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A new concept of wood bonding design for strength enhanced southern yellow pine wood products

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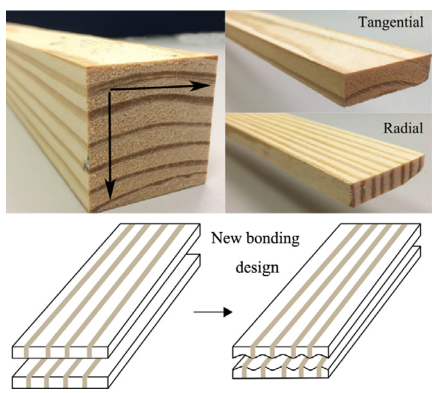
HIGHLIGHTS

- The compression features of early/late wood of southern yellow pine were studied.
- The radial section wood samples were used to develop a better bonding design.
- The new conceptual design has fully utilized the southern yellow pine features.
- Compared to conventional way, the new design has improved dry bonding strength.
- Wood density might be the main factor for fully exploiting the design.

GRAPHICAL ABSTRACT



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ABSTRACT

Bonding strength in the structure of engineered wood products and composites is one of the vital properties for their application. Up to now, numerous research efforts have been made on improving durability, wettability, and strength of resins or adhesives. However, there are only a few reports on how to improve bond line strength according to wood feature itself. In this study, a new conceptual bonding design based on wood radial section feature was reported. In this design, finger-joint like bonding interfaces were generated by hot pressing two resin coated wood radial sections together at optimized pressure of 300 lb per square inch (psi). By this design, the wet bonding strength of the bond line has potential to be higher than dry bonding strength. Meanwhile, with a compression ratio of 7.3% of wood strips, the obtained dry bonding or shear strength has been significantly increased up to 33.9%, as compared to end matched tangential controls. Wood specific gravity played an important role in this design. A proper compression ratio explored here in the radial section was about 17%. This work has provided a new route to improve wood bonding strength in an environmentally friendly way. Its impact on bending strength and dimensional stability of bonded wood structures needs to be further investigated.

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1. Introduction

Wood materials have been widely used in human's daily life for a very long time, due to its easy processing, abundant resource, renewable, and environmentally friendly features. With the increasing demand of the sustainable material, fast growing tree

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species are the main feedstock of wood based engineered products. Southern yellow pine trees are the most popular species in the southern United States. In order to add value of use, prolong service life, and broaden their application, many engineering approaches have been developed to produce wood based products, such as plywood, laminated veneer lumber, glued laminated timber, and cross laminated timber. In these products, all of them are assembled from single wood elements, such as wood veneer, wood strip, and lumber, which are bonded or glued together by adhesives. Therefore, bonding strength and bonding durability of these bond lines are the major concerns in applications. Generally, the bonding strength of engineered wood products is evaluated by its resistance to delamination and bonding creep behavior [1].

The strength prediction is, more or less, reliable in materials like steel and plastic, which are typical materials with relevant uniform structure. Most of the adhesives are, just like plastics, polymeric and their performance can be computationally modeled in a reliable way. The structures of solid wood material layers or elements are much more complicated than that of steel and polymers. Since wood is a type of anisotropic material, the quality of wood surface for bonding is less consistent [2]. The main variables include wood species and sections, reaction wood, moisture content, and wood defects. The bonding strength is significantly different even in the same wood species. In evaluation of the bonding strength of engineered or adhesive bonded wood products, generally wood failure is preferable since it indicates that the strength of resin or adhesive surpasses wood strength. Therefore, in order to enhance wood bonding strength, tremendous efforts have been committed to increase effective bonding area in wood products. It could be achieved by wood mechanical pre-treatments. Among these mechanical approaches, finger jointing has been used for a long time, as it is an efficient way to use low grade lumber and increase production yield [3]. By finger jointing, the high bonding strength is realized by a larger bonding surface area. The orientation of finger-joint could be easily adjusted to meet different load bearing conditions [4]. However, finger jointing is limited in end to end connections of wood, which is used for increasing the length of beams. It also has high requirements for wood prior to “finger” cuts, such as straight grain direction and defect free [5]. Comparing to finger jointing, other gentle mechanical treatments, such as face milling and sanding, could be used to increase wood surface roughness [6]. These treatments have lower requirements for wood and are relatively lower cost than finger jointing. The high surface roughness normally impart wood surface a better wettability to resin, which is beneficial for wood bonding [7]. In addition, it is expected that a dull knife would make the wood surface loose, causing a resin to penetrate deeper into the wood and form durable bonds [8]. Thus, methods mentioned are aimed at increasing wood surface bonding area via mechanical pre-treatments, which increase effective bonding area and resin penetration.

In this study, a new method was developed to improve wood bond line strength by bonding and compressing wood radial sections, which was realized by enlarging bonding areas without any mechanical pre-treatment. The fundament concept of this study is that the cross section of southern yellow pine logs contains a certain number of growth rings, which are composed of layers of latewood and earlywood growth ring bands. In the radial section of a piece of wood, latewood and earlywood are closely spaced, parallel, and lined alternatively to each other. In southern yellow pine trees, the difference in latewood and earlywood is usually very distinct and obvious. Latewood has deeper color than earlywood. Latewood has thicker cells and smaller cell lumens than earlywood, thus have higher density, hardness, and less compressible features. Therefore, under the same compression pressure, earlywood cells are easier to compress than latewood cells. In addition, the ratio or the width of earlywood compared to that of latewood in each growth ring is greater. Based on these facts, when two pieces of radial section southern yellow pine wood specimen are layered together and compressed, latewood layers on one piece of wood will force grooves on earlywood layers of the other side of wood piece and vice versa. In the end, indented shapes, similar to that of the finger-joint structure will be formed on the accumulation of the grooves of earlywood. The schematic illustration is shown in Fig. 1. When this feature or design is used in bonding wood, the bonding area is increased and as a result, the bonding strength of the specimens will be increased [9]. In this paper, the operational parameters to improve the bonding shear strength of both radial and tangential section bond line were studied and compared. The insight and methodology presented in this work should be of great application potential in wood bonding strength improvement, especially with southern yellow pine.

2. Materials and methods

2.1. Materials

Lumber was purchased from a local sawmill in Mississippi. The lumber was cut into wood strips with dimensions of 4 × 1 × 0.16 in. (101.6 × 25.4 × 4 mm; longitudinal × radial × tangential) for both radial and tangential sections, respectively. Each radial and tangential wood strip group was cut from the same piece of lumber with an end-matched pattern. In detail, for a group of radial and tangential wood strips, a long strip was ripped along wood longitudinal direction. Radial and tangential long strips were cut perpendicular and parallel to the growth ring of the lumber (Fig. 2). Finally, long strips were crosscut into shorter strips.

2.2. Resin preparation

Paraformaldehyde ($HO(CH_2O)_nH$) in crystalline form and reagent grade was obtained from Sigma Aldrich, USA. Urea (NH_2CONH_2) in crystalline form (98%) was purchased from Alfa Aesar, USA. Sodium hydroxide beads (NaOH) and sulfuric acid (H_2SO_4) certified ACS plus were purchased from Fisher Scientific, USA. All chemicals were used as received without further purification, except sodium hydroxide and sulfuric acid were diluted to 8% water solution.

In-house laboratory made urea formaldehyde (UF) resin was prepared by following three steps of urea addition [10]. Typically, paraformaldehyde was dissolved in water at the base condition (pH = 8.0). Then, urea was added in the formaldehyde solution for methylolation reaction, followed by poly-condensation or polymerization under acid condition. The UF resin solution was finally adjusted to the base condition, according to the desired viscosity measurements. The measured viscosity and solid content of the applied resin was 365 mPa·s (Viscosity Meter DV-I Prime, Brookfield) and 64% (Moisture Balance, CSC Scientific Company, Inc.), respectively.

2.3. Lap shear test sample preparation

Wood strips were used to make lap shear test samples. The prepared resin was applied to the ends of wood strips of 1 in.^{2} ± 0.01 (645.16 mm^2 ± 0.06) with resin loading of 6.3–10.1 g/ft^2 on one side. Two resin-coated strips were bonded together under pressure of 250, 300, 400, and 500 psi, and at 130 °C for 5 min using a lab-scale hot press (Carver Laboratory Press, Fred S. Carver, Inc.). Finally, the samples were cooled down naturally and conditioned at ambient temperature for a week before mechanical tests were conducted. For control samples, tangential wood strips were bonded under the same conditions.

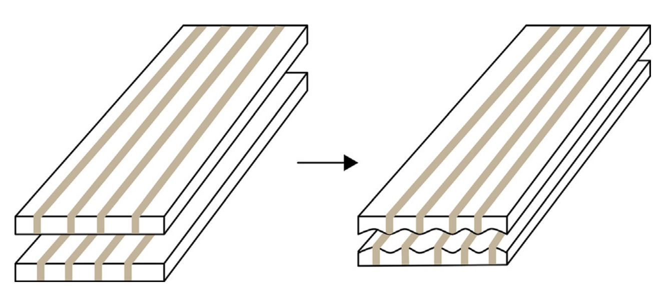

Fig. 1. A design of bonding southern yellow pine wood with radial sections. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)