Mechanical and Durability Properties of Steam-Pressed Scrim Lumber

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This study shows that the mechanical properties of steam-pressed scrim lumber (SPSL) are sufficient for use in many commercial wood products and pass APA certification values. Values are greater than many of the commercial products on the market today. This study indicates that adding borates and/or silane-based water repellents before pressing combined with a silane-based water repellent after pressing is effective for producing durable SPSL material.

Keywords: Steam-pressed scrim lumber; Structural composite lumber; Mechanical properties; Durability

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INTRODUCTION

Scrimber, a process for producing steam-pressed scrim lumber (SPSL), was developed and patented in 1975 by CSIRO in Australia, and its USA worldwide rights were granted to Timtek™. Timtek™ has been issued additional patents for the product, process, and equipment associated with making an engineered wood product (EWP). Scrim, the wood component that makes up SPSL, is produced by cracking and separating 2.3- to 3.0-m-long bolts of small-diameter trees (≤ 203 mm) into long fiber bundles that are formed into mats. The scrim mats are dried, supplemented with adhesives and additives, and collated into a press charge. Pressing turns the collated mats into products (beams, bridge timbers, *etc.*) of definite length and dimension by applying heat and pressure. The current focus with SPSL is to compete with other EWPs (*e.g.*, laminated veneer products) on the market in the form of beams, headers, and large timbers. Research has shown that the strength and physical properties of SPSL treated with Southern pine furnish are comparable to any of the EWP products currently on the market. The physical properties exhibited by the product indicate that drop-in replacements can be produced for nearly every commercial EWP produced in North America.

Finding alternative uses or markets for small-diameter raw materials is a critical problem (Wolfe 2000; Levan-Green and Livingston 2001; Forrest 2003). In the Southern United States a lack of markets for southern yellow pine (*Pinus* spp.) pulpwood is impacting the silvicultural practices of millions of acres of pine plantations. Silvicultural practices such as thinning and stand improvements promote increased growth, size, and value of the remaining trees. These practices would be more economical if there were viable markets for the removed material (Han *et al.* 2006). Such economical and value-added uses for small-diameter timber can help offset forest management costs and provide economic opportunities for many small, forest-based communities, but the variability and lack of predictability of the strength and stiffness of juvenile wood from small-diameter timber can be problematic in many engineering applications (Wang *et al.* 2003). In the

West the utilization of small, standing dead trees from wildfires or bark beetle attack presents a critical problem (Hill 1999; Zausen *et al*. 2005)

Juvenile wood differs from mature wood in that it has a lower percentage of summerwood, lower specific gravity, shorter tracheids with larger fibril angles, and occasionally disproportionate amounts of compression wood, distorted grain patterns, and pitch deposits (Larson *et al.* 2001). There is no definite line of demarcation between juvenile and mature wood within an individual tree. The transition from juvenile to mature wood is generally thought to take place over a period of 10 years (Pearson and Gilmore 1971). The strength of juvenile wood is inferior to that of mature wood.

The specific gravity of juvenile wood is considerably lower and the micro-fibril angle in the critical S-2 layer of the fiber is steeper. This results in greater longitudinal shrinkage, lower strength, and lower stiffness values (Lulay and Galligan 1981) than mature wood. Bendtsen and Senft (1986) conducted a study of plantation-grown loblolly pine (*Pinus taeda* L.) to see how the modulus of elasticity (MOE) values are affected by the presence of juvenile wood. They discovered that there was a 5-fold increase in MOE values from juvenile wood to mature wood, with one tree showing a 10-fold increase. The maturity of the wood also affects the modulus of rupture (MOR) values. In another study by Pearson and Gilmore (1971), MOR values were shown to increase by approximately 50% from juvenile wood to mature wood.

Kretschmann and Bendtsen (1992) conducted a study to see how ultimate tensile stress was affected by juvenile wood for fast-grown plantation loblolly pine lumber. They found that the average ultimate tensile stress in lumber containing juvenile wood was nearly half that of lumber composed entirely of mature wood. Kretschmann (1997) also conducted a study to determine the effects that juvenile wood has on compression perpendicular-to-grain strength properties of loblolly pine lumber. Loads applied to the radial face of the samples were more sensitive to changes in juvenile wood content than loads applied to the tangential face.

Juvenile wood can significantly decrease the performance of many wood products (Pugel *et al.* 1989); however, with the expected increase in demand for forest products, most of the future timber supply will come from managed plantation-grown trees (Kretschmann 1997).

Steam-pressed scrim lumber (SPSL), an engineered structural composite lumber product (SCL) that has been developed in Australia based on the Scrimber technology, utilizes small-diameter timber from first plantation thinnings (Barnes *et al*. 2010). The purpose of the research documented herein was to characterize the mechanical properties of SPSL, to determine design stress values for this new type of SCL, and to determine methods for improving its durability. This project focuses on evaluating small diameter trees (less than 200 mm diameter breast height) that will be used for manufacture into SPSL. Scrim has been produced from several renewable natural resource furnishes (Table 1).

The durability of SPSL, like other engineered wood products, can be enhanced during various stages of production. The type of durability-enhancing additive and when to apply the additive, are dependent on production parameters such as the resin, press temperature, and the intended use of the final product. For instance, additives that increase durability but have a negative effect on the adhesive cannot be added prior to resin curing. Likewise, those that decompose at press temperatures cannot be added prior to pressing. Pigmented or oil-borne additives, especially those with an odor, are unacceptable for beams designed for use in habitable spaces, whereas these properties are of little concern in beams used for bridge timbers or other exterior structures.

Table 1. Lignocellulosic Materials for which Scrimming Trials have been Conducted

Furnish	Scrim Quality (1 = superior, 5 = will not scrim)
Southern pine (*Pinus* spp.)	2
Lodgepole pine (*Pinus contorta*)	4
Ponderosa pine (*Pinus ponderosa*)	3
Fire-killed lodgepole pine	5
Fire-killed ponderosa pine	5
Hybrid poplar (*Populus* spp.), heartwood	5
Hybrid poplar (*Populus* spp.), sapwood	3
Sweetgum (*Liquidambar styraciflua*)	5
Yellow poplar (*Liriodendron tulipifera*)	3
Aspen (*Populus tremuloides*)	1
Bamboo (species unknown)	3
Corn stover (*Zea mays*)	4
Kenaf (*Hibiscus cannabinus*)	3
Spruce (*Picea* spp.)	1
Paper birch (*Betula papyrifera*)	2
Basswood (*Tilia americana*)	1

Before considering specific additives, one must determine which durability features are desired in the product being produced:

1. Water repellent
2. Dimensionally stable
3. Protection from decay and mold fungi and/or insects (heavy-duty protection exterior exposure, AWPA 2014 ; moderate exposure; interior exposure, Monticello *et al.* 2009; Amburgey 2008)
4. Fire retardant
5. Corrosion inhibition
6. Some combination of 1-5

Because multiple formulations are available that have one or more of these properties, the advantages/disadvantages of each must be considered. Do they:…

1. Inhibit curing of the resin (adhesive) being used?
2. Decompose at press temperatures or emit offensive odors when heated?

3. Corrode some types of fasteners?
4. Increase hygroscopicity?
5. Produce a pigmented and/or oily surface?
6. Produce clean surfaces that can be stained or painted?
7. Require application by a certified pesticide applicator? Are there hazards or restrictions involved with their use or the disposal of excess chemical and/or treated wood scraps?
8. Have compatibility problems that prohibit blending with other durability-enhancing formulations (*e.g.*, fungicide and fire retardant) if more than one type of durability is to be enhanced?
9. Have a documented history of use (*e.g.*, Carr 1959; Cockcroft and Levy 1973; Bunn 1974; Barnes *et al.* 1989; Drysdale 1994; Lloyd and Manning 1995; Obanda *et al.* 2008; Freeman *et al.* 2009)?
10. Have a favorable benefit-cost ratio?

The best combination of durability-enhancing additives will differ depending on the manufacturing facility and product mix. For a given manufacturing facility, durability-enhancing formulations may be added alone or in combination:

1. By being blended with adhesive (resin) prior to application to scrim
2. Added to scrim prior to drying
3. Added to scrim after drying but prior to pressing
4. Added to pressed material prior to cooling (penetration of topically-applied additives …spray or dip…is facilitated by the vacuum created in the cells of EMP as the air within them cools)
5. Added to pressed, trimmed, and cooled final product (this option minimizes problems associated with disposal of treated wood waste).

EXPERIMENTAL

Mechanical Properties

Juvenile southern pine trees from young plantations were harvested from eastern central Mississippi and western central Alabama. Logs measuring 79 to 178 mm in diameter were harvested and sent through a de-barker. The de-barked logs were soaked in a hot water bath at 54 to 60 °C for 6 h, and the hot logs were passed through a set of rollers to break them into large fiber bundle sections along the grain. They were then sent through a scrimming mill where they were passed down the scrim line to a series of scrimming heads of successively smaller size. These scrim mills produced scrim (fiber bundles) that was approximately 6 to 7 mm thick and up to 2.4 m long (for a demonstration of the technique, see http://www.cfr.msstate.edu/timtek/demonstration.asp). The beam production and the scrimming process have been described by Barnes *et al.* (2006) and Seale *et al.* (2006). The scrim was kiln-dried to a nominal moisture content of 20% at 80 °C, with no wet bulb control, followed by spraying with a stage B resole phenol formaldehyde resin to yield 12% solids on a total board basis. The scrim was re-dried in a commercial conveyor drier at 115 °C to 6% moisture content or less. Following hand forming, the beams were consolidated in a proprietary steam press. The rough beams (Fig. 1) were trimmed to a final size of 44.5 mm × 298 mm × 5.5 m.

Non-destructive evaluation

The finished beams were non-destructively graded using an Inspex™ (CA, USA) X-ray inspection system to determine if there were any low density areas (LDAs). This technique was previously described at the 2006 SmallWood conference (Leng *et al*. 2006). The LDAs are formed when uneven volumes of scrim are located in the mat as a result of hand forming and can be detrimental to the mechanical properties of the beam. X-ray technology was used to determine how the samples should be cut to achieve the maximum property value of each piece. Figure 2 shows the X-ray images taken from a set of samples. The light areas in each piece indicate LDA locations. Number 1 shows a sample that does not contain any LDAs; this is an example of a sample that was tested. Numbers 2, 3, and 4 show typical samples that were rejected because of the existence of LDAs. After the initial X-ray scans were completed, the beams were cut into the selected sample sizes.

Fig. 1. Typical rough beam shown immediately after pressing

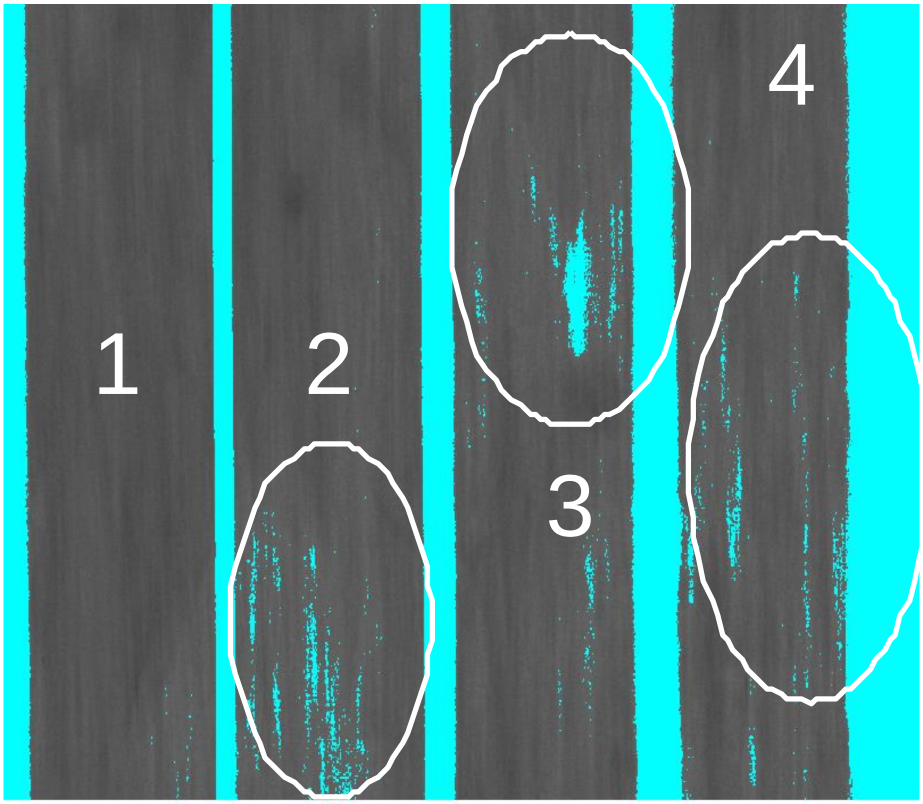

Fig. 2. X-ray images of SPSL beams showing areas of low density (denoted by circles)

Sampling and mechanical testing

Two groups of southern pine samples were tested. The first set contained full-sized beams measuring 44 mm × 286 mm × 5.3 m. The second set contained small-sized samples of different depths cut from the larger parent beams. All samples were nominally 44 mm in width. Samples were tested using ASTM standard D4761 (2007) using a third point loading in bending to determine MOR and MOE. All bending samples were tested in an 18:1 span-to-depth ratio. The effects of both depth and volume were determined. Tension tests were also conducted in the fiber direction using ASTM D4761 (2007). Compression testing was conducted both along and across the fiber direction using ASTM D4761 (2007). The compression tests used samples with dimensions of 1.5 in × 6 in, 2 in × 6 in, and 2 in × 8 in (38 mm × 152.4 mm, 50.8 mm × 152.4 mm, and 50.8 mm × 203.2 mm). The spans for these tests were the same as the lengths for each sample. Design values were calculated for various mechanical properties using ASTM D5456 (2004).

Data analysis of mechanical testing

The mechanical property data were analyzed using the GLM procedure in the SAS™ (Cary, NC) software system. Using this procedure, the means of each species and property were compared with the least squares method. Data were analyzed using analysis of variance and means were separated using Tukey’s test (SAS 2008).

Durability

Non-pressure treatments

Previous work has established the treatability of SPSL using pressure methods (Barnes *et al.* 2006). For the initial non-pressure treatments, laboratory samples (152.4 mm × 152.4 mm) of SPSL were formed using either: (a) scrim that was blended with Georgia-Pacific (GP) resin prepared with water according to the manufacturer's directions, or (b) scrim that was blended with GP resin prepared using the same weight of water that contained either 5% or 10% (wt/wt) disodium octaborate tetrahydrate (DOT). A DOT borate product was chosen for use because it is odorless, colorless, has a low mammalian toxicity, and is a corrosion inhibitor; all properties that would not preclude its use in either interior or protected exterior applications. Borates also are stable at press temperatures, making it possible to treat the scrim prior to board manufacture. Half of the test mats in both groups (a and b) were dip-treated after pressing and prior to cooling for 30 s in a silane-based water-repellent (WRP) formulated in mineral spirits (Fig. 3a, b).

Fig. 3. (a) Treating scrim in GP resin blended with 5% DOT, (b) pressing a 6 in × 6 in mat

A WRP was used because borates are often used in combination with WRPs to retard their loss from treated wood (Monticello *et al.* 2009).

The bonding was good in all test mats. The penetration of DOT and the WRP was 100%. Sections of the mats were used in additional tests to determine their resistance to a brown-rot decay fungus (*Gloeophyllum trabeum* Pers. Murr.) and subterranean termites (*Reticulitermes flavipes* Kollar), using AWPA standard procedures (AWPA 2014).

The results of these tests indicated that the resistance to both organisms increased in mats fabricated with resin containing either 5% or 10% DOT, with or without subsequent treatment with the WRP, and those mats treated with only the WRP. This indicates that such procedures could be used to increase the durability of SPSL beams used in interior or moderate exterior exposures.

Spray/dip treatments

Test 1

SPSL beams fabricated at the Mississippi State University (MSU) pilot plant were formed by adding the same silane-based WRP used in the initial tests to the dry scrim, (after being blended with resin) and prior to pressing. Figure 4 illustrates that no bonding problems were observed and nearly 100% penetration of the WRP (dyed red so that it could be tracked visually) was achieved.

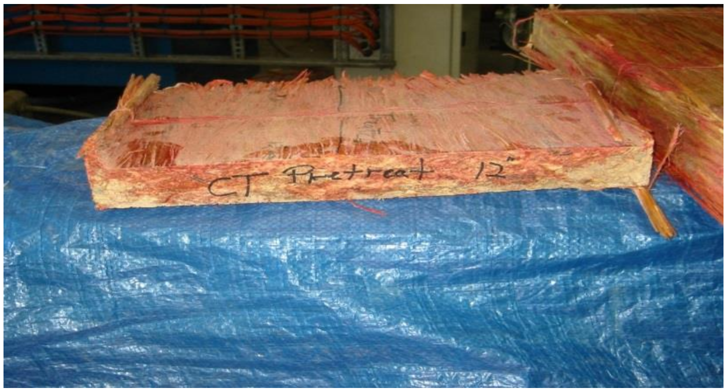

Fig. 4. Penetration of silane-based WRP (dyed red) in a beam formed using scrim treated prior to pressing

Test 2

Other sections of SPSL beams fabricated in the pilot plant were either made from scrim blended with resin containing DOT (1 lb/gal, (119.9 kg/m^3) wt/wt) or scrim blended with the standard GP resin formulation. Samples from both groups of beams were either spray-treated immediately after removal from the press (hot beams) (Fig. 5a, b) or dip-treated after cooling (cooled beams) (Fig. 6) with the silane-based WRP. The amount of solution absorbed by the cooled beam sections remained essentially the same for dip times ranging from 15 to 60 s. DOT-treated samples were sprayed with boron indicator (AWPA 2010 Standard A3) that turns red in the presence of boron at concentrations sufficient to protect wood. It was hypothesized that the surfaces of hot beams would cool enough as they were treated with silane-based WR to create a slight vacuum to facilitate its penetration. These results re-enforced those obtained from the 152.4 mm × 152.4 mm test mats.

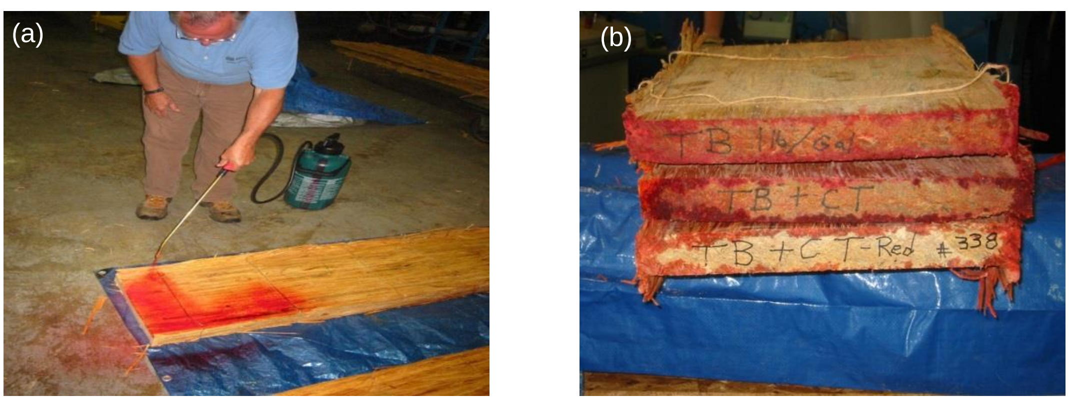

Fig. 5. (a) Spray-treating a hot SPSL beam with the silane-based WRP (dyed red), (b) penetration (100%) of DOT (top); borate (TB) and WRP (CT) (center) (deeper red around the perimeter was the penetration of CT); and WRP (CT) (bottom)

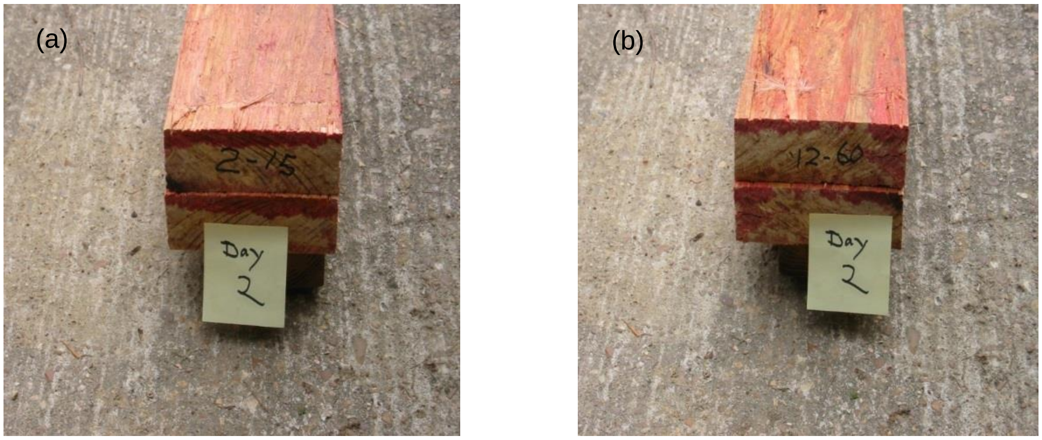

Fig. 6. Samples cut from SPSL beams two days following dip-treatment in the WR (dyed red) represented by the darker coloration for either (a) 15 s or (b) 60 s

Test 3

Additional sections of SPSL (no borate) dip-treated with a silane-based WRP after pressing were exposed above ground in AWPA Hazard Zone four, for five years. All samples were 24 in (61 cm) long and 1.75 in (4.4 cm) thick and were grouped according to their widths of 5.5 in (14 cm) (group 1), 5.75 in (14.6 cm) (group 2), or 11.25 in (28.6 cm) (group 3). Groups 2 and 3 were end-coated to prevent end grain absorption during treatment. The samples were weighed, dipped in 130F WRP for 0, 15, 30, 45, or 60 s, and re-weighed. Three days following treatment, half of the samples in groups 2 and 3 were bisected to determine the depth of WR penetration at midpoint. The other half remained intact and were exposed to the weather above ground with either a radial or tangential surface oriented upward (Fig. 7).

The amount of solution absorbed by the samples remained relatively constant for dip times of 15 to 60 s. The average retention was approximately 0.05 kg. The median depth of penetration of group 2 samples was 0.5 in (1.27 cm), and the maximum penetration was 0.75 in (1.9 cm). The median for group 3 samples was 0.75 in (1.9 cm), and the maximum penetration was 0.9 in (2.3 cm). No depth of penetration measurements were obtained for group 1.

Fig. 7. Samples of SPSL, treated with silane-based WRP, after five years of aboveground exposure in AWPA Hazard Zone 4

RESULTS AND DISCUSSION

Static Bending

The MOE and MOR values from the static bending tests are shown in Table 2, and depth effects are illustrated in Fig. 8. ASTM D5456 (2004) contains a table with adjustment factors for different mechanical properties of wood that can be applied to obtain the design values. Using these adjustment factors, the design stress values were calculated by dividing each value by the associated adjustment factor. Table 3 contains the design stress values for static bending tests conducted on SPSL.

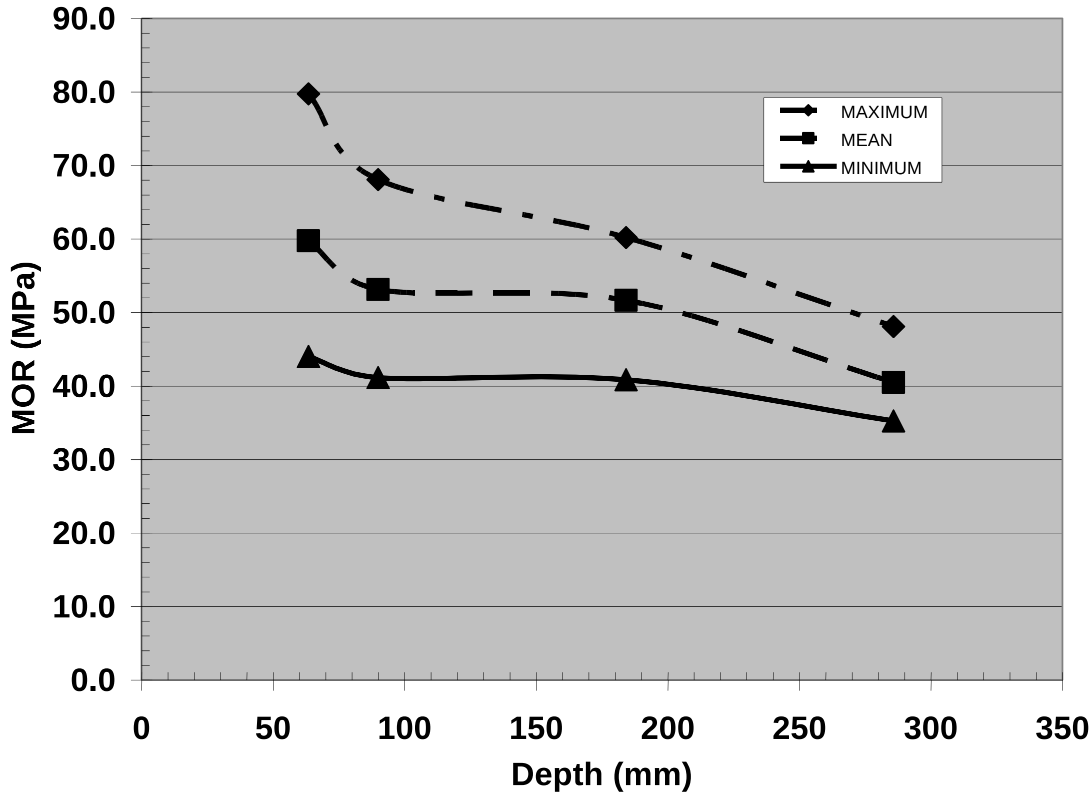

Fig. 8. MOR depth effects for beams tested in static bending

Table 2. Average Values for Mechanical Properties by Beam Depth for Southern Pine SPSL

Depth	**MOE** (GPa)	**MOR** (MPa)
63.5 mm		
Number of samples	78	78
Mean	16.8	59.7
Maximum	19.2	79.7
Minimum	13.7	44.0
COV %	7.6	11.7
89.9 mm		
Number of samples	36	36
Mean	16.9	53.1
Maximum	19.9	68.1
Minimum	13.4	41.1
COV %	9.2	13.4
184.2 mm		
Number of samples	20	20
Mean	17.7	51.6
Maximum	19.4	60.2
Minimum	15.7	40.8
COV %	6.1	12.3
285.8 mm		
Number of samples	20	20
Mean	15.3	40.5
Maximum	17.0	48.1
Minimum	13.2	35.2
COV %	6.6	8.8

Table 3. Design Bending Stress Values for Southern Pine SPSL

Sample size (depth × span, cm)	**MOE** (GPa)	**MOR** (MPa)
6.4 × 129.5	16.8	28.4
8.9 × 175.3	16.9	25.3
18.4 × 346.7	17.7	24.6
28.6 × 529.6	15.4	19.3

Durability

As discussed earlier, a variety of durability-enhancing treatments were added to SPSL furnish and/or finished beams using dip, spray, or pressure treatments without adversely affecting the SPSL strength properties. When all factors have been considered, SPSL with the desired durability features for either interior or moderate exterior exposure can be produced using DOT borate preservative and a silane-based WRP. A field test with cooled beam sections (no DOT treatment) dip-treated in a silane-based WRP and exposed above ground in AWPA Hazard Zone 4 for five years (Fig. 7) had limited decay, which was confined to the portions not penetrated by WRP.

After five years of aboveground exposure in AWPA Hazard Zone four, none of the treated areas of the samples decayed (Table 4).

Table 4. Durability of SPSL Samples Treated with Silane-based WR after Five Years of Aboveground Exposure in AWPA Hazard Zone 4*

Sample	Treatment	Results
1	Control – untreated	Decayed
2	Control (vertical exposure) - untreated	Decayed
3	15-s dip in WRP	Non-decayed in treated area, decayed inside
4	15-s dip in WRP	Non-decayed throughout
5	15-s dip in WRP (vertical exposure)	Non-decayed in treated area, decayed inside
6	30-s dip in WRP	Non-decayed throughout
7	30-s dip in WRP	Non-decayed in treated area, decayed inside
8	30-s dip in WRP (vertical exposure)	Decay at bottom (portion kept wet by adjacent units)
9	45-s dip in WRP	Non-decayed throughout
10	45-s dip in WRP	Non-decayed in treated area, decayed inside
11	45-s dip in WRP (vertical exposure)	Decay at bottom (portion kept wet by adjacent units)
12	60-s dip in WRP	Non-decayed in treated area, decayed inside
13	60-s dip in WRP	Non-decayed in treated area, decayed inside
14	60-s dip in WRP (vertical exposure)	Non-decayed in treated area, decayed inside

* Position of test units on the test fence was west to east

These results indicate that treatments with a WRP or with a more robust preservative system resulting in complete WRP penetration could increase the SPSL durability when exposed to relatively severe above ground conditions. The results also indicate that the addition of a DOT borate product before or after pressing can provide protection against wood-destroying organisms.

While hand-forming was used in this study, the authors see no barriers to automation. In fact, commercialization is being pursued. No attempt was made as part of this study to quantify the impact of steaming on stability or durability of the final product. Additionally, optimization of resin content was not part of this study. These questions will require additional study, perhaps when the process is scaled up.

CONCLUSIONS

The purpose of this research was to determine the mechanical and physical properties of a new SPSL engineered wood product and explore the addition of durability agents during various stages of production. Research was also done to determine the design stress values for beams made from southern pine. In this study, a new process using juvenile wood from a first plantation thinning was used to make structural beams.

1. After data analysis, it was determined that each sample passed APA guidelines and certification tests. MOR and MOE samples were determined to be comparable, and in many cases, exceeded the values for products already commercially available. Tensile

stress values and compression perpendicular to the grain values also met expectations and are comparable to commercially available products.

2. Durability-enhancing additives could be added to the SPSL scrim furnish or the final product by dip, spray, or pressure treatments. The results indicated that penetration and retention of these additives was very good. There is no indication that these additives affected the SPSL strength properties.
3. It was proven that SPSL is a product that can compete in today's market. Trees from first plantation thinnings typically have little value in today's market, but by utilizing SPSL forest products, landowners will be able to get more economic value out of their investments in a shorter period of time. By increasing the value of small-diameter timber, landowners will be more apt to practice proper silvicultural practices on plantations, which will promote increased growth, size, and value for the remaining trees.

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