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Effect of manufacturing parameters on mechanical properties of southern yellow pine cross laminated timbers

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HIGHLIGHTS

- Cross-laminated timber was produced by varying pressure, time, and addition of water.
- Bending and shear tests were used to evaluate CLT mechanical and bonding properties.
- Optimal manufacturing parameters for these CLT panels were recommended.

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ABSTRACT

Development of cross laminated timber (CLT) manufacturing facilities will require an optimization of manufacturing parameters to ensure efficient production. This study examined the effects of press pressure, press time and the addition of water to bond surfaces for a CLT panel composed of southern pine lumber and polyurethane adhesive. Evaluation of the CLT panels used the five-point bending test for bending stiffness, bending strength and shear stiffness in addition to measuring the resistance to shear by compression loading. The shear strength and percent wood failure values obtained from the resistance to shear by compression loading. The optimal combination of manufacturing parameters studied was 100% press pressure and a press time of 80% of the manufacturer recommendations. The addition of water to the bondline surfaces was deemed unnecessary for CLT materials conforming to the PRG-320 standard. Comparison of mechanical properties with Grade V3 showed higher bending strength and shear stiffness values.

1. Introduction

Cross laminated timber (CLT) is an engineered wood product composed of at least three layers of lumber glued together orthogonally [1] in an odd number of layers. Some advantages of CLT include improved dimensional stability, good in-plane and out-of-plane strength and stiffness properties due to cross laminating [1], rapid project completion due to prefabrication [2–4], good thermal, sound insulation and fire performance [4]. Production of CLT could result in a value added product from lower value timbers to stimulate rural economies that rely on forest products [5].

In 2012, ANSI/APA PRG 320 *Standard for Performance-Rated Cross-Laminated Timber*, known as PRG 320, was developed for performance-rated CLT in the United States [6]. PRG 320 defines standard requirements for dimensions and tolerances, performance requirements, test methods, quality assurance and trademarking [6], but manufacturing requirements are not discussed. Therefore more investigation on different combination of manufacturing parameters and species could be helpful for the development of CLT manufacturing facilities.

Several previous studies have evaluated the mechanical properties of CLTs from various wood species and adhesive combinations [7–11]. Three layer hybrid poplar (*Populus deltoides* × *Populus nigra*) panels, adhered with polyurethane were evaluated according to PRG 320 [7]. These panels met and exceeded the shear and bending strength requirements for CLT Grade E3 in *ANSI/APA PRG-320* [6], but not the bending stiffness requirements [7].

In another study yellow-poplar (*Liriodendron tulipifera*) CLTs glued with resorcinol were studied [9] to investigate the capability of hardwood lumber use in CLT production. The lengths of the yellow-poplar CLT specimens were too short to conduct the PRG-320 bending property evaluation. Alternatively, the five-point bending test [12] consisting of two different bending loadings and simultaneous solution of equation was used for evaluation of

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the bending stiffness, shear stiffness and bending strength. The allowable bending stiffness and bending strength of the yellow-poplar CLTs were much greater than the Grade V1 CLT properties listed in PRG 320 [9]. Higher shear strength compared to other CLT studies was thought to influence the rolling shear failures of the yellow-poplar CLT, thereby reducing the occurrence of rolling shear failures as a limiting factor of bending strength [9].

The structural performance, strength and stiffness, of three-layer CLT composed of different layups of laminated strand lumber (LSL), Spruce-Pine-Fir (SPF) lumber and polyurethane adhesive were investigated [10]. A four-point bending test was employed in both the minor and major strength directions of specimens. The quality of the CLT panels manufactured met the requirements of PRG 320 [6].

Mechanical properties of CLTs produced from beech (*Fagus sylvatica*) with different layer thicknesses were evaluated [11]. All the obtained mechanical values were greater than the spruce CLTs. The value of rolling shear was influenced by lamella thickness [11].

Bending and shear properties of multiple-lap jointed CLTs produced from southern pine (*Pinus* spp.) and polyurethane adhesive was studied in [8] and compared to PRG 320 Grade V3 values [6]. Allowable bending strength and bending stiffness were greater than the value specified in PRG 320 for Grade V3. Percent of wood failure met the value of the AITC 107 standard [13], but the bond line delamination was lower than the specified value of AITC 110 [14].

The results of previous research indicate cross laminated timber is an engineered wood product with high mechanical performance. However, no previous studies were found which investigated the effect of different manufacturing parameters on the mechanical performance of cross laminated timbers. In order to create efficient CLT production, the manufacturing process needs to be optimized.

As part of the manufacturing parameters, process variables such as press pressure, press time and press temperature are some of performance controlling factors of the bonded panel products, including plywood, oriented strand board (OSB), fiberboard, and particleboard [15]. For massive timber products such as glulam and CLT, because of the extensive use of cold curing adhesives (resorcinol formaldehyde, two component urea formaldehyde and polyurethane), the two main controlling manufacturing parameters of interest are press pressure and press time which are investigated in this paper. The use of one component polyurethane has increased in engineered wood products because of cold and fast curing at room temperature, with no need to mix, lack of formaldehyde emissions and clear bond line [16].

Southern pine has been found to be a suitable candidate for CLT production in the eastern United States [8]. Southern pine is one of the dominant softwood species in the eastern United States [17] with the area of plantations of approximately 30 million acres in 1997 and is forecasted to increase 60 percent by 2040 [18,19].

Based on the need to improve the manufacturing performance of CLT, the purpose of this paper was to evaluate the effect of different manufacturing parameters (press time, press pressure and added moisture to bond line) of southern pine one-component polyurethane CLT on the mechanical properties of CLT beams (southern pine one-component polyurethane CLT). Comparison of mechanical properties includes the bending stiffness, bending strength, shear stiffness and resistance to shear due to compression loading.

2. Material and methods

2.1. Materials

Three layer CLT panels were manufactured at the Research and Design Center for Advanced Manufacturing & Energy Efficiency (R&D CAMEE) at the Southern Virginia Higher Education Center (SVHEC) in South Boston, VA. A polyurethane resin and 2 × 4 (50.8 mm by 88.9 mm) No. 2 Southern Pine lumber were used. Each layer was edge glued and clamped using a customized clamping fixture. A computer numerically controlled (CNC) machine with a fly cutter bit was used to surface the layers to final thickness of 36 mm. A cold press was used to consolidate the three-layer CLT panel using a one-component polyurethane adhesive. The final CLT panel dimensions were 107 mm thick, 230 mm wide, and 1.83 m long.

The manufacturing parameters examined in this paper include the press pressure, press time, and the addition of water to the face of the material before glue application. The particular manufacturing parameter values studied are shown in Table 1.

Two levels of press pressure examined were 689 kPa, which was the recommended pressure from the adhesive manufacturer, and 827 kPa, which was a 20% increase. Two levels of press time were 96 min, representing 80% of the recommended pressing time, and 120 min, representing the recommended time by the adhesive manufacturer. Since polyurethane uses moisture at a catalyzer, the effect of adding moisture to the surface before gluing was also explored. Water was applied as a thin layer by a spray bottle to one side of the joint.

A mixed methods approach to evaluate the manufacturing parameters was used. A total of six groups of different manufacturing parameters were studied. Groups 1 through 5 contained four samples each. Group 6 had ten specimens so that the material properties can be converted to allowable properties according to PRG 320 [6] and ASTM D 2915 [20]. A total of thirty specimens were tested.

2.2. Five-point bending test

PRG 320 recommends a bending test span of 30 times the panel depth for bending stiffness and bending strength evaluation [6]. Because of the limitations on the size of press and laboratory space, production of CLT panels to meet this length was

Table 1
Manufacturing variables and number of samples.

Sample code	Press Pressure, kPa	Press Time, Min (%)	Water Added	Number of Samples
1	689	96 (80%)	Yes	4
2	689	120 (100%)	Yes	4
3	827	96 (80%)	Yes	4
4	827	120 (100%)	Yes	4
5	827	96 (80%)	No	4
6	689	120 (100%)	No	10
			Total	30

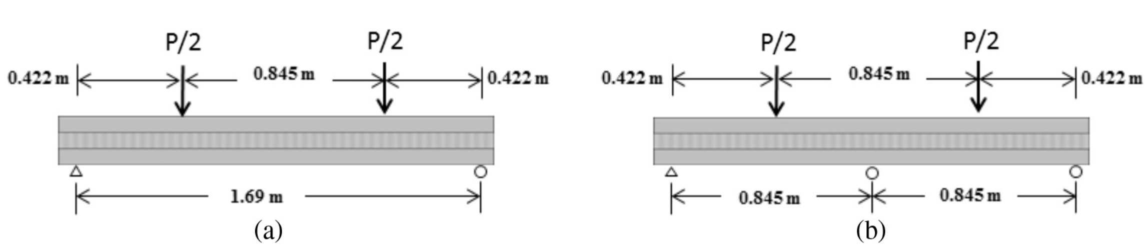

Fig. 1. Schematic setup of five (a) and four (b) point bending test of CLT.