

Production of Tension Chord Lumber from Southern Pine

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This paper presents the results of a study in which engineered composite lumber was developed, manufactured and tested. The engineered composite lumber was made by edge-laminating lower-grade No. 3 solid-sawn southern pine (SP) lumber with higher-grade tension chord material to yield tension chord lumber (TCL). Three groups of TCL were made with varying combinations of SP lumber including machine stress rated (MSR) 2.0E, MSR 2.0E finger joint, and No. 1 finger joint material. The three groups were tested in static four-point bending on a universal testing machine. One group of No. 3 lumber was tested as a control. Modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated and the results show that TCL lumber had significantly greater MOE values as compared with the control lumber. The mean MOE values of TCL ranged from 12.4 GPa to 12.6 GPa, as compared with 9.6 GPa for the control. The mean MOR values of TCL ranged from 39.3 MPa to 47.6 MPa, as compared with 35.9 MPa for control.

Key Words: engineered wood; wood composites; design values; softwood lumber; modulus of elasticity; modulus of rupture

Introduction

Recent mechanical testing studies on Douglas-fir and southern pine lumber have revealed reduced properties and increased variability (Dahlen et al 2012, 2013). For southern pine, this phenomenon has caused a minor decline in the lumber quality which has resulted in lower design values that engineers would use for construction. A reinforced composite lumber material that is manufactured with relatively low-technology equipment could be highly cost competitive and may be adopted into the light-frame construction field.

The principals behind reinforcing lumber are technically and economically sound. In general, one can improve the flexural properties of the material by adding higher strength material to the tensile face. To improve product performance for stiffness and strength, reinforced wood and wood-based materials such as solid sawn lumber, glulam, plywood, and particleboard have been successfully developed in the laboratory and commercialized. For example, fiber reinforced polymers can be affixed to the tensile face of wood beams. This allows for the use of a small amount of high strength material that when combined with a lower cost material such as wood allows for increases in strength and stiffness while still being economical. Alternative materials such as steel, aluminum, fiberglass-reinforced with polymers (FRP) or concrete have been used as the reinforcement material (Fiorelli and Dias 2003, Clouston et al 2005, Johns and Lacroix 2000). However, the relatively high costs of these reinforced materials have limited their availability in reaching commercial markets.

When optimized for both engineering and production, the result of laminated composites is a bending member with superior performance and only slightly increased unit cost (mainly from production), as compared to solid sawn lumber. One potential area for application of products is in residential construction where the design loads and spans are well known and have been traditionally limited to the allowable loads from solid sawn dimension lumber. Solid sawn 38×235mm (2×10 inch) and 38×286mm (2×12 inch) lumber is widely used for residential floor joists and rafters in the United States; the lumbers used in these beams are primarily visually graded (US Census Bureau 2012). The visual grading process allows for larger center knots than edge knots; however, for this application in edge-wise loading, the increase in allowable center knots is likely not accurate given that defects located near the neutral axis have relatively low importance in bending (Dahlen et al. 2013). During full scale in-grade static bending tests conducted on southern pine lumber by the authors it was found that the performance of lumber that had some clear material with relatively low localized slope of grain on the tension face was adequate to meet the design values, while some knots on the tensile edge led to failure below design values (Figure 1) (Dahlen et al. 2013).

(a) (b)

Figure 1: Typical failure mode of 2x10 lumber: (a) Failure above published design value; (b) Failure below design value.

The objectives of this study are to:

1. design a series of composite lumber products utilizing relatively low cost raw materials,
2. manufacture the products to specification of currently available materials,
3. determine the mechanical performance.

Materials and Methods

Materials and Manufacturing Process

Materials

Control lumber – Visually graded No.3 southern pine (SP)

- E= 1,300ksi
- F_b= 525psi

Chord Lumber – MSR 2.0 and visually graded No.1 SP
MSR 2.0 SP

- E=2,000ksi
- F_b=2,400psi

Visually graded No.1 SP

- E=1,600ksi
- F_b=1,500psi

Where:

E = modulus of elasticity (MOE) value, along the longitudinal direction
F_b = Allowable design stress for extreme fiber stress in bending
psi = pounds per square inch stress
1 ksi = 1,000 psi
1 psi = 6.8948 Pa

Four groups of SP specimens, with 28 pieces of lumber in each group, were investigated. One group that consisted of standard 2×8 No. 3 visual graded was tested as the control for comparison purposes. Three groups of lumber that had reinforcement attached to base lumber are: No.3 visual grade lumber with MSR Solid tension chord (MSR Solid); No.3 visual grade lumber with MSR finger joint tension chord (MSR FJ); and No.3 visual grade lumber with No.1 visual grade finger joint tension chord (No.1 FJ). The dimensions of control chord were 38mm×184 mm×4.9m. The dimensions of lumber with reinforcement were 38mm×235mm×4.9m, which included the added piece of reinforcement lumber (51 mm) at the tensile edge. Dimensional information of the composite and control lumber are listed in Table 1. Moisture content (MC) and the relative standard deviation (STD) information at the time of testing are shown in Table 2.

Table 1. Lists of Dimensions of Specimens

Specimen	**Count**	**Width**	**Depth**	**Length**	**S-Span**[1]
		(mm)		(m)	
Control	28	38	184	4.9	3.13
MSR Solid	28	38	235	4.9	3.99
MSR FJ	28	38	235	4.9	3.99
No. 1 FJ	28	38	235	4.9	3.99

[1] S-Span: Support span (measured from the center to center of the reaction supports)

Table 2. Moisture Content of Specimens

Specimens	**Base Lumber**		**Chord Lumber**	
	MC	STD	MC	STD
		-- % --		
No. 3 Control	13	3.5	--	
MSR Solid	14	2.7	12	1.0
MSR FJ	12	1.7	12	1.2
No. 1 FJ	12	2.0	12	0.8

Manufacturing Process

The No. 3 lumber raw material was randomly sorted into groups such that the control lumber was no worse (e.g. more or larger knots) than that which was selected for the No. 3 lumber of the TCL. Prior to gluing the composites together, a table saw was used to saw the parent reinforcement lumber into strips that were 51mm×38 mm for use as the tension chord material. To ensure an active surface for gluing, a straight bit router was used to joint, that is make both smooth and true, the edge surface of the No. 3 base lumber immediately prior to gluing. The manufacturing dimension designs are shown in Figure 2.

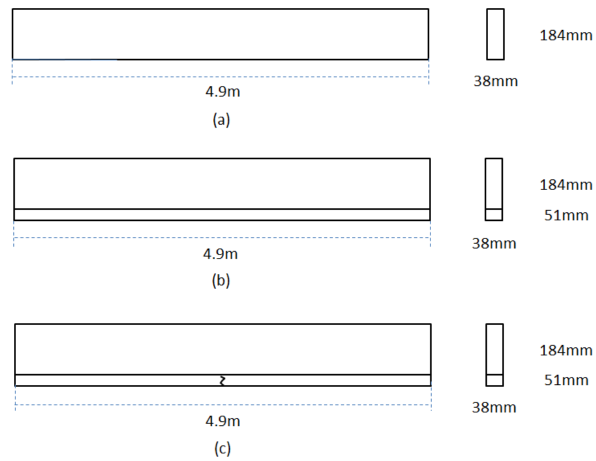


Figure 2: Dimensions of Test Lumber: (a) Control Chord; (b) TCL with Whole Piece Reinforcement; (c) TCL with Finger Joint Reinforcement

Liquid phenol resorcinol formaldehyde and resin hardener in powder form were used to adhere the base and reinforcement lumber along the longitudinal direction. Redundant clamps at 318mm spacing were used to ensure adequate and uniform pressure between the tension chord and base lumber. Figure 3 shows the connecting method of the manufacture process. The time and temperature combination followed the guidance of the adhesive manufacturer.

Figure 3: Photograph of the clamping system for manufacture of TCL specimens. In the clamps are three individual TCL specimens.

Static Bending Tests

All specimens were tested in a four-point bending setup in third-point loading with a span to depth ratio of 17 to 1 (Control lumber: 3131 mm to 184 mm; TCL: 3994 mm to 235 mm) following ASTM D 198-08 (Figure 4). Bending tests provide meaningful results on full scale specimens as it combines tension, compression, and shear forces develop during the testing. During testing, the lumber was laterally supported to prevent lateral-torsional buckling. An electronic linear variable displacement transducer (LVDT) was connected perpendicularly to the neutral axis of the beam at mid-span. The LVDT was then directly wired into the data acquisition computer to record deflection mid-span deflection. The beams were loaded at a rate of approximately 4,448 N per minute. Data recordings included load force, load head displacement, and LVDT displacement over the duration of the test.

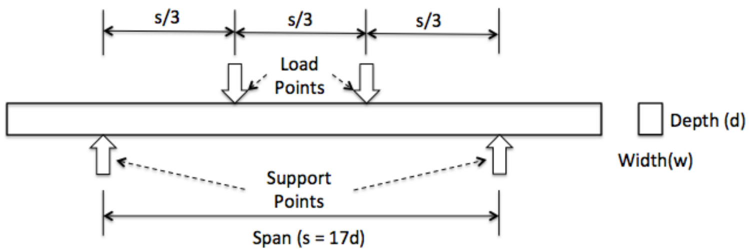


Figure 4: Third-point Loading Test Configuration for four-point bending

Results and Discussion

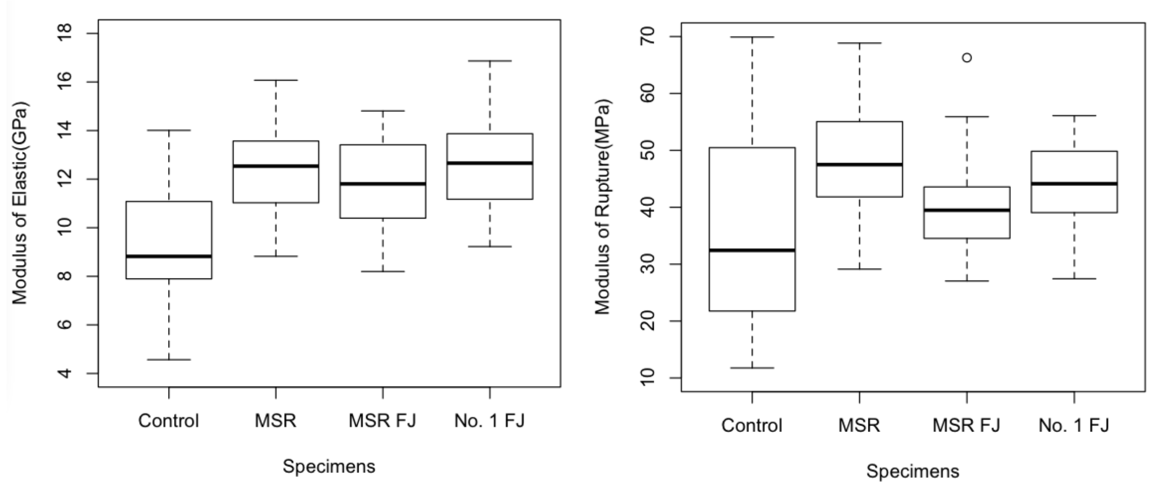
With the recorded data, modulus of elasticity (MOE) and modulus of rupture (MOR) were calculated based on equations from ASTM D-198 (2009). Statistical results of MOE and MOR values are listed in Table 3. The mean and variation for MOE and MOR are shown in Figure 5.

Mean MOE values of all TCL (12.4 GPa for MSR Solid, 11.9 GPa for MSR FJ and 12.6 GPa for No.1 FJ), increased compared with the control lumber (9.6 GPa) on the order of 24 to 30%. Mean MOR values of all TCL (47.6 MPa for MSR Solid, 38.9 MPa for MSR FJ and 43.3 MPa for No.1 FJ), increased compared with the control lumber (35.9 MPa) on the order of 8 to 33%. Minimum value of treated lumbers also increased accordingly compared with control group.

The standard deviation (STD) of treated lumbers decreased compared with control group. STD of MOE decreased from 2.2GPa for the control lumber to approximately 1.8GPa of all treated lumbers; and that the STD of MOR decreased substantially from 16.5MPa for the control lumber to approximately 8.6MPa for all treated lumbers.

Table 3. Summary Statistics of MOE and MOR.

	Specimen	Mean	STD	Increase Rate
	No.3 Control	9.6	2.2	--
MOE	MSR 2.0 Solid	12.4	1.8	29%
(GPa)	MSR 2.0 FJ	11.9	1.8	24%
	No. 1 FJ	12.6	1.9	30%
	No.3 Control	35.9	16.5	
MOR	MSR 2.0 Solid	47.6	10.0	33%
(MPa)	MSR 2.0 FJ	38.9	8.0	8%
	No. 1 FJ	43.3	7.8	21%

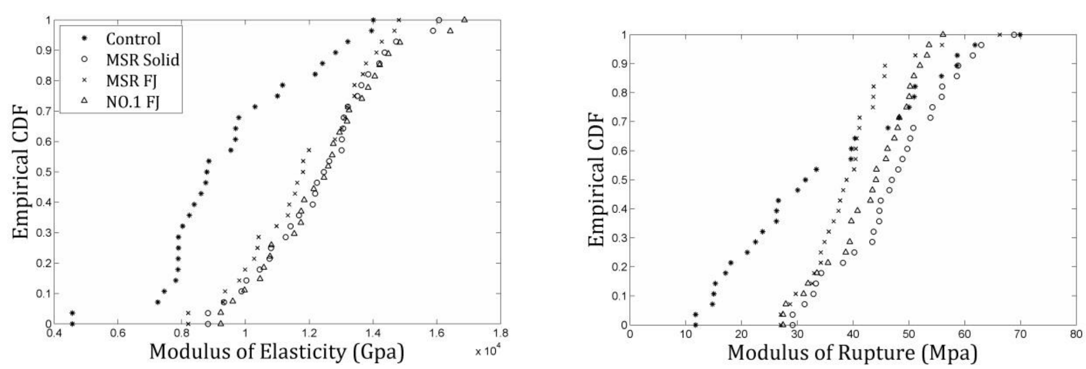


(a) (b)

Figure 5: Boxplots: (a) Modulus of Elasticity; (b) Modulus of Rupture

Analysis of variance (ANOVA) at the 5% level of significance was conducted to characterize the differences within the treated lumber groups. The test hypothesis H_0 is the bending strength and stiffness of all treated chord lumber groups is equal. Test result of MOE (p value = 0.3993) shows that there is no significant difference between chord groups. This means that the MOE values of all TCL are statically equal. Test result of MOR (p value = 0.0068) shows that there is a significant difference among chord groups.

Empirical cumulative distribution function (CDF) of MOE and MOR were plotted. Visual representations of the individual MOE and MOR values of all groups are shown in Figure 6. Figure 6a shows that, compared with control lumbers, bending stiffness values (MOE) of the treated lumbers are overall higher and very similar among each other. Figure 6b shows that among the treatment groups, TCL lumbers with finger joint reinforcement have lower bending strength (MOR) result. Finger joint reinforcement could reduce the maximum load that the treated lumber can receive.



(a) (b)

Figure 6: Cumulative Distribution Function: (a) Modulus of Elasticity; (b) Modulus of Rupture

While not a primary component of the study, the resulting TCL had noticeably less warp than the control lumber that was used to construct the TCL. Thus it appears that in the process of manufacturing the composite lumber warp may be reduced. This finding is consistent with other examples of laminated wood such as edge glued table tops wherein individual pieces with some level of warp may be straightened and restrained during and as a result of the laminating process.

Conclusion

The study results indicate that No.3 lumber, which has relatively low economic value, can be up graded into a higher strength and stiffness product with relatively low technology along with minimal capital and labor cost input. With the higher-grade lumber reinforcements, the bending strength and stiffness of the TCL lumber was superior as compared to the solid sawn control lumber group. With respect to both MOE and MOR, the variation of the TCL lumber was reduced as compared to solid sawn controls. It is believed that these products could be feasible products for use in applications such as floor joists, treated decks, headers, beams or light commercial/multi-occupant housing structures where wood I-joists may not be favorable because fire codes.

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