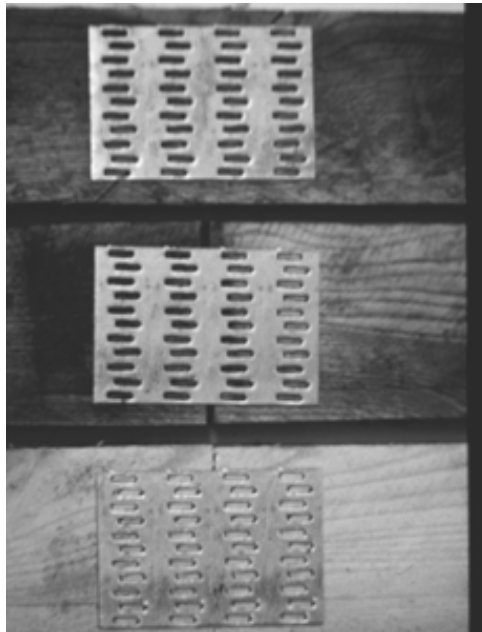


Figure 3.7 Photograph of typical Splices tested (from up to down are AS, VSG, and VS splices)

Two MCPs were pressed into opposite faces of stringers using a pneumatic plater. The plating procedure was: 1) two segments to be connected together were laid on the press table, 2) both segments were pushed together by end-pressure, 3) a metal connector plate was then placed over the joint line and pressed in with a pneumatic ram (see Figure 3.8), and 4) The specimen was turned over and processing steps, 1 to 3, were repeated.



Figure 3.8 Photograph of splicing stringer segments

In this experiment, testing was performed almost immediately after specimen assembly. Therefore, such stress relaxation around the plate teeth is not considered.

3.5 Experimental Design

In total, 130 stringers were used, 100 stringers for static bending tests of stringers, and 30 stringers for static uniform bending tests of pallets with spliced stringers (see **Table 3.3**).

3.5.1 Stringer Tests

3.5.1.1 Specimen Selection

The species, oak, yellow-poplar (yp), and southern pine (sp) were used because they are typically used in pallet construction. Two combination species stringers, oak and yellow-poplar (oak-yp), and oak and southern yellow pine (oak-sp), were also tested. Pallet manufacturers located in the southeast United States provided all test stringers. However, the specimens of some species came from a single manufacturer. Quality of tested stringers exceeded the minimum quality to Pallet Design System (PDS) Grade 3

Since specimens were green when they were obtained, they were stored in an environmentally controlled chamber at a 50% relative humidity and at 70°F until the specimens' moisture content (MC) reached 12%. Wood MC before testing was evaluated using a moisture meter.

3.5.1.2 Stringer Dimension

Full stringer test specimen dimensions (L x W x H) were:

$$48'' \times 1\frac{1}{2}'' \times 3\frac{1}{2}''$$

Stringer segment dimensions (L x W x H) were:

$$24'' \times 1\frac{1}{2}'' \times 3\frac{1}{2}''$$

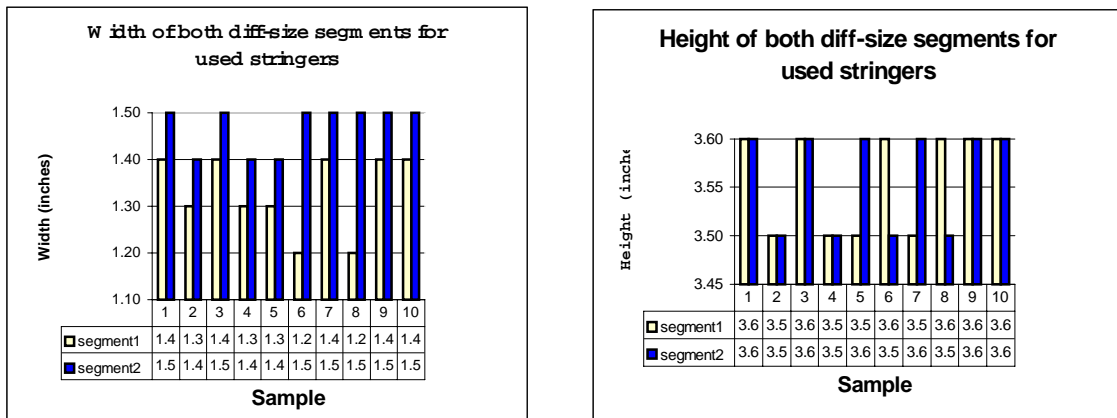
Used oak stringer segment dimensions (L x W x H) were:

$$24'' \times 1\frac{1}{2}'' \times 3\frac{1}{2}''$$

Spliced used segments were randomly assembled from twenty segments which were cut from ten 1½'' x 3½'' x 48'' used oak stringers. Some segments in the same splice

were cut from the same used stringer, such that they had almost the same cross-sectional dimensions. These were called a same size splice (s-size splice). Other spliced segments were from different stringers of different widths and these were called different size splices (d-size splice).

Widths and heights of paired used stringer segments for d-size used stringers are shown in **Figure 3.9** a and b. The maximum difference in paired stringer segment was 0.10 inches in height and 0.30 inches in width.



(a) Differences of width of d-size stringers (b) Differences of height of d-size stringers

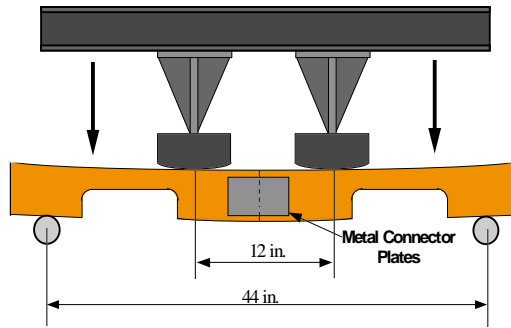
Figure 3.9 Width and height of paired spliced used segments of different size used stringers

3.5.1.3 Static Bending Test Setup

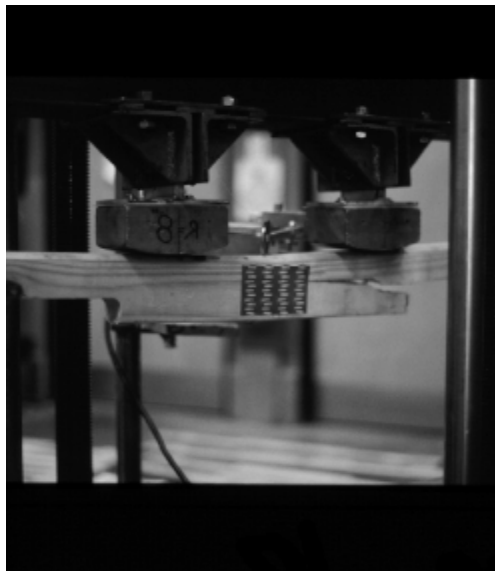
All stringers were tested in the Tinius Olsen 12000 pounds electromatic universal testing machine. A two-point loading test was used according to methods in ASTM D

198-94⁽¹⁾. The unsupported free span was 44 inches, and the span between both loading heads was 12 inches (see **Figure 3.10**). To accelerate testing a load speed of 1.0 inch/minute was used. In this study, ultimate strength, stiffness, and load at proportional limit were measured. The stiffness is defined by load at proportional limit divided by deflection of testing item.

All specimens were measured before testing with calipers to determine actual x-sectional dimensions to nearest 0.001 inch. The following dimensions were measured: length, width and height of stringer, length, width depth, and location of notch. The specimen moisture content was measured with a Delmhorst J-3 moisture meter before each test. Ten samples were randomly selected from each species to determine the average moisture content according to ASTM D 4442-92 (Method B—oven-Drying)⁽⁶⁾ immediately after testing. Specific gravity of the ten random samples were determined according to ASTM D 2395-93 (Method B—Volume by Water Immersion)⁽⁴⁾.



(a) Stringer bending test setup



(b) Photograph of stringer bending test setup

Figure 3.10 Photograph of the bending tests of spliced stringers

3.5.2 Pallet Tests

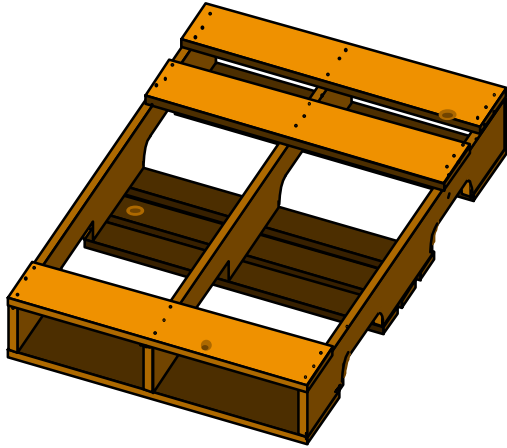
3.5.2.1 Specimen Selection

Only new oak components were used in the test pallets. Components were stored at 50% relative humidity and 70 °F temperature, until their moisture content reached 12%. Stringers segments were then plated and the pallets constructed for test.

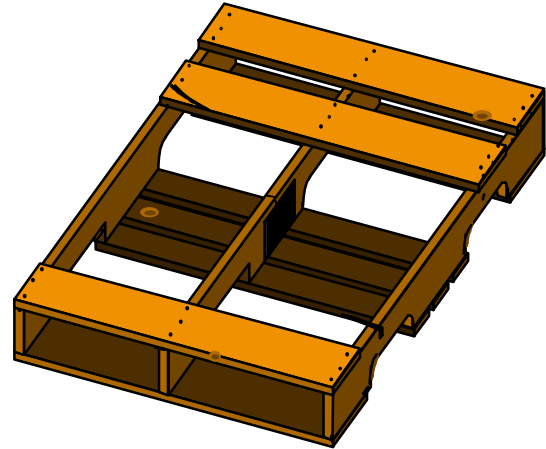
Three pallet configurations using spliced stringers were test: 1) Both side stringers were spliced and the center stringer was not; 2) Only the center stringer was spliced; and 3) All three stringers were spliced. Control pallets consisted of pallets with all three stringers made with non-spliced material (see **Figure 3.11** a, b, c, d; and **Table 3.2** and **3.3**).

Table 3.2 Description of the test pallets

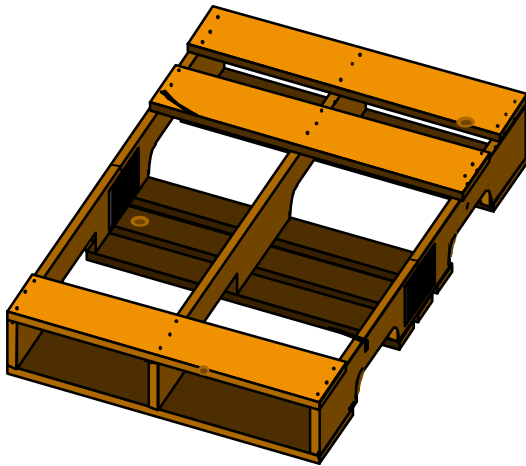
| Pallet types | Types of Spliced Stringers | Descriptions | Replications |
|------------------------------------|----------------------------|---|--------------|
| Control pallet | none | all three stringers are the full stringers | 5 |
| Pallet with one spliced stringer | VS | the center stringer is a VS-splice, and others are full stringers | 5 |
| Pallet with two spliced stringer | VS | both sides stringers are VS-splice, and the center one is full stringer | 5 |
| Pallet with three spliced stringer | VS | all three stringers are VS-splice | 5 |



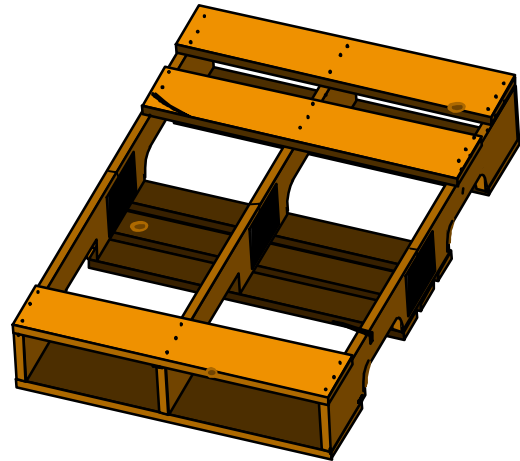
(a) Control pallet



(b) Pallet with center spliced stringer



(c) Pallet with both sides spliced stringers



(d) Pallet with three spliced stringers

Figure 3.11 Schematic diagrams of spliced stringer test pallet designs

3.5.2.2 Test Pallet Components

Tested pallets were the 48" x 40" GMA (Grocery Manufacturers of America) style constructed as follows:

Top deck boards – 2 pieces, 0.5" x 5.5" x 40" (edge boards)

5 pieces, 0.5" x 3.5" x 40"

Bottom deck boards – 2 pieces, 0.5" x 5.5" x 40"

3 pieces, 0.5" x 3.5" x 40"

Stringers – 3 pieces, 1½" x 3 ½" x 48"

3.5.2.3 Uniform Bending Test Setup

All samples, control pallets and spliced stringer pallets, were destructively tested. Pallets tested were suspended across the pallet length (Rack Across Stringer - RAS) at a 44" span, according to ASTM D 1185-94 ⁽³⁾, Section 8.4. All static bending tests were conducted using the pneumatic pressure bag-testing machine (see **Figure 3.12** and **Figure 3.4**). The air bag expansion rate was 18 liters/min.

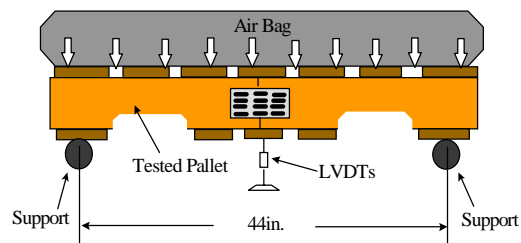


Figure 3.12 Uniform bending test setup

Table 3.3 Summary of stringer and pallet test design and replicate tests

| <u>Splice Type</u> | <u>plates & species combinations</u> | | | <u>Test</u> | <u>Replications</u> |
|---------------------------------|--|---------|-------------------|-----------------|---------------------|
| | <u>Truss plates</u> | | <u>Plug plate</u> | | |
| | 3" x 4" | 3" x 6" | 3" x 4" | | |
| VS splice: | | | | | |
| new stringer | oak-oak | oak-oak | oak-oak | bending | 10,10,10 |
| new stringer | sp-sp | | | bending | 10 |
| new stringer | yp-yp | | | bending | 10 |
| new stringer | oak-yp | | | bending | 10 |
| new stringer | oak-sp | | | bending | 10 |
| new stringer | oak-oak (+truss plate 1.25"x 6" on bottom) | | | bending | 10 |
| used stringer | oak-oak (same size segments) | | | bending | 10 |
| used stringer | oak-oak (diff. (random) size segments) | | | bending | 10 |
| AS splice: | | | | | |
| new stringer | oak-oak | | | bending | 10 |
| VSG splice: | | | | | |
| new stringer | yp-yp (with 1/4" gap) | | | bending | 10 |
| new stringer | sp-sp (with 1/4" gap) | | | bending | 10 |
| Full Pallet: | | | | | |
| pallets with ctr-spliced str. | oak-oak | | | uniform bending | 5 |
| pallets with 2side-spliced str. | oak-oak | | | uniform bending | 5 |
| pallets with 3-spliced str. | oak-oak | | | uniform bending | 5 |
| Control specimens: | | | | | |
| new stringer | oak | | | bending | 10 |
| new stringer | sp | | | bending | 10 |
| new stringer | yp | | | bending | 10 |
| new GMA pallet | oak | | | uniform bending | 5 |

Notes: In the table, yp and sp denote yellow poplar and southern pine, respectively. Oak-yp and oak-sp designate both splice segments oak and yellow poplar, and oak and southern pine species, respectively.

3.6 Statistical Methods of Data Analysis

One-way ANOVA statistical analysis was used to compare treatment affects. For pallet tests, hypotheses testing were based on Turkey's Multiple Comparison method to determine test components. The statistical tests were conducted to differentiate between mean observations at the 95% confidence level ($\alpha = 0.05$). MINITAB version 10.5 Xtra was used for all statistical comparisons.

3.7 Comparing Types and Percentage of Stringer Failure

In addition to comparing the ultimate strength, stiffness, and load at proportional limit, failure modes were also used to analyze the affects of splicing stringers.

4. RESULTS AND DISCUSSION

4.1 Overview

This study was conducted in two phases. The first involved comparing spliced stringers with non-spliced stringers (control stringers), and the second focused on comparing pallets with spliced stringers with pallets containing no spliced stringers (control pallets). Comparisons are based on ultimate strength, elastic stiffness, and load at proportional limit.

ANOVA, Tukey's multiple comparison statistical tests and comparing types and percentage of stringer failures were used to analyze all data from stringer and pallet tests.

4.2 Failure Modes of Spliced Stringer with MCP

Most failures were between notch (BN), above notch (AN), or plate failures. BN failures were the most common. It is a split that starts at the notch and extends until the stringer completely fractures (see **Figure 2.1**). It is caused by a stress concentration at the notch area. AN failure occurred at defects, such as unsound knots or decay.

There were two types of plate failures. One type was plate fracture (PF) where the plate is either torn under tensile force or buckled under compression force during the bending test. Plate fracture (PF) started on the tension edge of the plate near the splice, and extends until complete failure. The second type of plate failure was plate tooth withdrawal (PTW). The teeth of the plate are pulled from the wood. Usually PTW failure

started in the corner of the plate on the tension side. **Figures 4.3 – 4.7** illustrate all types of failures. More than one failure mode occurred during some tests.

4.3 Spliced Stringer Test Results

All values appearing in the following tables are mean values of tested components (see Appendix C for a complete set of test data). Each specimen type was assigned a number. These numbers were arranged from greatest to smallest values for each property for presentation of hypothesis testing results. Test components with equivalent underlines indicates they are not significantly different at the confidence level tested. For example, $1 > \underline{3} > 2$, it is indicate that tested components presented by digital “1” and “3” are not significantly different. However, the tested component “2” is significantly different and smaller than “1” and “3”.

4.3.1 The Effect of MCP Design and Splice Method on the Bending Strength and Stiffness of Spliced Oak Stringers

Table 4.1 contains the mean strength and stiffness from the bending tests along with failure modes from tests of different plates and splices using oak stringer segments. The ranked comparisons are shown above the table.

Max.load: 1>2>3>4>5>6; Stiffness: 4>2>6>1>3>5; Pl.load: 4>6>2>3>1>5

Table 4.1 Bending strength and stiffness of oak spliced stringer segments or a fraction of plate type

| Num | Splice | Plate | MC | SG | Max. load | Stiffness | Pl. load | BN/AN | PF | PTW | CV (%) | | |
|-------------------|--------|-----------------------|------|-----|-----------|-----------|----------|-------|----|-----|--------|-------|----------|
| | | | | | | | | | | | (%) | (lbf) | (lbf/in) |
| ----- means ----- | | | | | | | | | | | | | |
| 1 | VS | truss 3x4 | 13.0 | .69 | 1163 | 1632 | 508 | 60 | 50 | 0 | 4.9 | 6.5 | 19.1 |
| 2 | VS | truss 3x6 | 14.4 | .69 | 1137 | 1816 | 714 | 90 | 10 | 0 | 15.8 | 9.0 | 25.5 |
| 3 | AS | truss 3x4 | 14.4 | .69 | 1069 | 1515 | 615 | 80 | 20 | 10 | 14.5 | 10.9 | 22.0 |
| 4 | Contl | ---- | 14.6 | .69 | 1036 | 2195 | 942 | 100 | -- | -- | 23.9 | 13.2 | 19.9 |
| 5 | VS | plug 3x4 | 13.2 | .69 | 921 | 1444 | 493 | 70 | 30 | 10 | 12.0 | 13.8 | 18.8 |
| 6 | VS | truss 3x4 & 1.25x6 | 14.4 | .69 | 915 | 1812 | 756 | 100 | 0 | 0 | 20.8 | 12.3 | 28.3 |

Notes: the total percentage of BN/AN failures, plate failure, and plate tooth withdrawal may be greater than 100% due to at least two kinds of failures occurring on a same specimen at same test. CV represents coefficient of variation of tested data. "Contl" represents the control.

The results indicate the spliced stringers tested were comparable in strength to the control non-spliced stringers. The 3" x 4" and 3" x 6" truss plates were greater than the 3"x 4" plug plate splices in strength and stiffness. The non-spliced stringer was stiffer than all splices. The performance of the vertical splice and angle splice method are not different. The results indicate the 3" x 4" truss plate results in a stronger splice than the 3" x 4" plug plate. The failure modes are different. The plug plate exhibited more tooth withdrawal than truss plate. The performance of the splice with the 3" x 6" truss plate on bottom is probably the suspect. All failures of these specimens occurred at the notch (100%), and not the plate. It appears that the poor performance of this splice may be attributable to the use of weaker specimens and not a plating effect. The lower strength of

the control specimens was likely the result of weaker notches compared to the notches in the spliced specimens. One would expect the control to be similar to spliced where notch failure determined the result.

The coefficient of variation (CV) 4.9% from the strength testing of the VS specimens with 3" x 4" truss plates was quite low compared with the other tests. These specimens exhibited the largest percentage of plate failure. Wood mechanical properties are more variable than the metal mechanical for the plates, therefore the relative uniformity of the metal strength may be biased the results. Proportional limit loads are lower for spliced stringers than control non-spliced stringers. The larger plates and plate combination represent higher proportional limit loads.

There is no significant difference in performance of the angle and vertical splices. This indicates that splices do not have to be vertical so long as the ends of the two pieces are matched. The scarf shape of the angle splice provides no additional strength or stiffness.

For all five treatments, failures between notch (BN failure) were the most frequent. This indicates that for notched stringers the greatest defect is the notch and not the splice.

4.3.2 The Effect of A Gap between Segments on the Bending Strength and Stiffness of Southern Yellow Pine and Yellow-Poplar Spliced Stringers

Table 4.2 contains the results of testing spliced stringers with and without gaps (1/4") between segments at the time of splicing. Results clearly indicate that the quality of a

splice will depend on how tight the segments are at the time of splicing. The gapped segments of yellow-poplar and southern pine were significantly weaker than the non-gapped specimen by 30% to 40%. For yellow-poplar, the stiffness of the tight splice was greater than the gapped splice, but less than non-splice specimen. Stiffness of spliced southern pine segments was unaffected by the gap.

For yellow poplar:

Max.load: 1>2>3; Stiffness: 2>1>3; Pl.load: 2>1>3

For southern pine:

Max.load: 1>2>3; Stiffness: 1>2>3; Pl.load: 2>1>3

Table 4.2 The effect of a gap between segments on the bending strength and stiffness of southern yellow pine and yellow-poplar spliced stringers

| Num | Species | Splice | Plate (truss) | MC (%) | SG | Max. load (lbf) | Stiffness (lbf/in) | Pl. load (lbf) | BN/AN (%) | PF (%) | PTW (%) | CV (%) | | |
|---------------------------|---------|--------|------------------|-----------|-----|--------------------|-----------------------|-------------------|--------------|-----------|------------|-----------|-----------|----------|
| | | | | | | | | | | | | Max. load | Stiffness | Pl. load |
| ----- YELLOW POPLAR ----- | | | | | | | | | | | | | | |
| 1 | yp | VS | 3x4 | 12.3 | .51 | 934 | 1516 | 480 | 100 | 0 | 0 | 11.2 | 9.2 | 33.6 |
| 2 | control | --- | ---- | 12.3 | .51 | 910 | 2091 | 890 | 100 | 0 | 0 | 15.4 | 11.8 | 16.3 |
| 3 | yp | VSG¼ | 3x4 | 12.3 | .51 | 569 | 1319 | 298 | 20 | 20 | 80 | 12.8 | 9.5 | 8.1 |
| ----- SOUTHERN PINE ----- | | | | | | | | | | | | | | |
| 1 | sp | VS | 3x4 | 12.3 | .46 | 737 | 1436 | 429 | 90 | 10 | 10 | 25.0 | 14.5 | 21.6 |
| 2 | control | --- | ---- | 11.9 | .46 | 565 | 1422 | 539 | 100 | 0 | 0 | 23.1 | 36.4 | 25.0 |
| 3 | sp | VGS¼ | 3x4 | 12.3 | .46 | 511 | 1153 | 255 | 20 | 10 | 70 | 9.9 | 13.0 | 15.4 |

Notes: the total percentage of BN/AN failures, plate failure, and plate tooth withdrawal may be greater than 100% due to at least two kinds of failure occurring on same specimen during same test.

Eighty percent of failures of the spliced stringers with gaps were tooth withdrawal failures, and twenty percent of failures were bending failures of the plates. If during the splicing process gaps occur, plate design should be modified. Heavier gauge plates with

fewer teeth in the middle of plate will reduce the frequency of plate failures. Also tooth density should be modified. Longer but fewer teeth may be preferable.

Clearly when splicing, stringer segments the joint should be flush and tight at the time of splicing. Sawn surfaces will probably provide better performance than sheared surfaces.

4.3.3 Splicing Stringer Segments of Different Wood Species

When splicing stringer segments it will not always be possible to match species, because mixed hardwoods and softwood are used to manufacture pallets, Many workers can't identify the individual species. Stringer segments recovered from different stringers will likely be of different species. Because differentiating stringer species is extremely difficult during manufacture, a test using unmatched yellow-poplar, oak, and southern pine segments was conducted

Two species combinations were studied, oak-yellow-poplar (oak-yp), oak-southern pine (oak-sp). In this experiment, the oak-oak, yp-yp, and sp-sp spliced stringers were controls. The 3 x 4-inch truss plate was applied to all specimens. Average strength, stiffness, and load at proportional limit for stringer bending tests are shown in Table 4.3. The results of hypothesis testing are:

Max. load: 1>3>2>4>5; Stiffness: 2>1>3>4>5; Pl. load: 2>1>3>4>5

According to Table 4.3, when failures occurred at stringer notches, the strength of the weaker species will determine the strength of the spliced stringer. It is clear that

selecting and matching stringer segment species will influence the performance of spliced stringers when species mixes occur.

Table 4.3 The effect of mixing species on the bending strength and stiffness of spliced stringers

| Num | Splice (vs) | Plate (truss) | MC (%) | SG | Max. load (lbf) | Stiffness (lbf/in) | Pl. load (lbf) | BN/AN (%) | PF (%) | PTW (%) | CV (%) | | |
|-------------------|----------------|------------------|-----------|---------|--------------------|-----------------------|-------------------|--------------|-----------|------------|-----------|-----------|----------|
| | | | | | | | | | | | Max. load | Stiffness | Pl. load |
| ----- means ----- | | | | | | | | | | | | | |
| 1 | oak-oak | 3x4 | 13.0 | .69 | 1166 | 1632 | 508 | 100 | 50 | 0 | 4.9 | 6.5 | 19.1 |
| 2 | oak-yp | 3x4 | 12.7 | .69/.51 | 929 | 1635 | 607 | 100 (yp) | 20 | 10 | 15.0 | 12.0 | 34.2 |
| 3 | yp-yp | 3x4 | 12.3 | .51 | 934 | 1516 | 480 | 100 | 0 | 0 | 11.2 | 9.2 | 33.6 |
| 4 | sp-sp | 3x4 | 12.3 | .46 | 737 | 1436 | 429 | 100 | 10 | 10 | 25.0 | 14.5 | 21.6 |
| 5 | oak-sp | 3x4 | 12.7 | .69/.46 | 510 | 1283 | 428 | 100 (sp) | 0 | 0 | 34.4 | 11.1 | 30.9 |

Notes: 1) the total percentage of BN/AN failures, plate failure, and plate tooth withdrawal may be greater than 100% due to at least two kinds of failures occurring on the same specimen during same test. 2) 100(yp) and 100(sp) represent the 100% failures occurring on yellow-poplar and southern pine respectively.

4.3.4 Splicing New and Used Oak Stringer Segments

Test results reported in Sections 4.2.1 through 4.2.3 are from bending tests of spliced new stringer segments. Commercially, stringer segments for splicing will often be salvaged from broken, used pallets. Such segments may be unequal in width and height. This may influence spliced stringer performance. Therefore, a comparative of test of spliced stringers using non-matched used segments (d-size stringer) and using matched used segments cut from same stringer (s-size stringer) was conducted. The results of hypothesis testing are shown below. The average strength and stiffness are in Table 4.4.

Max. load: 1>2>3; Stiffness: 3>2>1; Pl. load: 1>3>2

Ultimate strengths of 1184 lb. for s-size splice and 1096 lb. for d-size splice were not significantly different from that for new oak-oak splice. The stiffness of 1,538 lbf./in. for s-size splice and 1732 lbf./in. for d-size splice were also not significantly different from that for new oak-oak splice.

Table 4.4 The effect of variation of segments size on the bending strength and stiffness of spliced stringers

| Order | Splice (vs) | Plate (truss) | MC (%) | SG | Max. load (lbf) | Stiffness (lbf/in) | Pl. load (lbf) | BN/AN (%) | PF (%) | PTW (%) | CV (%) | | |
|-------------------|----------------|------------------|-----------|-----|--------------------|-----------------------|-------------------|--------------|-----------|------------|-----------|-----------|----------|
| | | | | | | | | | | | Max. load | Stiffness | Pl. load |
| ----- means ----- | | | | | | | | | | | | | |
| 1 | s-size(used) | 3x4 | 12.0 | .69 | 1184 | 1538 | 764 | 40 | 70 | 30 | 10.7 | 12.3 | 13.5 |
| 2 | oak-oak | 3x4 | 13.0 | .69 | 1163 | 1632 | 508 | 60 | 50 | 0 | 4.9 | 6.5 | 19.1 |
| 3 | d-size (used) | 3x4 | 12.0 | .69 | 1096 | 1732 | 582 | 40 | 40 | 50 | 11.1 | 17.9 | 32.7 |

Notes: 1) the total percentage of BN/AN, plate break, and plate teeth withdrawal may be greater than 100% due to at least two kinds of failures occurred on a same specimen at same test.

Not surprisingly, when splicing stringer segments of different sizes more tooth withdrawal failures occur. Although the average performance of new, used of same size and used of different size stringers are not statistically significantly different. However, a trend is evident as shown in Figure 4.1, as the difference in stringer segment width increases, the strength of spliced stringers decreases. A difference in width of 0.10 inches resulted in a reduction in average strength of 10% and a difference of 0.30 inches a reduction in strength of 25%. These data indicate that to avoid a significant reduction in strength, the difference in segment width should not exceed 0.125 or $1/8$ inches.

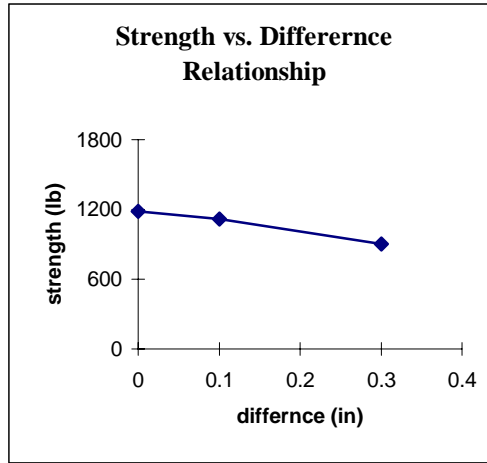


Figure 4.1 The effect of segment width difference on the bending strength of spliced stringers

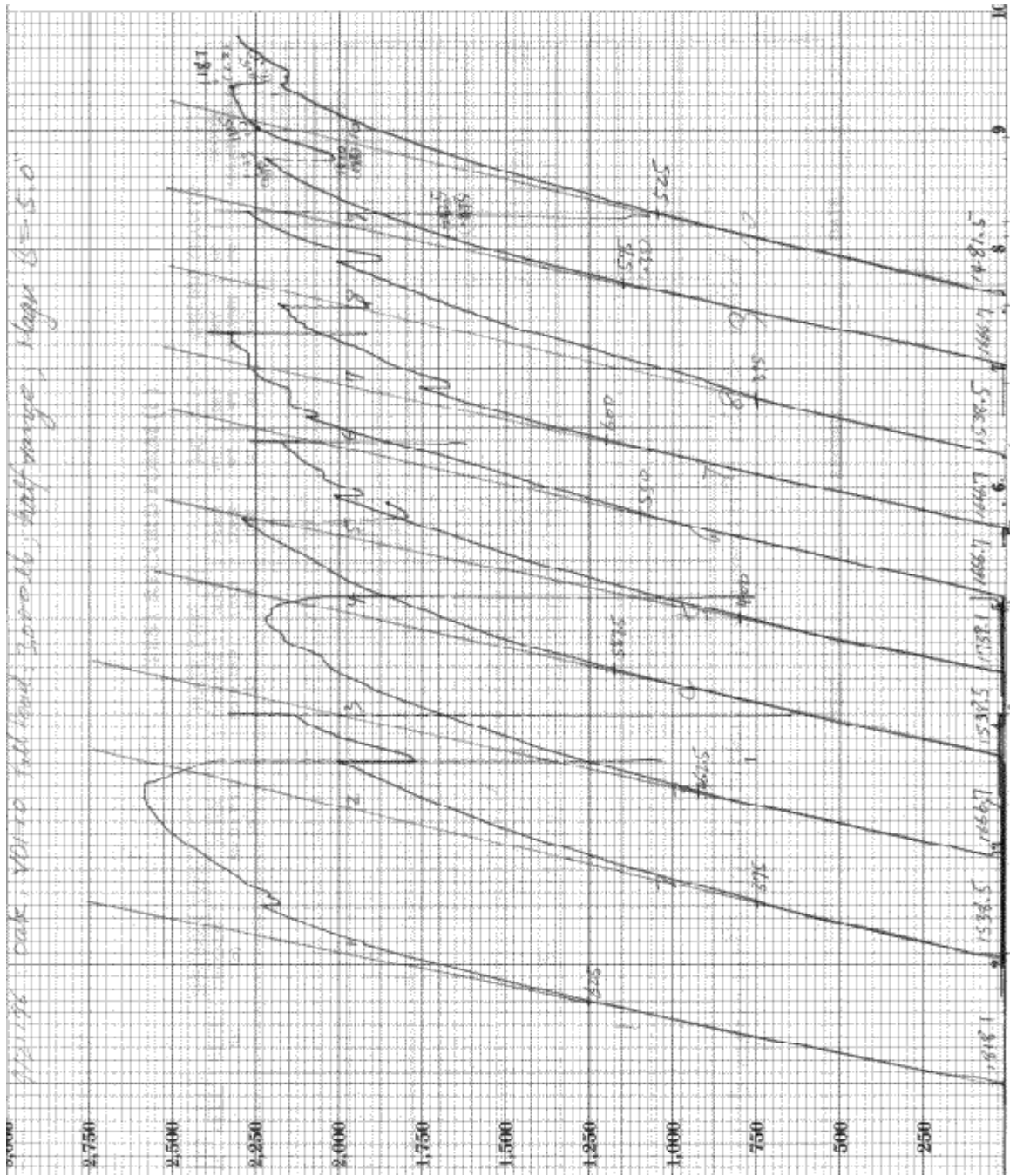


Figure 4.2 Typical Load vs. deflection plot from the bending tests of spliced oak stringers

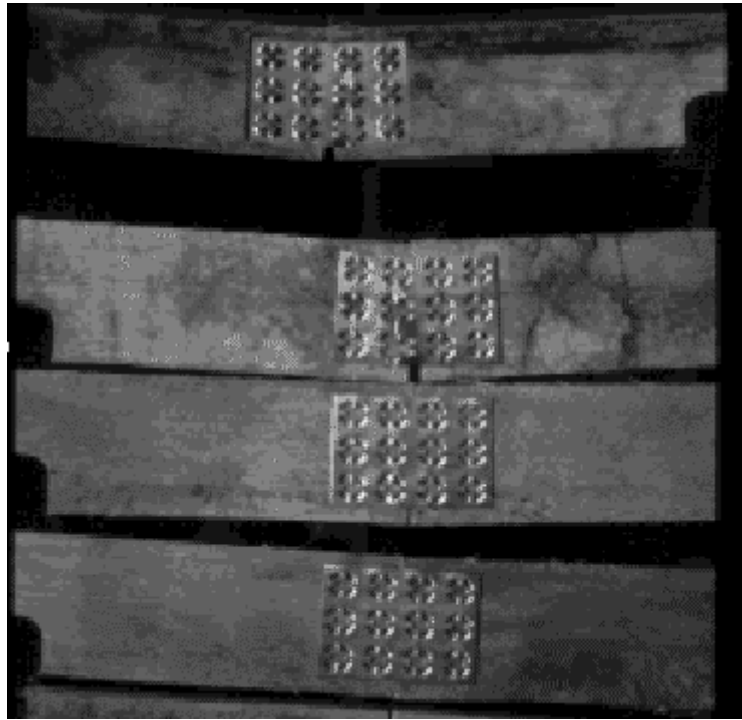
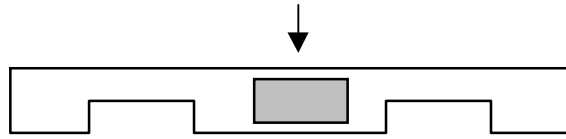


Figure 4.3 Photograph showing the tension failures of plug plates that occurs during the bending tests of vertical spliced stringers

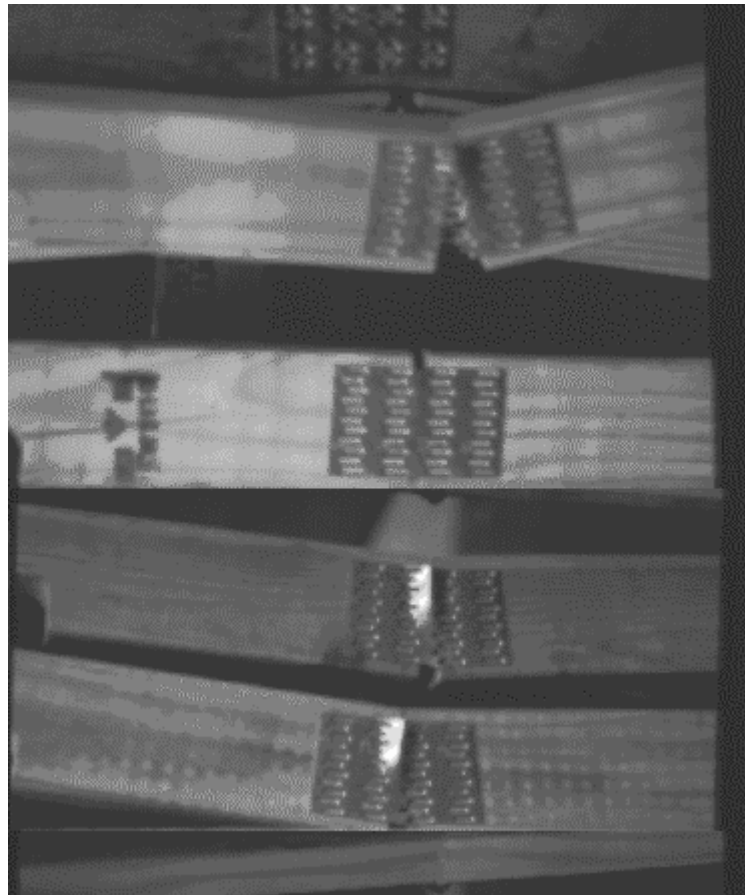
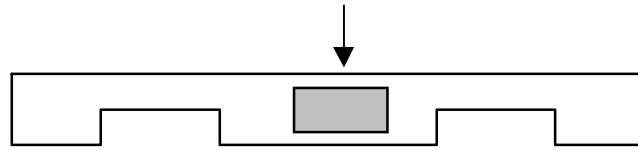


Figure 4.4 Photograph showing the compression and buckling failures of truss plates that occurs during the bending tests of spliced stringers with gap

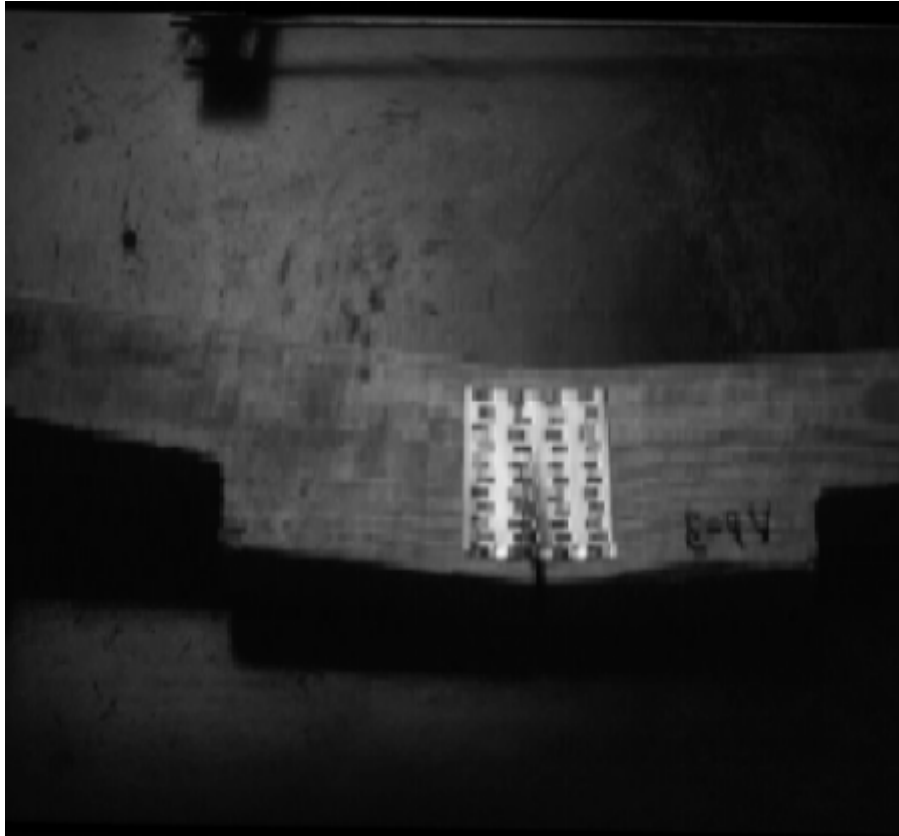


Figure 4.5 Photograph showing the tension failures of truss plates that occurs during the bending tests of vertical spliced stringers
(Note: The portion of plate is enlarged)

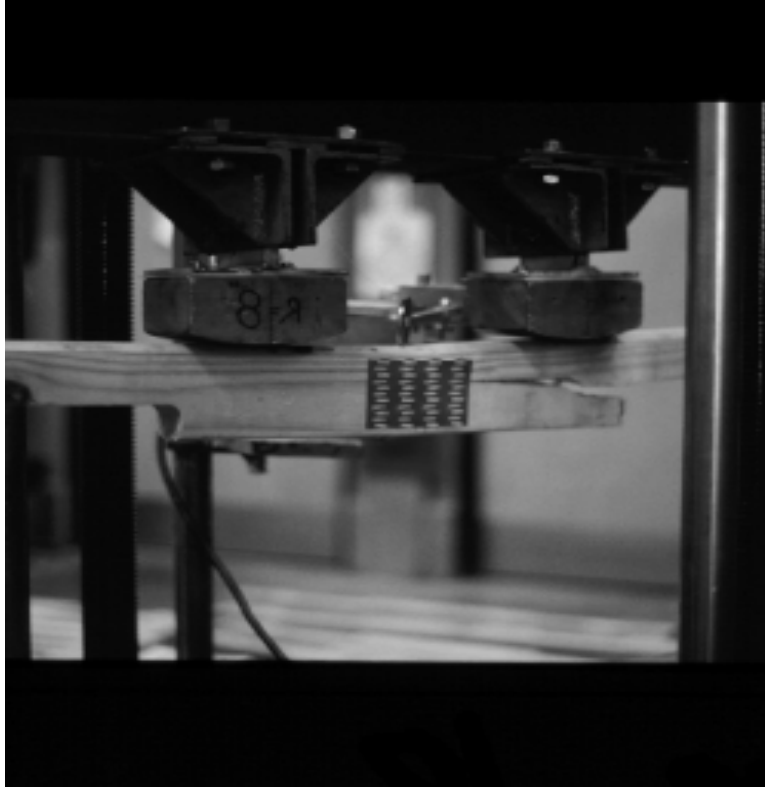


Figure 4.6 Photograph showing the between notch (BN) failure that occurs during the bending tests of vertical spliced stringers



Figure 4.7 Photograph showing the plate withdrawal (PTW) failure that occurs during the bending tests of angle spliced stringers

4.4 Pallets with Spliced Stringers

A test to determine effects of splicing stringers on pallet bending strength and stiffness was conducted. Control pallets and pallets with only the center stringer spliced, with the two side stringers spliced, and with all three stringers spliced, were tested. Control pallets contained no spliced stringers. Vertical splices with 3 x 4-inch truss plates were used. Statistical methods used were similar to those used to analyze the results of stringer bending tests (see Sections 4.2 and 4.3). Figures 4.8-4.11 show load vs. deflection plots from the pallet bending tests. Average pallet bending strengths and stiffnesses are shown in Table 4.5. The hypothesis test results are shown below:

Max. load: 3>1>2>4; Stiffness: 1>2>4>3; Pl. load: 1>2>4>3

Table 4.5 The effect of spliced stringers on pallet bending strength and stiffness

MC(%): 13.2; SG: 0.69; Species: Oak; Splice type: VS; Plate: truss 3"x4"

| Num | Spliced-loc. | M. load (lbf) | Stiff. (lbf/in) | P. load (lbf) | Ctr-stringer (%) | | | Side-stringer (%) | | | CV (%) | | |
|-------------------|--------------|------------------|--------------------|------------------|------------------|-----|-----|-------------------|-----|-----|--------|-----------|---------|
| | | | | | BN/AN | P-B | P-P | BN/AN | P-B | P-P | M-load | Stiffness | Pl-load |
| ----- means ----- | | | | | | | | | | | | | |
| 1 | control | 4870 | 9316 | 3674 | 100 | -- | -- | 90 | -- | -- | 7.1 | 8.1 | 10.0 |
| 2 | center | 4735 | 8417 | 3488 | 40 | 60 | 20 | 60 | -- | -- | 16.7 | 17.8 | 20.5 |
| 3 | 2-side | 5176 | 7885 | 3043 | 120 | -- | -- | 70 | 10 | 40 | 26.6 | 25.8 | 34.9 |
| 4 | all 3 str | 4323 | 6785 | 3245 | 40 | 40 | 20 | 40 | 20 | 30 | 33.2 | 18.3 | 16.6 |

Notes: 1) the total percentage of BN/AN, plate break, and plate teeth withdrawal may be greater than 100% due to at least two kinds of failures were occurred on a same specimen in same test. 2) center, 2-side, and all 3 str respectively represent that the center, both two sides, and all three stinger(s) are spliced stinger(s).

Hypothesis testing indicates no significant differences in average strength or stiffness between the control pallets and those containing, 1, 2, or 3 spliced stringers. The 50 to 80 percent plate failures which occurred in spliced stringer pallets did not significantly influence the results. However, the variation of the bending strength and stiffness of the control pallet tested was significantly lower than the variation bending strength and stiffness of pallets containing 1, 2 and 3 spliced stringers.

The 5% lower exclusion limit (LEL) of maximum load, stiffness, and load at proportional limit for the three tests are shown in Table 4.6.

Table 4.6 5% lower exclusion limit (LEL) of pallet banding strength and stiffness measurement

| Spliced stringer location | M. load (lbf) | Stiff.(lbf/in) | P. load (lbf) |
|----------------------------|---------------|----------------|---------------|
| Control | 4303 | 8067 | 3067 |
| Center stringer plated | 3434 | 5946 | 2310 |
| Both side stringers plated | 2913 | 4539 | 1290 |
| Three stringers plated | 1961 | 4745 | 2350 |

When one accounts for the difference in variation, it is clear that pallet with spliced stringers have 50 to 75% of the stiffness of pallets with non-spliced stringers, and strength decreases by 20, 33 and 55% as spliced stringers are used to replace non-spliced stringers. While any stringer in pallets had opportunity to fail, the center stringer failed most frequently due to the fact that under the support condition of the tests the center stringer supports the most load. From Table 4.7, it is shown that 80% of the failures in all specimens tested occurred in the center stringer. When one compares the slope of the force-deflection curves in Figures 4.8 to 4.11, pallets with all three stringers spliced

exhibited a non-linear response. Therefore, spliced stringers should not be placed in the center of pallets and the number of spliced stringers per 3 stringer pallet should not exceed two.

Table 4.7 Location of first failure during pallet bending tests

| | Non spliced Stringers | | Center Spliced Stringers | | 2-side Spliced Stringers | | 3-spliced Stringers | |
|-----|-----------------------|-------|--------------------------|-------|--------------------------|------|---------------------|------|
| | Center | Sides | Center | Sides | Center | Side | Center | Side |
| (%) | 80 | 20 | 80 | 80 | 80 | 20 | 80 | 40 |

Note: The percentages of center and side stringers in a splice test are more than 100% because center stringer and side stringer fractures occurred at almost the same time.

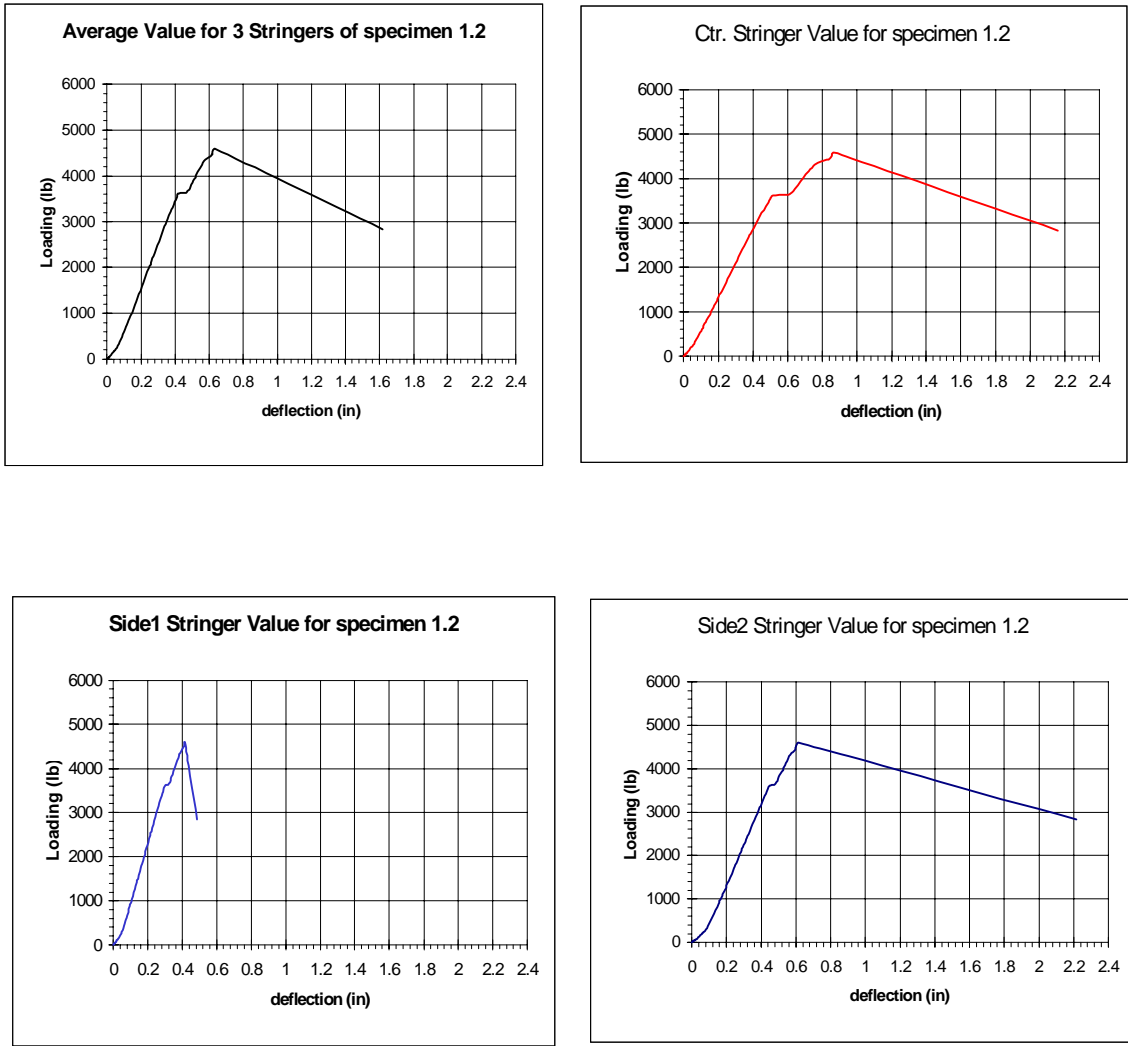


Figure 4.8 Load vs. deflection relationship from pallet bending tests (examples) of pallet without spliced stringers

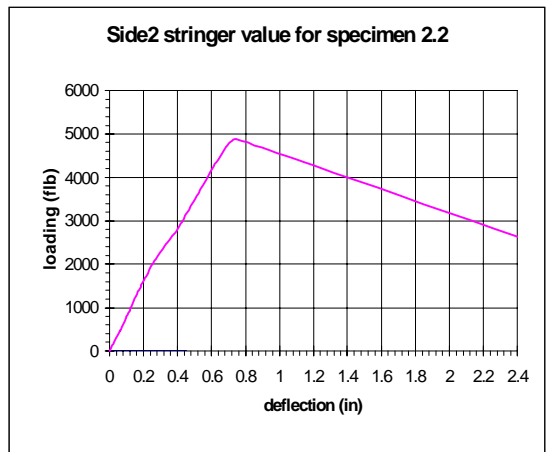
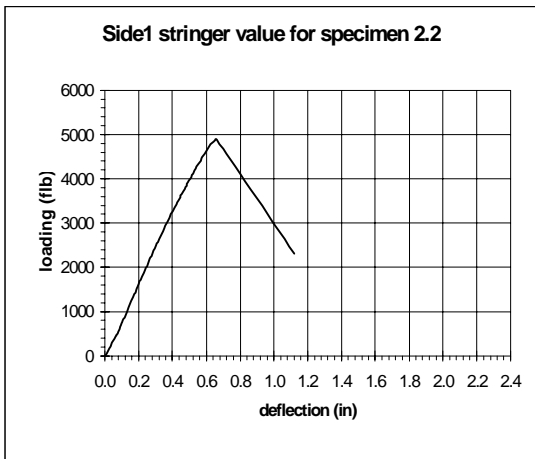
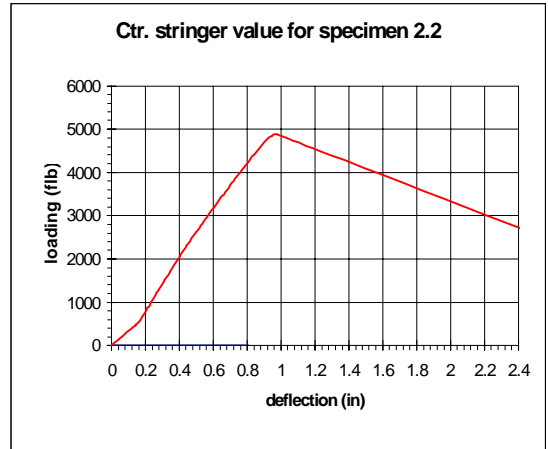
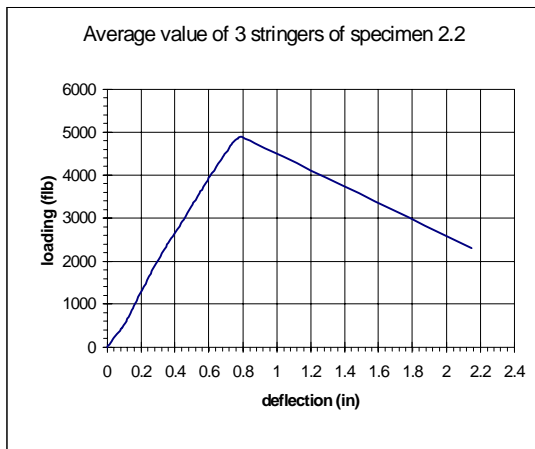


Figure 4.9 Loading vs. deflection relationship of pallet bending tests (examples) of pallet with center stringer spliced

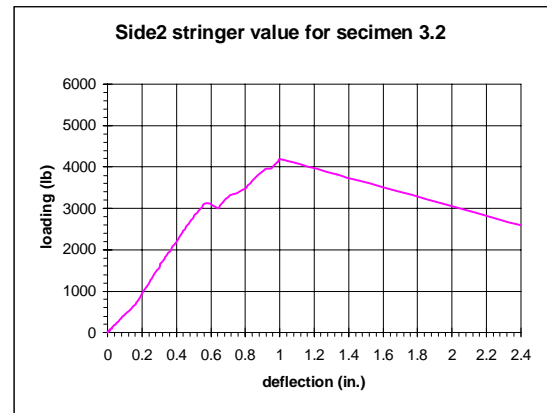
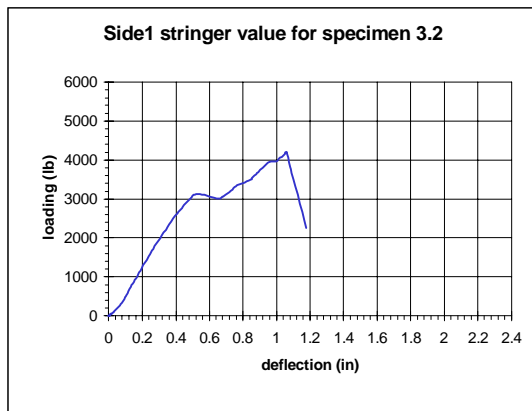
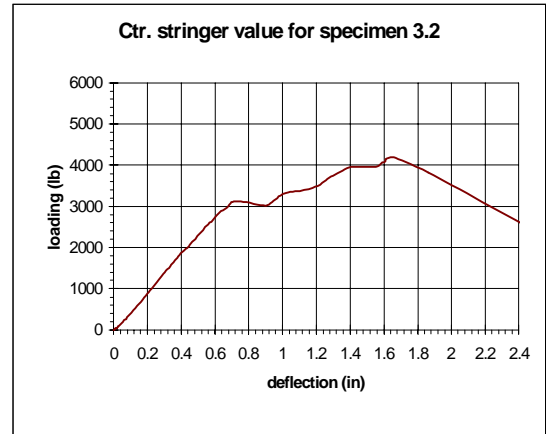
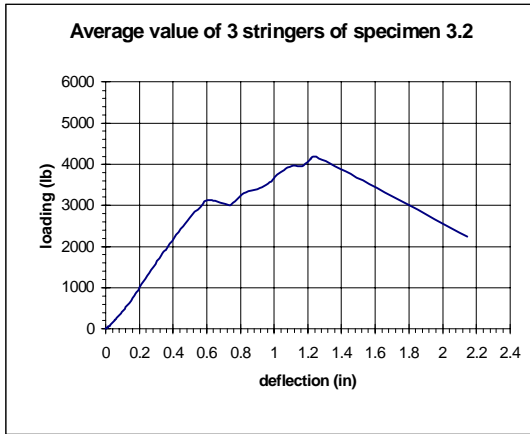


Figure 4.10 Loading vs. deflection relationship from pallet bending tests (examples) of pallet with both side stringers spliced

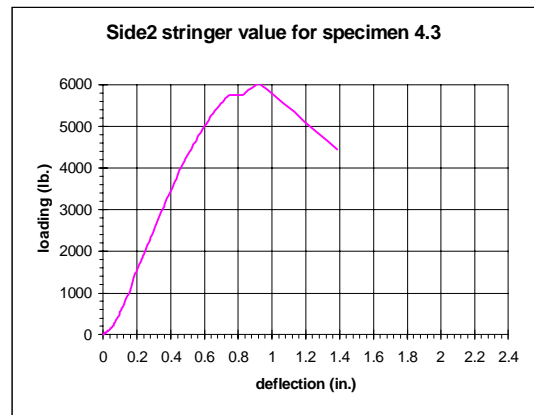
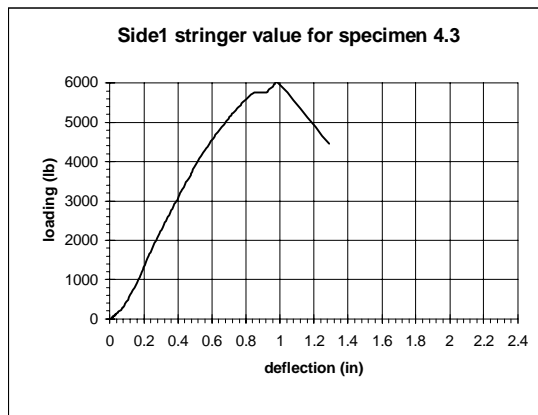
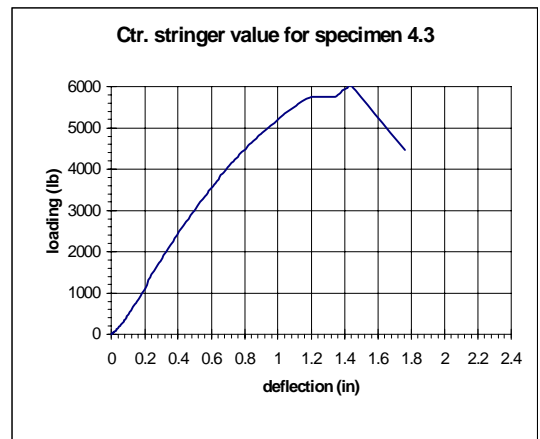
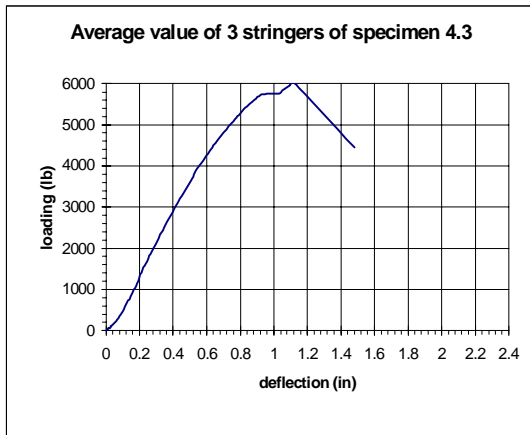


Figure 4.11 Loading vs. deflection relationship from pallet bending tests (examples) of pallet with three spliced stringers

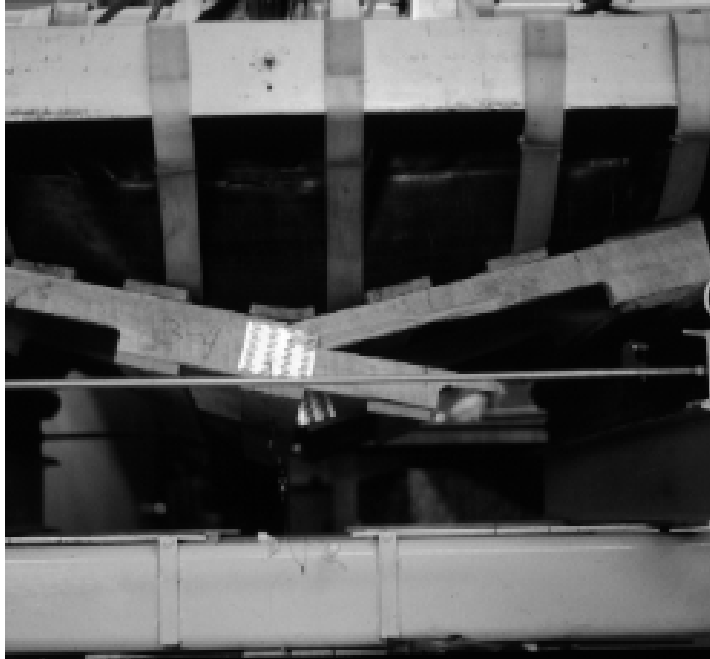


Figure 4.12 Photograph showing the between-notch (BN) failure of stringer in pallet bending test



Figure 4.13 Photograph showing the plate break (PF) failure in pallet bending test



Figure 4.14 Photograph showing the plate withdraw (PTW) failure in pallet bending test



Figure 4.15 Photograph showing the between-notch (BN) and plate break (PF) failure of stringers in bending pallet test

5. SUMMARY AND CONCLUSIONS

5.1 Summary

A. Stringers

New and used oak, yellow-poplar, and southern pine notched stringer segments were spliced with different types of metal connector plates, and tested in bending. Plates tested were 20 gauge 3 x 4 and 3 x 6 inch truss plates, a 3 x 4 inch plug plate and a combination 3 x 4 and 3 x 6 inch truss plates. Sensitivity of splicing stringer segments to the type of the connection and gaps at the splicing was studied. Quality variations such as unmatched species and segment size were also evaluated.

Non-spliced whole stringers were used as control specimens. Average ultimate bending strength, stiffness, load at proportional limit, and failure mode were compared.

B. Pallets

To test the influence of stringer splicing on pallet performance, 48 x 40 GMA style oak pallets containing one, two and three spliced stringers were tested in bending spanning in the direction parallel to the stringer. Specimens contained one spliced center stringer, two spliced side stringers, and all three spliced stringers.

5.2 Conclusions

All conclusions are based on the particular materials and test procedures used in the experiment. The results apply only to the splicing of notched stringer segments or pallets with spliced notched stringers.

5.2.1 Spliced Stringers

- The greatest defect is the notch and not the splice. The notch determined spliced stringer performance.
- There is no significant difference in strength between the spliced and non-spliced stringers without gaps, but the stiffness was significantly lower for spliced stringers except for southern pine.
- There is no difference in performance between stringer spliced with 3 x 4 and 3 x 6 truss plates.
- The strength of spliced stringers with truss plates was greater than that of spliced stringers with plug plates.
- Angle or vertical surfaces at the splice perform in a similar manner, therefore, the most cost effective orientation should be used.
- Gaps between the two spliced segments weaken the spliced stringers. The ¼-inch gap significantly reduces splice strength and stiffness by an average of 35% and 16%. During splicing, end pressure should be applied to ensure tight joints. Smooth sawn matching surfaces are necessary at the splice for the best performance.
- When combining species, if fracture occurs in stringer notches, the mechanical behavior is principally determined by the weaker species segment.

- Slots in plates near the splice interface weaken the joint. Most plate failures occur at the edge of plate on the tension side, therefore, reinforcing this area by improving the structural design of the metal plate could help reduce plate failures and improve average performance.
- A difference in width of spliced stringer segments up to 0.30 inches did not significantly decrease the spliced stringer performance. However, a trend of reduced performance occurs.

5.2.2 Pallets with Spliced Stringer(s)

- The average strength and stiffness of GMA pallets containing 0, 1, 2 and 3 spliced stringers are not significantly different.
- Pallets with spliced stringers are less stiff.
- Failures occurred more frequently at center stringers than at both side stringers, because the center stringer supports a greater load on the pallet.
- The strength and stiffness of pallets with spliced stringers varies significantly more than pallet with no spliced stringers.
- The variation of strength increases as the number of spliced stringers increases in a pallet.
- Predicted design loads for spliced stringer pallets are lower than pallets without spliced stringers.

6. RECOMMENDATIONS FOR FUTURE RESEARCH

In this study, only static bending tests of stringers and pallets were performed. Because pallets are subjected to dynamic stresses during use, it is recommend that dynamic tests are conducted. Future tests should include larger sample sizes and different segment sizes and gaps. Splicing longer non-notched segments should be evaluated, because long stringers represent a significant cost during pallet recycling.

Plate design influences splice performance. Tooth density should be adjusted to obtain maximum tooth withdrawal resistance yet minimize plate failure in tension due to bending. Figure 6.1 is an example of such a design.

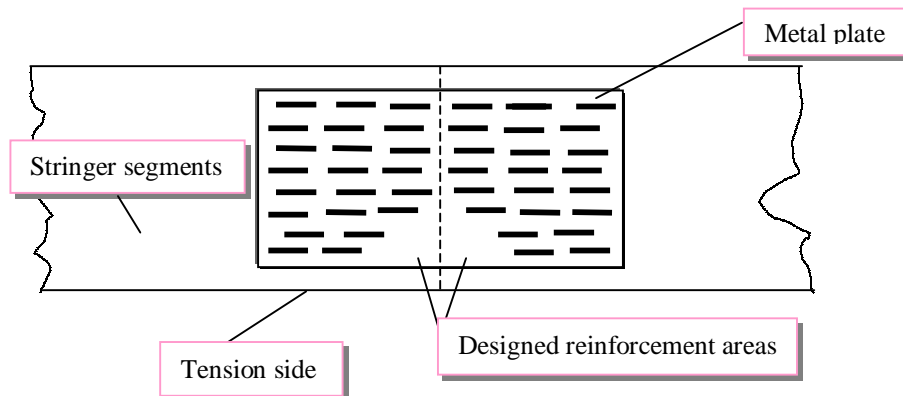


Figure 6.1 Reinforcement plate design

LITERATURE CITED

1. ASTM, 1996. Standard method of static tests of lumber in structural sizes. ASTM D 198 – 94. ASTM, Philadelphia, PA.
2. ASTM, 1996. Standard practice for evaluating allowable properties for grades of structural lumber. ASTM D 2915 – 93. ASTM, Philadelphia, PA.
3. ASTM, 1996. Standard test method for pallet and related structures employed in materials handling and shipping. ASTM D 1185 – 94. ASTM, Philadelphia, PA.
4. ASTM, 1996. Standard test method for specific gravity of wood and wood-base materials. ASTM D 2395 – 93. ASTM, Philadelphia, PA.
5. ASTM, 1996. Standard test method for tensile strength properties of steel truss plates. ASTM E 489 – 81. ASTM, Philadelphia, PA.
6. ASTM, 1996. Standard test method for direct moisture content measurement of wood and wood-base materials. ASTM D 4442 – 92. ASTM, Philadelphia, PA.
7. ASTM, 1997. Standard specification for steel, sheet, zinc-coated (galvanized) by the hot-dip process, structural (physical) quality. ASTM A653/A653M – 96. ASTM, Philadelphia, PA.

8. Bush, J. R., Reddy, S. V., Bumgardner, S. M., Chamberlain, L. J., Araman, .A. P. 1997. Recycling in the U. S. Pallet Industry: 1995. Center for Forest Products Marketing and Management. Virginia Tech, Blacksburg, VA 24061.
9. Clarke, W. J., McLain E. T., White, S. M., and Araman, A. P. 1993. *Evaluation of metal connector plates for the repair of wood pallet stringers*. Forest Products Journal 43(10):15-22.
10. Clarke, W. J. 1993. *Evaluation of metal connector plates for the repair of wood pallet stringers*. Thesis for MS. degree in Wood Sci. & Forest Prod. Virginia Tech, Blacksburg, VA 24061.
11. Edward E. Callahan, P. E., 1993. *Metal plate connected wood truss handbook*. Wood Truss Council of America, Madison, WI 53711-4125.
12. Groom, L. and Polensek, A. 1992. *Nonlinear modeling of truss-plate joints*. Journal of structural engineering 118(9): 2541-2531.
13. Gupta,R. 1994. Metal-plate connected tension joints under different loading conditions. Wood and Fiber Science. 26(2): 212-222.
14. Hansen, Eric, R. Bush, J. Panches, P. Araman, 1994. *Recycling in the US pallet industry*, 1993. Report for the Center for Forest Products Marketing. Dept. of Wood Science and Forest Products. VPI&SU. Blacksburg, VA 24061-0503.

15. ISO, 1991. *General-purpose flat pallets for through transit of goods – test methods*.
ISO 8611. International Organization for standardization, Case Postale 56 • CH-1211
Genève 20 • Switzerland.
16. Kirk, L.S., McLain, T.E., and Woeste, F.E. 1989. *Effect of gap size on performance of metal-plated joints in compression*. *Wood and Fiber Science*. 21(3): 274-288.
17. Laundrie, F. J. 1986. *Unitizing goods on pallets and slipsheets*. Gen. Tech. Rep. FPL-GTR-52. USDA Forest Service, Forest Products Lab, Madison, WI.
18. Mackes, H. K., Loferski, R. J., and White, S. M. 1995. *A pneumatic pressure bag testing machine for applying a uniform load to panels and pallets*. Department of William H. Sardo Jr. Pallet & container Research Laboratory, Blacksburg, Virginia 24061-0503.
19. McCurdy, R. D., Phelps E. J. 1996. *The pallet industry in the United States 1980, 1985, 1990, and 1995*. Department of Forestry, College of Agriculture, Southern Illinois University at Carbondale, Illinois.
20. Noguchi, M. 1980. *Ultimate resisting moment of butt joints with plate connectors stressed in bending*. *Wood Science* 12(3): 168-175.
21. NWPCA. 1993. *Uniform voluntary standard for wood pallets*. NWPCA, Arlington, VA 22209-2109.

22. O'Regan, J. P. 1997. *Combined tension and bending loading in bottom chord splice joints of metal-plate-connected wood trusses*. Thesis for MS. Degree in Biological Systems Engineering. Virginia Tech, Blacksburg, VA 24061.
23. Reddy, S. V., Bush, J. R., Bumgardner, S. M., Chamberlain, L. J., Araman, .A. P. 1997. *Wood use in the U.S. pallet and container industry: 1995*. Center for Forest Products Marketing and Management. Virginia Tech, Blacksburg, VA 24061
24. Résumé en français. 1976. *Reusable wood pallets: selection and proper design*. Department of Fisheries and the Environment, Canadian Forestry Service, Ottawa.
25. Stahl, C. D., Wolfe, W. R., Cramer, M. S., and Mcdonald, D. 1994. *Strength and stiffness of large-gap metal-plate wood connections*. Res. Pap. FPL-RP-535. USDA Forest Service, Forest Products Lab. Madison, WIS.
26. Truss Plate Institute (TPI). 1995. National design standard for metal plate connected wood truss construction - ANSI/TPI 1-1995. Truss Plate Institute, Madison, WI 53719.
27. Truss Plate Institute (TPI). 1995. Commentary and appendices to ANSI/TPI 1-1995 National design standard for metal plate connected wood truss construction. Truss Plate Institute, Madison, WI 53719.
- 28.** Wolfe, R.W., Hall, M., and Lyles, D. 1991. *Test apparatus for simulating interactive loads on metal plate wood connections*. Journal of Testing and Evaluation.19(6): 421-

428.

Appendix A

Some Metal Connector Plates used to Pallet Stringer Repairs and Splices

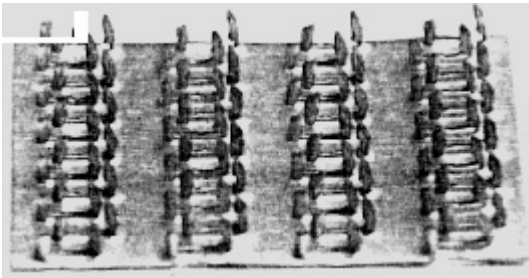


Figure A.1 Truss plate 3x4 or 3x6-inch
(20 gauge, 2-tooth, alternating)

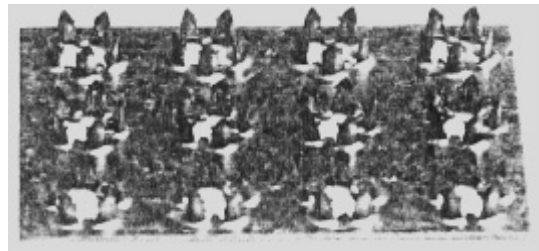


Figure A.2 Plug plate 3x4-inch (20 gauge,
5-tooth plug, round)

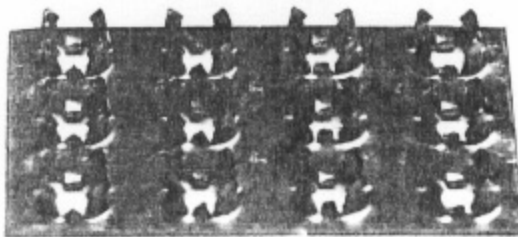


Figure A.3 Plug plate 3x4-inch (20 gauge,
4-tooth, round)

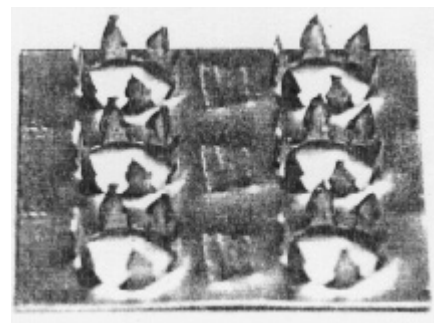


Figure A.4 Plug plate 3x3-inch (20 gauge,
6-tooth, round)

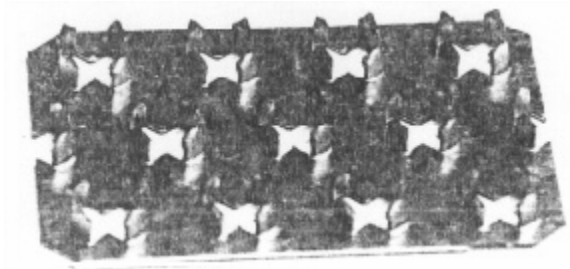


Figure A.5 Plug plate 3x4-inch (20 gauge, 4-tooth, x-shaped alternating)

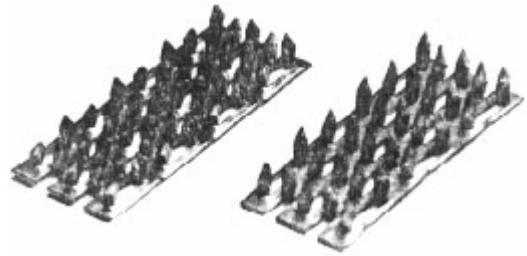


Figure A.6 Truss plate 1.25x3.25-inch (20 gauge, 2-tooth)

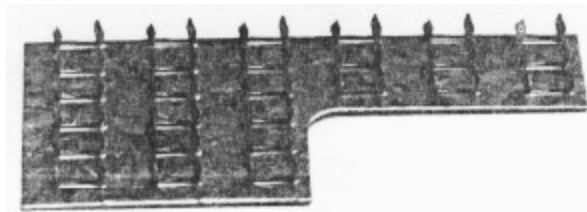


Figure A.7 Truss plate 2x6 and 3x6-inch (20 gauge, 2-tooth, in-series)



Figure A.8 Plug plate 2x6-inch (20-gauge, 5-tooth, round)

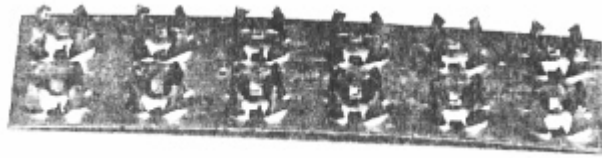


Figure A.9 Plug plate 2x6-inch (20 gauge, 4-tooth, round)



Figure A.10 Plug plate 2x6-inch (20 gauge, 4-tooth, x-shaped)

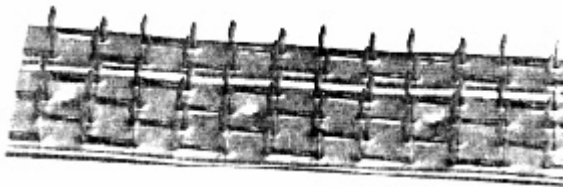


Figure A.11 Truss plate 2x6-inch (20 gauge, 2-tooth, alternating)



Figure A.12 Truss plate 2x13 and 3x13-inch (20 gauge, 2-tooth, in-series)

Appendix B

Values of the t Statistics Used in This Study

Table 1 Values of the t Statistics Used in Calculating Confidence Intervals^A

| n - 1 | CI = 75% | df CI = 95% | CI = 99% |
|-------|----------|----------------|----------|
| 1 | 2.414 | 12.706 | 63.657 |
| 2 | 1.604 | 4.303 | 9.925 |
| 3 | 1.423 | 3.182 | 5.841 |
| 4 | 1.344 | 2.766 | 4.604 |
| 5 | 1.301 | 2.571 | 4.032 |
| 6 | 1.273 | 2.447 | 3.707 |
| 7 | 1.254 | 2.365 | 3.499 |
| 8 | 1.240 | 2.306 | 3.355 |
| 9 | 1.230 | 2.262 | 3.250 |
| 10 | 1.221 | 2.228 | 3.169 |
| 11 | 1.214 | 2.201 | 3.106 |
| 12 | 1.209 | 2.179 | 3.055 |
| 13 | 1.204 | 2.160 | 3.012 |
| 14 | 1.200 | 2.145 | 2.977 |
| 15 | 1.197 | 2.131 | 2.947 |
| 16 | 1.194 | 2.120 | 2.912 |
| 17 | 1.191 | 2.110 | 2.898 |
| 18 | 1.189 | 2.101 | 2.878 |
| 19 | 1.187 | 2.093 | 2.861 |
| 20 | 1.185 | 2.086 | 2.845 |
| 21 | 1.183 | 2.080 | 2.831 |
| 22 | 1.182 | 2.074 | 2.891 |
| 23 | 1.180 | 2.069 | 2.807 |
| 24 | 1.179 | 2.064 | 2.797 |
| 25 | 1.178 | 2.060 | 2.787 |
| 26 | 1.177 | 2.056 | 2.779 |
| 27 | 1.176 | 2.052 | 2.771 |
| 28 | 1.175 | 2.048 | 2.763 |
| 29 | 1.174 | 2.045 | 2.756 |
| 30 | 1.173 | 2.042 | 2.750 |
| 40 | 1.167 | 2.021 | 2.704 |
| 60 | 1.162 | 2.000 | 2.660 |
| 120 | 1.156 | 1.980 | 2.617 |
| ∞ | 1.150 | 1.960 | 2.576 |

Note: This table copy from ASTM D 2915 of 1996

Appendix C

The Data Display of Bending Stringer and Pallet Tests

A. Bending Stringer Tests:

1. Oak full stringers (control):

| Specimen | Max.Load | Pl.Load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 562.5 | 562.5 | 2105.3 |
| 2 | 1115.0 | 1062.5 | 2500.0 |
| 3 | 1105.0 | 1105.0 | 2597.4 |
| 4 | 937.5 | 937.5 | 2352.9 |
| 5 | 935.0 | 935.0 | 2222.2 |
| 6 | 1400.0 | 1250.0 | 2500.0 |
| 7 | 835.0 | 835.0 | 1739.1 |
| 8 | 960.0 | 960.0 | 2105.3 |
| 9 | 1147.5 | 985.0 | 1923.1 |
| 10 | 1357.5 | 787.5 | 1904.8 |
| average | 1035.5 | 942.0 | 2195.0 |
| CV(%) | 23.9 | 19.9 | 13.2 |

2. Oak vertical spliced stringers using 3x4 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 1245.0 | 625.0 | 1818.1 |
| 2 | 1165.0 | 375.0 | 1538.5 |
| 3 | 1110.0 | 462.5 | 1666.7 |
| 4 | 1147.0 | 587.5 | 1538.5 |
| 5 | 1132.5 | 400.0 | 1739.1 |
| 6 | 1200.0 | 550.0 | 1666.7 |
| 7 | 1045.0 | 600.0 | 1666.7 |
| 8 | 1187.5 | 375.0 | 1538.5 |
| 9 | 1202.5 | 575.0 | 1666.7 |
| 10 | 1200.0 | 525.0 | 1481.5 |
| average | 1163.4 | 507.5 | 1632.1 |
| CV(%) | 4.9 | 19.1 | 6.5 |

3. Oak vertical spliced stringers using 3x6 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 1240.0 | 712.5 | 1600.0 |
| 2 | 1390.0 | 912.5 | 2105.3 |
| 3 | 1087.5 | 491.3 | 1612.9 |
| 4 | 1055.0 | 800.0 | 1904.8 |
| 5 | 1277.5 | 887.5 | 1739.1 |
| 6 | 1276.0 | 825.0 | 1818.2 |
| 7 | 1052.5 | 537.5 | 1739.1 |
| 8 | 1130.0 | 935.0 | 1739.1 |
| 9 | 1125.5 | 562.5 | 1904.8 |
| 10 | 737.5 | 475.0 | 2000.0 |
| average | 1137.2 | 713.9 | 1816.3 |
| CV(%) | 15.8 | 25.5 | 9.0 |

4. Oak vertical spliced stringers using 3x4 & 3x6 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 905.0 | 825.0 | 1562.5 |
| 2 | 1165.0 | 1165.0 | 2173.9 |
| 3 | 1190.0 | 737.5 | 2118.6 |
| 4 | 757.5 | 757.5 | 1666.7 |
| 5 | 1112.0 | 675.0 | 1923.1 |
| 6 | 762.5 | 737.0 | 1666.7 |
| 7 | 617.5 | 375.5 | 1785.7 |
| 8 | 850.0 | 837.5 | 1923.1 |
| 9 | 945.0 | 925.0 | 1785.7 |
| 10 | 840.0 | 525.0 | 1515.2 |
| average | 914.5 | 756.0 | 1812.1 |
| CV(%) | 20.8 | 28.3 | 12.3 |

5. Oak 45° angle spliced stringers using 3x4 truss plates:

| Row | Max.load | Pl.load | Stiffness |
|---------|----------|---------|-----------|
| 1 | 805.0 | 450.0 | 1538.5 |
| 2 | 1245.0 | 700.0 | 1666.7 |
| 3 | 1062.5 | 825.0 | 1904.0 |
| 4 | 1240.0 | 662.5 | 1481.5 |
| 5 | 1025.0 | 537.5 | 1350.0 |
| 6 | 987.5 | 725.0 | 1481.5 |
| 7 | 1112.5 | 437.5 | 1482.6 |
| 8 | 1275.0 | 562.5 | 1481.5 |
| 9 | 1045.0 | 500.0 | 1379.3 |
| 10 | 887.5 | 750.0 | 1379.3 |
| average | 1068.5 | 615.0 | 1514.6 |
| CV(%) | 14.5 | 22.0 | 10.9 |

6. Oak vertical spliced stringers using 3x4 plug plates:

| <i>Specimen</i> | <i>Max.load</i> | <i>Pl.load</i> | <i>Stiffness</i> |
|-----------------|-----------------|----------------|------------------|
| 1 | 857.5 | 425.0 | 1111.1 |
| 2 | 920.0 | 475.0 | 1666.7 |
| 3 | 862.5 | 675.0 | 1481.5 |
| 4 | 1050.0 | 562.5 | 1538.5 |
| 5 | 985.0 | 500.0 | 1176.5 |
| 6 | 940.0 | 512.5 | 1538.5 |
| 7 | 955.0 | 362.5 | 1503.8 |
| 8 | 660.0 | 375.0 | 1250.0 |
| 9 | 952.5 | 500.0 | 1481.5 |
| 10 | 1022.5 | 537.5 | 1694.9 |
| average | 920.5 | 492.5 | 1444.3 |
| CV(%) | 12.0 | 18.8 | 13.8 |

7. Used oak vertical spliced stringers (same size segments) using 3x6 truss plates:

| Specimen | Max.Load | Pl.Load | Stiffness |
|-----------------|-----------------|----------------|------------------|
| 1 | 1265 | 875 | 1333.3 |
| 2 | 887 | 581 | 1156.1 |
| 3 | 1160 | 750 | 1538.5 |
| 4 | 1165 | 705 | 1538.5 |
| 5 | 1250 | 700 | 1818.2 |
| 6 | 1255 | 906 | 1666.7 |
| 7 | 1230 | 725 | 1739.1 |
| 8 | 1150 | 900 | 1515.2 |
| 9 | 1120 | 725 | 1538.5 |
| 10 | 1360 | 775 | 1538.5 |
| average | 1184 | 764 | 1538.3 |
| CV(%) | 10.7 | 13.5 | 12.3 |

8. Used oak vertical spliced stringers (different size segments) using 3x6 truss plates:

| Specimen | Max.Load | Pl.Load | Stiffness |
|-----------------|-----------------|----------------|------------------|
| 1 | 950 | 575 | 1666.7 |
| 2 | 960 | 206 | 1212.1 |
| 3 | 1150 | 725 | 2222.2 |
| 4 | 1238 | 700 | 1666.7 |
| 5 | 1085 | 375 | 1538.5 |
| 6 | 955 | 389 | 1333.3 |
| 7 | 1280 | 750 | 1904.8 |
| 8 | 1013 | 700 | 2000.0 |
| 9 | 1168 | 700 | 1904.8 |
| 10 | 1158 | 700 | 1869.2 |
| average | 1096 | 582 | 1731.8 |
| CV(%) | 11.1 | 32.7 | 17.9 |

9. Yellow-poplar full stringers (controls):

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 1057.5 | 1057.5 | 2222.2 |
| 2 | 1095.0 | 1095.0 | 2090.8 |
| 3 | 765.0 | 765.0 | 2090.8 |
| 4 | 965.0 | 965.0 | 2000.0 |
| 5 | 775.0 | 762.5 | 1666.7 |
| 6 | 950.0 | 950.0 | 2222.2 |
| 7 | 935.0 | 831.3 | 1904.8 |
| 8 | 650.0 | 650.0 | 2105.3 |
| 9 | 1000.0 | 1000.0 | 2500.0 |
| 10 | 907.5 | 818.5 | 2105.3 |
| average | 910.0 | 889.5 | 2090.8 |
| CV(%) | 15.4 | 16.3 | 11.8 |

10. Yellow-poplar vertical spliced stringers using 3x4 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 987.5 | 562.5 | 1538.5 |
| 2 | 805.0 | 637.5 | 1333.3 |
| 3 | 905.0 | 625.0 | 1818.2 |
| 4 | 1135.0 | 687.5 | 1587.3 |
| 5 | 977.5 | 550.0 | 1538.5 |
| 6 | 937.5 | 412.5 | 1481.5 |
| 7 | 925.0 | 287.5 | 1481.5 |
| 8 | 995.0 | 475.0 | 1428.6 |
| 9 | 912.5 | 362.5 | 1600.0 |
| 10 | 755.0 | 200.0 | 1351.4 |
| average | 833.5 | 480.5 | 1515.9 |
| CV(%) | 11.2 | 33.6 | 9.2 |

11. Yellow-poplar vertical gap (1/4") spliced stringers using 3x4 truss plates:

| Row | Max.load | Pl.load | Stiffness |
|---------|----------|---------|-----------|
| 1 | 512.5 | 300.0 | 1428.6 |
| 2 | 652.5 | 312.5 | 1379.3 |
| 3 | 450.0 | 300.0 | 1176.5 |
| 4 | 657.5 | 287.5 | 1212.1 |
| 5 | 657.5 | 250.0 | 1250.0 |
| 6 | 500.0 | 287.5 | 1250.0 |
| 7 | 567.5 | 337.5 | 1307.2 |
| 8 | 522.5 | 312.5 | 1600.0 |
| 9 | 600.0 | 312.5 | 1250.0 |
| 10 | 565.0 | 275.0 | 1333.3 |
| average | 568.5 | 297.5 | 1318.7 |
| CV(%) | 12.8 | 8.1 | 9.5 |

12. Southern yellow pine stringers (control):

| Specimen | Max_load | Pl_load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 575.5 | 575.0 | 1538.5 |
| 2 | 362.5 | 362.0 | 869.6 |
| 3 | 712.0 | 700.0 | 1422.0 |
| 4 | 550.0 | 538.0 | 1290.0 |
| 5 | 447.5 | 400.0 | 816.3 |
| 6 | 675.5 | 668.8 | 2352.9 |
| 7 | 547.5 | 537.5 | 1142.9 |
| 8 | 575.0 | 515.0 | 1481.5 |
| 9 | 775.5 | 731.3 | 2222.2 |
| 10 | 425.0 | 362.5 | 1081.0 |
| average | 564.6 | 539.0 | 1422.1 |
| CV(%) | 23.1 | 25.0 | 36.4 |

13. Southern yellow pine vertical spliced stringers using 3x4 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 912.5 | 325.0 | 1428.6 |
| 2 | 832.5 | 412.5 | 1666.7 |
| 3 | 917.5 | 412.5 | 1538.5 |
| 4 | 900.0 | 512.5 | 1333.3 |
| 5 | 802.5 | 487.5 | 1428.6 |
| 6 | 842.5 | 400.0 | 1709.4 |
| 7 | 580.0 | 387.5 | 1052.6 |
| 8 | 387.5 | 350.0 | 1600.0 |
| 9 | 635.0 | 635.0 | 1176.5 |
| 10 | 555.0 | 362.5 | 1428.6 |
| average | 736.5 | 428.5 | 1438.6 |
| CV(%) | 25.0 | 21.6 | 14.5 |

14. Southern yellow pine vertical gap ($\frac{1}{4}$ ") spliced stringers using 3x4 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 550.0 | 275.0 | 1081.1 |
| 2 | 435.0 | 275.0 | 1000.0 |
| 3 | 505.0 | 212.5 | 1052.6 |
| 4 | 470.0 | 312.5 | 1290.3 |
| 5 | 605.0 | 287.5 | 1290.3 |
| 6 | 475.0 | 225.0 | 1428.6 |
| 7 | 505.0 | 187.5 | 1025.6 |
| 8 | 487.5 | 287.5 | 1250.0 |
| 9 | 567.5 | 250.0 | 1111.1 |
| 10 | 510.0 | 237.5 | 1000.0 |
| average | 511.0 | 225.0 | 1153.0 |
| CV(%) | 9.9 | 15.4 | 13.0 |

15. Oak-yellow-poplar vertical spliced stringers using 3x4 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 970.0 | 350.0 | 1428.6 |
| 2 | 925.0 | 787.5 | 1818.2 |
| 3 | 770.0 | 675.0 | 1600.0 |
| 4 | 1165.0 | 712.5 | 1738.1 |
| 5 | 775.0 | 387.5 | 1428.6 |
| 6 | 1145.0 | 675.0 | 1904.8 |
| 7 | 950.0 | 337.5 | 1739.1 |
| 8 | 937.5 | 937.5 | 1538.5 |
| 9 | 837.5 | 465.0 | 1818.2 |
| 10 | 812.5 | 737.5 | 1333.3 |
| average | 982.7 | 606.5 | 1634.7 |
| CV(%) | 15.0 | 34.2 | 12.0 |

16. Oak-southern yellow pine vertical spliced stringers using 3x4 truss plates:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1 | 600.0 | 587.5 | 1538.5 |
| 2 | 785.0 | 350.0 | 1052.6 |
| 3 | 340.5 | 243.8 | 1250.0 |
| 4 | 345.0 | 490.1 | 1281.2 |
| 5 | 390.0 | 390.0 | 1176.5 |
| 6 | 402.5 | 402.5 | 1428.6 |
| 7 | 332.5 | 281.5 | 1142.9 |
| 8 | 725.0 | 675.0 | 1379.3 |
| 9 | 490.0 | 390.5 | 1281.2 |
| 10 | 692.5 | 469.0 | 1295.6 |
| average | 510.3 | 428.0 | 1282.6 |
| CV(%) | 34.4 | 30.9 | 11.1 |

B. Bending Pallet Tests:

1. Oak pallet with non-spliced stringers:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 1.1 | 4642 | 3400 | 9444 |
| 1.2 | 4667 | 4100 | 8542 |
| 1.3 | 4593 | 3620 | 9784 |
| 1.4 | 5060 | 4000 | 10256 |
| 1.5 | 5389 | 3250 | 8553 |
| average | 4870 | 3674 | 9316 |
| CV(%) | 7.1 | 10.0 | 8.1 |

2. Oak pallet with center spliced stringers:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 2.1 | 4495 | 2400 | 9600 |
| 2.2 | 4886 | 4400 | 6471 |
| 2.3 | 5871 | 3500 | 8140 |
| 2.4 | 4749 | 3470 | 10256 |
| 2.5 | 3672 | 2680 | 7667 |
| average | 4735 | 3488 | 8417 |
| CV(%) | 16.7 | 20.5 | 17.8 |

3. Oak pallet with both side spliced stringers:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 3.1 | 6264 | 3360 | 7636 |
| 3.2 | 4194 | 1920 | 6000 |
| 3.3 | 4873 | 3910 | 5836 |
| 3.4 | 3645 | 1900 | 10000 |
| 3.5 | 6904 | 4080 | 9951 |
| average | 5176 | 3043 | 7885 |
| CV(%) | 26.6 | 34.9 | 25.8 |

4. Oak pallet with three spliced stringers:

| Specimen | Max.load | Pl.load | Stiffness |
|----------|----------|---------|-----------|
| 4.1 | 3479 | 2999 | 5355 |
| 4.2 | 3901 | 3700 | 7115 |
| 4.3 | 6025 | 3900 | 7359 |
| 4.4 | 5582 | 3100 | 8378 |
| 4.5 | 2626 | 2630 | 5717 |
| average | 4323 | 3245 | 6785 |
| CV(%) | 33.2 | 16.6 | 18.3 |

VITA

Chao Tong was born in Harbin, Heilongjiang province of China on June 18, 1960. He moved to Tongyuan county, then Achen county, where he graduated from high school in 1984, and later moved back to Harbin, where he finished his first university degree.

He received BS in Forest Products Industry at Northeast Forestry University, Harbin in 1984. After that, he worked at China Technical Standardization Committee for Wood for one-half year, then as a researcher he worked at Heilongjiang Forest Products Industry Research Institute from 1986 to 1993. In June 1993, Chao Tong came to the United States of America. From June 1993 to August 1995, he worked at the USDA Forest Service, Southern Research Station as a visiting scholar. He went to Virginia Tech in 1995 for his Master Degree and received a MS degree in Wood Science and Forest Products in January 1998.

Chao Tong is married to Yingtao Yu, and they have a daughter Michelle Tianyi Tong.