United States Department of Agriculture

Effects of Cedar Oil and Silica Gel Treatment on Dimensional Stability and Mechanical Properties of Southern Yellow Pine Boards

Xiping Wang
Christopher A. Senalik
Robert Ross
Neal Bennett
Deborah Conner

Forest Service | Forest Products Laboratory | Research Note FPL–RN–0339 | September 2016

Abstract

A laboratory study was conducted to investigate the effects of cedar oil and silica gel treatment on dimensional stability and mechanical performance of southern yellow pine (SYP) boards. Two hundred pieces of SYP and 100 pieces of red oak boards with a nominal dimension of 1 by 6 by 48 in. (25 by 152 by 1,219 mm) were selected for this study. The red oak boards were included as a standard ammunition pallet stock for comparison. The experimental procedure involved stress wave E-rating, grouping, defect mapping, preservative treatment, high-temperature kiln exposure (simulating hot and dry service condition), and flatwise static bending test. Cedar oil and silica gel treatment had a positive effect on dimensional stability of the No. 2 SYP boards, as indicated by reduced visible end-splits and board warp. Our results also indicated that cedar oil and silica gel treatment had a detrimental effect on stiffness and strength of the No. 2 SYP boards. Both modulus of elasticity and modulus of rupture decreased significantly in treated SYP compared with those of untreated SYP.

Keywords: End split, pallet deck boards, stiffness, strength, warp, work to maximum load

September 2016

Wang, X.; Senalik, C.A.; Ross, R.; Bennett, N.; Conner, D. 2016. Effects of cedar oil and silica gel treatment on dimensional stability and mechanical properties of southern yellow pine boards. FPL-RN-0339. Madison, WI: U.S. Department of Agriculture, Forest Service, Forest Products Laboratory. 5 p.

A limited number of free copies of this publication are available to the public from the Forest Products Laboratory, One Gifford Pinchot Drive, Madison, WI 53726-2398. This publication is also available online at www.fpl.fs.fed.us. Laboratory publications are sent to hundreds of libraries in the United States and elsewhere.

The Forest Products Laboratory is maintained in cooperation with the University of Wisconsin.

Contents

Effects of Cedar Oil and Silica Gel Treatment on Dimensional Stability and Mechanical Properties of Southern Yellow Pine Boards

Xiping Wang, Research Forest Products Technologist
Christopher A. Senalik, Research General Engineer
Robert Ross, Project Leader
Forest Products Laboratory, Madison, Wisconsin

Neal Bennett, General Engineer
Deborah Conner, Biological Technician
Forest Products Laboratory, Princeton, West Virginia

Introduction

Use of wood in the manufacture of shipping containers, specifically pallets, is well documented and based on a strong theoretical and experimental research base. Wood pallets are now in use worldwide to ship a wide range of products, from agricultural food stuffs to ammunition used in military operations. The USDA Forest Products Laboratory (FPL) was recently contacted by technical representatives from the U.S. Department of Defense (DoD) and asked to provide assistance in evaluating the performance of a new wood preservative treatment that is being considered for potential use in the manufacture of wood pallets used to transport small-arms ammunition. The hypothesis tested in this project was if cedar oil and silica gel, a commercially available and environmentally friendly preservative product, can cause softwood four-way entry ammo pallets to perform as well as hardwood pallets yet without experiencing dimensional stability problems.

The foundation for the preservative treatment utilizes natural wood oils extracted from *Juniperus* species. Research has been conducted to determine the termiticidal and fungal activities of heartwood, bark/sapwood, and leaves from dominant juniper species in the United States as part of an evaluation of the commercial potential of plants that are now considered to be a noxious tree species in rangelands (Adams and others 1988; Adams 1991; Clark and McChesney 1990). Based on results from these studies, a commercial cedar oil and silica gel product was developed and is now manufactured and marketed as an environmentally friendly wood preservative.

The goal of this project was to investigate the effects of the cedar oil and silica gel treatment on the dimensional stability and mechanical performance of southern yellow pine (SYP) boards. Red oak boards were included as a standard ammunition pallet stock for comparison. The project involved stress wave E-rating, grouping, defect mapping, preservative treatment, high-temperature kiln exposure (simulating hot and dry service condition), and flatwise static bending. Specific objectives were to (1) develop technical data on the effect of high-temperature kiln exposure on end splits and warp in preservative-treated and untreated deck boards; (2) determine the effect of cedar oil and silica gel treatment on dimensional stability of SYP boards; and (3) determine the effect of cedar oil and silica gel treatment on mechanical properties of SYP boards.

Materials and Methods

Materials

In late November 2014, 150 pieces of red oak and 300 pieces of SYP boards were obtained by the Department of Ammunition Center (DAC) and shipped to the wood laboratory in Princeton, West Virginia. All boards were in a nominal dimension of 1 by 6 by 48 in. (25 by 152 by 1,219 mm). The red oak group appeared to be clear and high-quality wood; all the SYP boards were No. 2 kiln dried and heat treated (Fig. 1). Through initial stress wave E-rating procedure, we selected 100 pieces of red oak and 200 pieces of SYP boards as test specimens:

- Group 1—100 oak boards, standard pallet materials
- Group 2—100 SYP boards (kiln dried and heat treated), no preservative treatment and used as a control group
- Group 3—100 SYP boards (kiln dried and heat treated), to be treated with cedar oil and silica gel

In mid-February 2015, Group 3 was shipped to McAlester Army Ammunition Plant (MAAP) to receive preservative treatment. At MAAP, all boards of Group 3 were treated with cedar oil and silica gel through immersion method for

Figure 1—Red oak and southern yellow pine boards as received: (top) red oak boards (nominal 1 by 6 by 48 in.); (bottom) southern yellow pine boards (nominal 1 by 6 by 48 in.).

Figure 2—Board samples entered into the dry kiln to be heated to 160 °F for a 30-day exposure.

over 12 h. In mid-June 2015, the treated SYP boards (Group 3) were shipped back to Princeton, West Virginia, for physical measurements.

Testing Procedures

Board samples were measured for basic physical properties at the time received, before entering the kiln, and after 30 days of high-temperature exposure in the kiln. A kiln exposure of 160 °F dry-bulb temperature with low relative humidity in a 1,000-board-foot Irvington Moore Dry Kiln (Jacksonville, Florida) was used to simulate a hot and dry environmental condition that the ammo pallets could experience during service. Figure 2 shows all the sample boards wheeled into the dry kiln to be heated for a 30-day high-temperature exposure. The physical measurements on the board samples at each stage included the following:

- Measure warp (crook, bow, twist) of each board using aluminum wedges and a measurement table
- Mark end splits with a color pen (defect mapping)
- Measure stress wave velocity on each board (E-rating)
- Weigh each board
- Measure moisture content on a subsample of boards

Following the 30-day kiln exposure and final physical measurements in Princeton, boards of all three groups were shipped to the Forest Products Laboratory in Madison, Wisconsin, and stickered in a conditioning room of 75 °F and 65% relative humidity. Upon reaching equilibrium moisture content, the boards were subjected to flatwise static bending testing with a center point load according to ASTM standard D 198 (ASTM 2014). Load-deflection data for each board were recorded to determine mechanical properties: modulus of elasticity (MOE), modulus of rupture (MOR), and work to maximum load (WML). During the static bending test process, a subsample of 20 boards were randomly selected from each group and a moisture block was cut from each of these boards for determination of moisture content (MC) using oven dry method ASTM D 4442-15 (ASTM 2015).

Results and Discussions

Dimensional Stability

As service conditions change during service, wood pallets tend to change dimension and develop defects such as checks, cracks, and splits. These defects could cause wood pallets to be downgraded or rejected if they are not within specifications. The quantitative parameters we examined concerning the dimensional stability of the pallet boards were end splits and board warp (bow, crook, and twist). Figure 3 shows the distribution of end splits for three groups of pallet deck boards measured before and after the high-temperature kiln exposure. Table 1 summarizes the cumulative length of the end splits for each group.

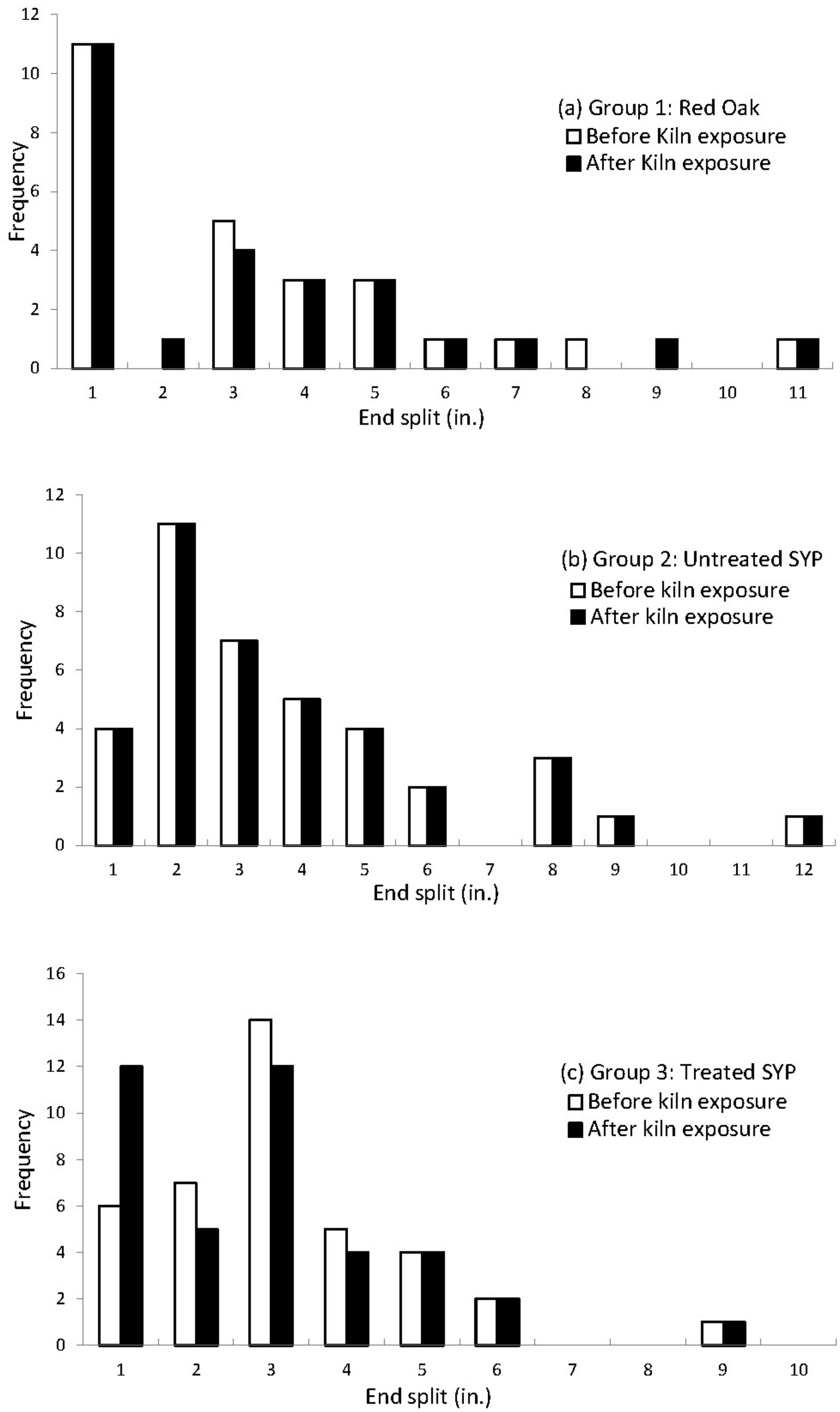

Figure 3—Distribution of end splits measured on red oak and southern yellow pine boards (1 in. = 25.4 mm).

Table 1—Cumulative length of end splits visually mapped on the boards at the time received, before kiln exposure, and after kiln exposure

		Cumulative length of all end splits (in.)[a]		
Pallet deck board	No. of boards	Received	Before kiln exposure	After kiln exposure
Group 1: Red oak	100	75.6	73.7	73.9
Group 2: Untreated SYP	100	93.7	89.0	89.4
Group 3: Treated SYP	100	71.3	72.3	64.3

[a] 1 in. = 25.4 mm.

No discernible differences in end splits for both red oak (Group 1) and untreated SYP (Group 2) were found before and after the kiln exposure. However, overall end splits in treated SYP (Group 3) were reduced 11% after kiln exposure. The cedar oil and silica gel treatment may have contributed to relief of drying stress during kiln exposure and subsequently yielding very few new short end splits while reducing the length of some visible splits based on our visual observation.

Table 2 shows cumulative warp for each board group. Overall, the red oak group had much less warp than the SYP groups. This is not surprising, because the oak boards we received were high-quality wood with few defects (Fig. 1a). The SYP boards, on the other hand, were No. 2 grade and had various defects such as big knots, slope of grain, wane, and blue stain (Fig. 1b). For SYP boards, cumulative warp for the untreated group increased with a magnitude higher than that for the treated group. The cedar oil and silica gel treatment seemed to help stabilize wood and reduce the tendency of warping in SYP boards.

Mechanical Properties

Table 3 shows basic properties of the pallet boards measured at the time they were received. Both density and dynamic MOE of the oak group were significantly higher than those of two SYP groups ($p = 0.0000$) at a 95% confidence level. These measured properties are consistent with property values given in the *Wood Handbook* (FPL 2010) for the species.

For SYP boards, no statistical differences in density ($p = 0.2538$) and dynamic MOE ($p = 0.0682$) between Group 2 (Untreated SYP) and Group 3 (SYP to be treated) were found at 95% confidence level, indicating that the SYP boards in these two groups can be deemed as having the same quality.

Table 4 shows the moisture conditions of the red oak, untreated SYP, and treated SYP boards before and after the kiln exposure and at the time of static bending tests. The MC dropped to 2.2% for red oak and about 7% for SYP after the 30-day kiln exposure. After conditioning in the environmental room at 75 °F and 65% RH for 2 months, the MC was up to 7.9% for red oak, 10.6% for untreated SYP, and 10.4% for treated SYP.

Table 5 tabulates static bending properties (MOE, MOR, and WML) of the pallet boards after the 30-day kiln exposure. All static bending properties of the oak group are significantly higher than those of the two SYP groups at a 95% confidence level ($p = 0.0000$). There are statistical differences in MOE ($p = 0.0218$) and MOR ($p = 0.0263$) between Group 2 (SYP with no preservative treatment) and Group 3 (SYP with preservative treatment) at the 95% confidence level. Both MOE and MOR decreased significantly in the treated SYP group compared to that in untreated SYP group, indicating a possible detrimental effect of the preservative on mechanical performance. There is no statistical difference in WML ($p = 0.1778$) between the two SYP groups at 95% confidence level.

Conclusions

The red oak boards received were high-quality boards with very few defects. The 30-day dry kiln time did not have much effect on existing end splits and warp of the boards. Mechanical properties of the red oak group obtained through destructive bending tests were significantly higher than those of untreated SYP and preservative-treated SYP.

The cedar oil and silica gel treatment had a positive effect on dimensional stability of the No. 2 SYP boards. Cumulative length of the end splits in treated SYP was reduced by 11% after kiln exposure, compared to that before kiln exposure, whereas cumulative length of end splits in untreated SYP remained the same after kiln exposure. The cedar oil and silica gel treatment likely contributed to relief of drying stress during high-temperature exposure and subsequently reduced the length of visible splits, though technically end

Table 2—Cumulative board warp (crook, bow, twist) physically measured at time received, before kiln exposure, and after kiln exposure

	Cumulative warp (in.)[a]								
	Received			Before kiln exposure			After kiln exposure		
Pallet deck board	Crook	Bow	Twist	Crook	Bow	Twist	Crook	Bow	Twist
Group 1: Red oak	0.00	3.56	0.75	0.00	1.16	0.84	0.19	6.63	0.38
Group 2: Untreated SYP	0.66	5.84	7.31	0.63	3.53	6.59	1.84	11.44	11.75
Group 3: Treated SYP	0.81	4.78	5.19	0.29	4.21	3.25	1.69	7.31	5.41

[a] 1 in. = 25.4 mm.

Table 3—Basic properties of the pallet deck boards measured at the time received[a]

Pallet deck boards	No. of boards	Density (lb/ft^3) Mean	Standard dev.	Dynamic MOE ($\times 10^6$ lb/in^2) Mean	Standard dev.
Group 1: Red oak	100	42.50	3.50	2.01	0.283
Group 2: Untreated SYP	100	32.54	3.53	1.56	0.320
Group 3: SYP to be treated	100	32.10	3.54	1.49	0.310

[a] 1 lb/ft^3 = 16.02 kg/m^3; 1 lb/in^2 = 6.895 kPa.

Table 4—Moisture content of pallet deck boards during the course of the project

Pallet deck boards	Moisture content (MC) (%) Before kiln exposure	After kiln exposure	At time of static testing
Group 1: Red oak	7.1	2.2	7.9
Group 2: Untreated SYP	9.1	6.8	10.6
Group 3: Treated SYP	13.0	6.7	10.4

splits did not heal and just visually closed. Treated SYP also had less warp than the untreated SYP group. The treatment seemed to help stabilize the wood and reduce the tendency of warping in SYP boards.

The cedar oil and silica gel treatment had a detrimental effect on stiffness and strength of the No. 2 SYP boards. Both MOE and MOR decreased significantly in the treated SYP group compared to that of untreated SYP group. However, the preservative treatment had no significant effect on WML.

Literature Cited

Adams, R.P.; McDaniel, C.A.; Carter, F.L. 1988. Termiticidal activities in the heartwood, bark/sapwood and leaves of *Juniperus* species from the United States. Biochemical Systematics and Ecology. 16(5): 453-456.

Adams, R.P. 1991. Cedar wood oils—analysis and properties. In: Modern methods of plant analysis. New Series, Volume 12. Essential oils and waxes. Linskens, H.F.; Jackson, J.F., eds. Berlin: Springer-Verlag. pp. 159-173.

ASTM. 2014. D 198-14. Standard test methods for static tests of lumber in structural sizes. West Conshohocken, PA: American Society for Testing and Materials.

ASTM. 2015. D 4442-15. Standard test methods for direct moisture content measurement of wood and wood-base materials. West Conshohocken, PA: American Society for Testing and Materials.

Clark, A.M.; McChesney, J.D. 1990. Antimicrobial properties of heartwood, bark/sapwood and leaves of *Juniperus* species. Phytotherapy Research. 4(1): 15-19.

Forest Products Laboratory. 2010. Wood handbook—wood as an engineering material. General Technical Report FPL-GTR-190. Madison, WI: USDA Forest Service, Forest Products Laboratory. 510 p.

Table 5—Static bending properties of pallet boards after 30-day high-temperature exposure[a]

Pallet deck boards	No. of boards	MOE ($\times 10^6$ lb/in^2)[b] Mean	Standard dev.	MOR (lb/in^2)[b] Mean	Standard dev.	WML ($in\text{-}lbf/in^3$)[c] Mean	Standard dev.
Group 1: Red oak	100	2.03	0.320	15,021	2,455	10.6	3.60
Group 2: Untreated SYP	100	1.58	0.363	10,191	2,618	5.2	2.51
Group 3: Treated SYP	100	1.47	0.389	9,417	2,990	4.9	2.62

[a] Average moisture content (MC) of boards was 7.9% for red oak, 10.6% for untreated SYP, and 10.5% for treated SYP. *Wood Handbook* property values at 12% MC: northern red oak, MOE = 1.82×10^6 lb/in^2, MOR = 14,300 lb/in^2, WML = 14.5 in-lbf in^3; loblolly pine, MOE = 1.34×10^6 lb/in^2, MOR = 9,400 lb/in^2, WML = 10.4 in-lbf in^3.
[b] 1 lb/in^2 = 6.895 kPa.
[c] 1 in-lbf/in^3 = 6.923 kJ/m^3.