Field Test of Sticker Thickness in Kiln Drying of Southern Pine

Laya Khademibami, Fatemeh Rezaei,* Rubin Shmulsky, and Seyed Abolghasem Fatemi

The effect of sticker thickness on final moisture content (MC) of southern pine lumber was investigated in this work. Three kiln charges of lumber were dried to examine the impact of sticker thickness. Sticker thicknesses were 0.75-, 1.00-, and 1.25-in. The moisture contents at different locations within the kiln pack (edge vs middle / course position) were noted. Three course positions were top 5, middle, and bottom 5 courses. Two within-pack locations were considered: outer 25% and middle 50%. Drying time decreased as sticker thickness increased from 0.75 in. to 1.00 in. Statistically significant interactions were noted for sticker thickness and course position (<0.0001) as well as location and course position (P= 0.0378); 1.25 in. thick stickers exhibited higher MC in comparison to 0.75 in. and 1.0 in. for top to bottom positions. Additionally, 1.0 in. thick stickers developed lower MC at the top and bottom. Lower MC was observed in outer relative to inner location regardless of course position. Lower MCs were observed at the top courses for both inner and outer location. The 1.25 in. thick stickers did not produce acceptably dry lumber given the production time constraint. The results suggested that 1.0 in. sticker thickness was most favorable.

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*Contact information: Department of Sustainable Bioproducts, Mississippi State University, Box 9820, Starkville, MS 39762, USA; *Corresponding author: fr280@msstate.edu*

INTRODUCTION

Kiln drying is a process in which the moisture content (MC) of wood is reduced in chambers that have controlled air circulation, relative humidity, and temperature. As compared to air drying, overall processing time and avoidance of degradation in the course of drying are more favorable (Rahimi *et al.* 2023). It is well-documented that appropriate MC is required for sawn timber that is used in different product applications, including furniture and flooring (Kumar *et al.* 2022; Majka and Sydor 2023). Southern yellow pine structural lumber is mainly kiln dried. This process results in lumber that conforms to Products Standard 20 (NIST 2020). Kiln dried lumber can be directly used in construction. It can be reprocessed into glulam, cross laminated timber, and trusses, or it can be pressure treated for outdoor applications.

The aim of kiln drying is to maximize throughput while minimizing drying-related defects such as splits, warp, as well as MC variation among samples. Cold spots in the kiln result in higher MC lumber. Hotter spots result in overdried lumber. Over-drying increases warp and may increase air emissions.

Stickers, also called kiln sticks, are the thin strips of material (usually wood, laminated lumber, or steel) that can be used to separate individual courses of lumber. The stickers create air channels above and below of each course of lumber through which warm dry air is passed in order to heat the lumber and carry away moisture laden air as the lumber dries. Stickers also help create stability and integrity of the kiln packages and help fix lumber in a straight and true position such that warp is minimized. Kiln throughput optimization (maximizing production while minimizing MC variation) can be achieved by choosing the optimal sticker thickness.

In previous research, various kiln sticker thicknesses have been studied. In one study, sticker thickness ranged from 0.25 to 0.75 in. (0.63 to 1.9 cm) and was combined with different air velocities from 325 to 350 ft/min (99 to 107 m/min) for testing 2 in. (5cm) thick western hemlock to determine the uniformity of airflow (Horton and Resch 1976). It was found that thicker sticks improved air flow uniformity. There, maximum air velocity was observed between 0.438- and 0.75-in. (1.11 cm and 1.9 cm) sticker thickness, while lowest uniformity occurred at the 0.25 in. (0.63 cm) thickness. Price and Koch (1981) reported that 1.5 in. (3.81cm) sticker thickness with 1,400 ft/min (426 m/min) air velocity was needed to reach 10% average MC in approximately 12 h. Herzberg *et al.* (1983) investigated sticker thicknesses from 0.125 to 1.0-in. (0.317 to 2.54 cm) and kiln package widths of 4, 6, and 8 ft (1.21 m, 1.82 m, and 2.43 m). There, drying time was reduced by more than one-half when 9/16 in. (1.42 cm) thick stickers, combined with narrow kiln packages (4 ft equivalent to 1.22 m) were used. In addition, air velocity and maximum air temperature have been found to be key factors for final MC variation in high temperature drying of pine (Taylor and Mitchell 1987). Furthermore, it has been suggested that the MC varies with position in the stack (Herzberg *et al*. 1983; Taylor and Mitchell 1987). The study by Taylor and Mitchell (1987) was limited, however, to only one sticker thickness (0.75 in. equivalent to 1.9 cm). In the study conducted by Herzberg *et al*. (1983), high-temperature drying of pine 2×6 in. (5×15 cm) lumber was performed with two sticker thicknesses, while other variables were held constant.

Thinner sticks are associated with greater total input courses of lumber in the kiln (Price and Koch 1981). Thus, thinner sticks may increase output due to a fewer kiln charge changes per time. However, thinner stickers can result in greater MC variation due to low air volume in channels between adjacent lumber courses leading to the air saturation with moisture before it exits the lumber package (Price and Koch 1981). Thicker sticks facilitate greater airflow across each board and thus shorten drying times and improve MC uniformity. This action can result in an increase in MC located at or in the near exiting edge of lumber, leading to an increase in the MC variation at the end of the drying cycle (Price and Koch 1981). Also, if the kiln is heat-capacity (burner, boiler, or fin pipe) limited, then stuffing more courses of lumber in each kiln charge does not increase throughput. According to previous studies, the influence of all three factors including sticker thicknesses, course position (bottom to top), and location (edge to middle) on total MC variation has not been previously investigated. It was hypothesized that the optimum MC would be determined with individual or combination effects of above-mentioned factors. Therefore, the objective of this study was to compare the final MC characteristics of pine lumber when dried with the different combinations of the kiln sticker thicknesses, course position, and location.

EXPERIMENTAL

Material Preparation and Kiln Drying Process

Southern pine (*Pinus* spp.) lumber was received directly from a regional sawmill located in MS. Lumber was rough green, freshly sawn 2 × 4 in. cross section, equivalent to approximately 5 × 10 cm. Lumber was 16 ft (5 m) long. The lumber was matched to the extent that it was all cut from the same run of logs on the same day. Lumber was randomized among the three kiln charges followed by drying according to the following measurements: kiln pack length and width: 16 ft (5 m) by 8 ft (2.43 m). Kiln maximum exiting dry bulb temperature and steam pressure: 240 °F (116 °C), and 120 to 150 psi (827 to 1034 kPa). The three sticker thicknesses were: 0.75-, 1.00-, and 1.25-in. (1.9-, 2.54-, and 3.17 cm, respectively). The stickers were manufactured from solid pine lumber. Air velocity at ambient temperature (approximately 65 °F (18 °C)) was set at approximately 976 ft/min (297 m/min) for the 0.75 in. (1.9 cm) thick stickers. Fan speed, as motor rpm, was then held constant for the 1.0- and 1.25-in. (2.54 and 3.17-cm) thick stickers. Lumber course measurements within the kiln pack were considered at three levels: top 5, middle, and bottom 5. These divisions were chosen because often the upper courses reach a lower MC (often overdried) as compared to the lower courses. Each course (layer) of lumber contained 24 pieces. Edge position was classified as the outer 25% (6 pieces per course) on each side of the kiln pack. The middle position was classified as the central 50% (that is 12 pieces per course). The above-mentioned classification was also recommended by Taylor and Mitchell (1987). This division was obtained to investigate the MC gradient from the edge to the middle of the pack. An example showing the outer 25% and middle 50% positions at a commercial pine kiln is shown in Fig. 1.

Fig. 1. Exemplar packages of 2 in. (5-cm) thick pine lumber, stacked on sticker, awaiting drying at a commercial kiln

Lumber course positioning and corresponding divisions are illustrated in Fig. 2. Table 1 describes the single lumber package as well as drying time for each kiln charge.

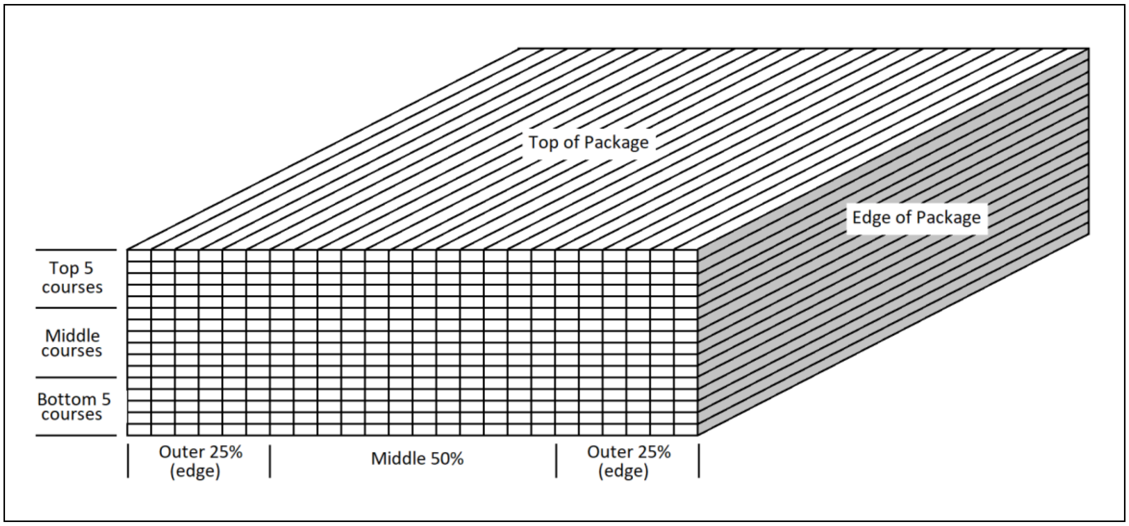

Fig. 2. Sketch of exemplar kiln package. Each package is 16 ft (4.87 m) long, 24 pieces (8 ft (2.43 m)) wide and contains either 16, 17, or 18 courses (layers)

Table 1. Lumber Package Details by Sticker Thickness

	Sticker Thickness		
	0.75 in. (1.9 cm)	1.0 in. (2.54 cm)	1.25 in. (3.17 cm)
N courses	18	17	16
N pieces per course	24	24	24
N total pieces	432	408	384
N board feet	4609	4353	4096
Measured initial air velocity (ft/min)	976	932	944
Drying time (h)	23.8	20.2	18.5

Drying times for the 0.75 in. (1.9 cm), 1.0 in. (2.54 cm), and 1.25 in. (3.17 cm) thick stickers were 23.8, 20.2, and 18.5 h (h), respectively (Table 1). Drying times were estimated and controlled based on weight loss, temperature drop across the load over time, and final wet bulb temperature. The 18.5 h used for 1.25 in. (3.17 cm) lumber has been shown to be approximately the maximum duration at the cooperating production facility without interfering overall production. Approximately 6.5% less lumber would fit in each kiln charge for the 1.25 in. (3.17 cm) *versus* 1.0 in. (2.54 cm) thick stickers. That volume equates to four fewer courses fitting in the commercial cooperator's kiln with 1.25 in (3.17 cm) *vs.* 1.0 in. (2.54 cm) thick stickers. In the test kiln, the weight of lumber was measured continually throughout the drying process *via* a hydraulic load cell system under the kiln cart. From the past experience and input from the cooperating sawmill, it was estimated that at target 15% MC, the unit weight of the rough dry pine lumber would be 2.41 pounds per board ft (approximately 464 kg/m^3). The initial moisture content of the lumber was estimated to be 110%. These values were helpful in estimating when the drying was complete. Upon completion, the MC% of each piece of lumber was measured with a Wagner capacitance type moisture meter (model L601-3) that was calibrated to measure the average value from the surface to the center of each piece, that is, to a depth of 1.0 in. (2.54 cm).

Statistical Analysis

The experimental design was a completely randomized design, and the experimental unit was each lumber piece. All data were analyzed using three-way analysis of variance (ANOVA) with 3 × 2 × 3 factorial arrangement of treatments to test for the main and interactive effects of the 3 thickness treatments, 2 location treatments, and 3 course position treatments (Table 2). General linear mixed models (PROC GLIMMIX) of SAS 9.4© (SAS Institute Inc, Cary, NC) were used to analyze all data. Treatment differences were deemed to be significant at $P \leq 0.05$. Fishers protected least significant difference was performed for treatment means separations (Steel and Torrie 1980). The following statistical model was used for all data,

$$Y_{ijk} = \mu + T_i + L_j + (TL)_{ij} + P_k + (TP)_{ik} + (LP)_{jk} + (TLP)_{ijk} + E_{ijk} \quad (1)$$

where μ was the population mean; T^i was the effect of thickness treatment (i = 1 to 3); L_j was the effect of location treatments (j = 1 to 2); $(TL)_{ij}$ was the interaction of each thickness treatment with location treatment; P_k was the effect of course position treatments (P = 1 to 3); $(TP)_{ik}$ was the interaction of each thickness treatment with course position treatment; $(LP)_{jk}$ was the interaction of each location treatment with course position treatment; $(TLP)_{ijk}$ was the interaction of each thickness treatment with each location and course position treatments; and E_{ij} was the residual error.

Table 2. Experimental Design

Factors	Effect
Thickness	0.75 in. (1.9 cm)
	1.0 in. (2.54 cm)
	1.25 in. (3.17 cm)
Location	Outer 25%
	Inner 50%
Course position	Top 5 courses
	Middle courses
	Bottom 5 courses

RESULTS AND DISCUSSION

Moisture content results along with production rates based on board feet per charge *versus* drying time as well as average drying rates are shown in Table 3. The numerical differences among the three sticker thicknesses showed that the MC, average rate loss, and production rate increased by an increase in the thickness. However, the MC coefficient of variation decreased with the thickest stickers. Also, the percentage of wet pieces, that was those at or above 20% MC, was highest with the thickest stickers.

Weight data indicated that lumber on the 0.75 in. (1.9 cm) and 1.0 in. (2.54 cm) thick stickers reached the target weight in the allotted time. The lumber on the 1.25 in. (2.54 cm) stickers did not reach its target weight. Initial, final, and target weights are shown in Table 4.

Table 3. Moisture Content and Production Rate Information Based on the MSU Tests

	Sticker Thickness		
	0.75 in. (1.9 cm)	1.0 in. (2.54 cm)	1.25 in. (3.17 cm)
Average MC (%)	15.5	13.3	24
Stdev (%)	5	5.2	6.8
COV* (%)	32.2	39.1	28.3
% of pieces above 20% MC	11.8	8.3	64.1
Production rate (board ft/h)	194	215	221
Average rate loss (Δ%MC/h)	3.97	4.79	4.65

*Coefficient of Variation

Table 4. Initial, Final, and Target Weights of the Three Kiln Charges

	Sticker Thickness		
	0.75 in. (1.9 cm)	1.0 in. (2.54 cm)	1.25 in. (3.17 cm)
Initial weight	20300 (lb) 9208 (kg)	19175 (lb) 8698 (kg)	18050 (lb) 8187 (kg)
Average initial weight / board foot	4.4	4.41	4.41
Final charge weight	11075 (lb) 5024 (kg)	10050 (lb) 4559 (kg)	11050 (lb) 5012 (kg)
Final weight/board foot	2.4	2.16	2.7
Target final charge weight	11125 (lb) 5046 (kg)	10500 (lb) 4763 (kg)	9875 (lb) 4479 (kg)

The statistical differences in MC among different sticker thicknesses, locations, and course positions are shown in Table 5. No significant MC% interactions were observed among sticker thickness, location, and course position. However, there was significant interactive effect on MC% between sticker thickness and course position (P=<0.001), and between location and course position (P= 0.038; Table 5). Thus, no main effects were reported due to significant interaction effects for at least 1 of class that was involved in analysis.

Pieces from the 1.25 in. (3.17 cm) sticker thickness charge had the highest MC as compared to any other course position or treatment group from the other two kiln charges. This finding is likely attributable to the fact that the drying time associated with the thickest stickers was reduced to maintain production. More drying time would have been required as compared to what was available given the production-related time constraints. Furthermore, mean MC did not differ from top to the bottom course position for the 0.75 in. (1.9 cm) sticker thickness. For the 1.0 in. (2.54 cm) sticker thickness, the highest MC was observed at the bottom, intermediate in the middle courses, and lowest at the top. Additionally, for the 1.0 in. (2.54 cm) sticker thickness the pieces from the top and middle developed lower MC as compared to 0.75 in. (1.9 cm) (Fig. 3).

Table 5. Effects of Sticker Thickness at 2 Within-pack Locations and 3 Course Positions on Kiln Dried Moisture Content Percent

Treatment	n	Thickness (in.)	Course Position	MC (%)
Sticker thickness*Course position				
	127	0.75	Top 5 courses	15.3[c]
	127		Middle courses	16.1[c]
	127		Bottom 5 courses	15.3[c]
	127	1.0	Top 5 courses	10.9[e]
	127		Middle courses	13.2[d]
	127		Bottom 5 courses	15.2[c]
	127	1.25	Top 5 courses	23.4[b]
	127		Middle courses	23.7[ab]
	127		Bottom 5 courses	24.9[a]
SEM				0.70
Location*Course position		Location	Course position	
	187	Inner 50%	Top 5 courses	17.8[bc]
	187		Middle courses	18.5[b]
	187		Bottom 5 courses	20.2[a]
	187	Outer 25%	Top 5 courses	15.2[e]
	187		Middle courses	16.8[cd]
	187		Bottom 5 courses	16.7[d]
SEM				0.57
Source of variance	df	*P*-value		
Sticker thickness	2	<0.0001		
Location	1	<0.0001		
Course position	2	<0.0001		
Sticker thickness*Location	2	0.6839		
Sticker thickness*Course position	4	<0.0001		
Course position*Location	2	0.0377		
Sticker thickness*Location*Course position	4	0.6237		

[a-e] Treatment means within the same column within effect without common superscripts are significantly different (P ≤ 0.05).

The results of this study showed that none of the individual factors, acting alone, was effective in lowering the final MC, and the combination of sticker thickness plus course position or sticker thickness plus course position and location was needed to minimize the MC. In consideration of thickness, results showed that 1.25 in. (3.17 cm) resulted in higher MC given the time constraints. With 1 in. (2.54 cm) thickness, the MC increased from the top of the lumber package to bottom. Herein, results showed the best MC uniformity was achieved with 0.75 in. (1.9 cm) thick sticks. These results indicate that 0.75 in. (1.9 cm) sticker thickness can be a suitable candidate to achieve uniform MC; however, drying time must be increased, and thus production declines. A slight increase in sticker thicknesses from 0.56 in. to 0.75 in. (1.4 cm to 1.9 cm) has been shown to cause significant effects on air velocity (Horton and Resch 1976; Price and Koch 1981), MC (Horton and Resch 1976; Price and Koch 1981; Herzberg *et al*. 1983; Taylor and Mitchell 1987), and drying time (Price and Koch 1981) of pine lumber. However, there is limited information with regards to the influence of sticker thickness above 1 in. (2.54 cm). For the lumber dried on 1.0 in. (2.54 cm) thick stickers, no statistically significant difference in final MC was detected at the bottom of the package as compared to the lumber dried on 0.75 in. (1.9 cm) thick stickers. In sum, the results indicate that the 1-in. (2.54 cm) thick stickers are superior, given the allotted drying times. 1.0-in. stickers achieved the target MC in the allotted time and developed greater percentage of MC drop per unit time as compared to 0.75-in. (1.9 cm).

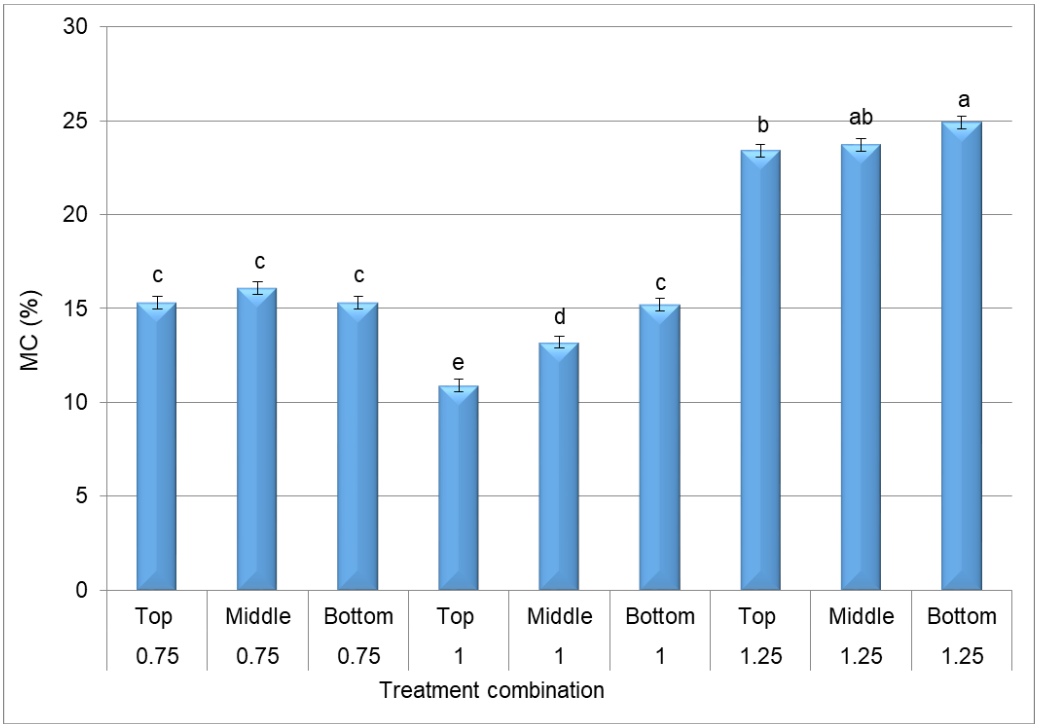

Fig. 3. Interaction effects between thickness and course position on moisture content percent. a-e Treatment means within the same column within effect without common superscripts are significantly different ($P \leq 0.05$). The number of replications per treatment combination is 127; SEM= 0.632

In the inner location, higher MC was observed in pieces at the bottom course position in comparison to those at the middle or top. Additionally, those pieces located at top outer location developed lower final MC as compared to those in the middle or bottom outer locations. Moreover, the pieces at the outer location developed lower MC as compared to those from the inner location regardless of their course position (Fig. 4). The lower final MC observed at the top and edges of the kiln package can likely be attributed mainly to the lower density of hotter air, which causes it to rise as well as the higher static air pressure closest to the fans at the top of the kiln package.

The aim of this study was to evaluate the influence of sticker thickness on MC. Of particular interest were drying time and MC variation. The results appear to show that the 1.0 in. (2.54 cm) sticker thickness was superior, given the allotted drying times. The 1.0 in. (2.54 cm) sticker thickness achieved the target MC in the allotted time and it developed greater MC drop per unit time as compared to others. With the 1.0 in. (2.54 cm) sticker thickness, MC increased from top to bottom. The results showed that 1.25 in. (3.17 cm) thickness resulted in higher final MC average and standard deviation. Ultimately, to maintain production with the 1.25 in. (3.17 cm) thick stickers, the drying time needed to be reduced and was not sufficient to adequately dry the lumber. The 0.75 in. (1.9 cm) sticker thicknesses permitted more lumber to be contained in each kiln charge; the additional air resistance associated with the thinner sticker channels and the greater volume of wood in the kiln (which has a fixed heat supply) caused a net decrease in production as compared to that of 1.0 in. (2.54 cm) sticker thickness.

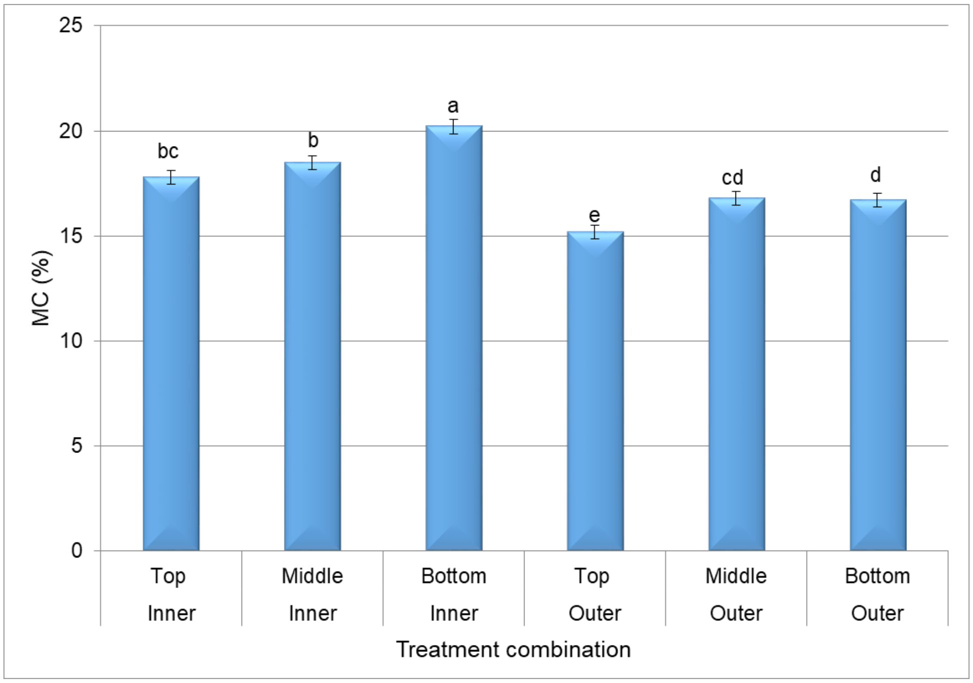

Fig. 4. Interaction effects between sticker location and course position on moisture content percent. a-e Treatment means within the same column within effect with no common superscripts are significantly different ($P \leq 0.05$). The number of replications per treatment combination is 187; SEM= 0. 572.

If equal time were allowed for the 1.25 in. (3.17 cm) thick stickers, that is 20.2 h, the result would likely show similar final MC distribution; however, net production would decline because less lumber would be dried in each kiln charge. For this test, the 1.25-inch-thick sticks (3.17 cm) showed the highest production rate and greatest amount of moisture removed per unit time; however, 64% of the pieces finished wet. It was estimated that nearly two additional kiln h would have been required to sufficiently dry the lumber on the 1.25 in. (3.17 cm) stickers. This time would have been equivalent to that of the lumber on the 1.0 in. (2.54 cm) thick stickers.

Although the results of this work showed the most uniformity and relatively low final MC belonged to 0.75 in. (1.9 cm) thickness, the lowest MC was observed in 1.0 in. (2.54 cm) thickness, but only at the top and middle course position. The results suggest that when balancing production with uniformity, the 1.0 in. (2.54 cm) sticker thickness is superior. The 1.0 in. (2.54 cm) thick stickers achieved the target MC in the allotted time and developed a greater percentage of MC drop per unit time as compared to 0.75 in. (1.9 cm).

CONCLUSIONS

The research aimed to investigate the impact of sticker thickness on the final MC of kiln dried pine lumber. The lumber position and division in kiln dried were also considered. The main conclusions are as follows:

1. The final MC of kiln-dried lumber with thicker stickers was higher than that of lumber with thinner stickers. This finding was likely mainly due to the abbreviated time allotment for the lumber that was dried with these thicker sticks. Thus, when evaluating sticker thickness, not only final MC average and standard deviation but also overall drying time and productivity should be considered.
2. Average final MC was lower among the top courses of the lumber compared to the middle and bottom courses when using a sticker thickness of 1 in. (1.9 cm).
3. Average final MC was consistently lower in the outer (25% edges) as compared to middle (50%) locations regardless of course position.
4. With respect to final MC variation, the 1.0 in. (1.9 cm) thick stickers seemed to provide better performance as compared to 1.25 in. (3.17 cm) stickers. However, as compared to 0.75 in. sticker thickness, the 1.0 in. (1.9 cm) performance was dependent on the location of course position.
5. The 1.25 in. (3.17 cm) sticker thickness exhibited unfavorable results with respect to achieving the final target MC in the allowable time.
6. The results showed that the 1.0 in. (1.9 cm) thick stickers provided the best combination of uniformity and production.

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REFERENCES CITED

Herzberg, B. L., Taylor, F. W., and Rosen, H. N. (1983). "Kiln characteristics can influence drying time and moisture uniformity in high-temperature-dried lumber," *Proceedings, Western Dry Kiln Clubs Joint Meeting*, pp. 58-64.

Horton, R. K., and Resch, H. (1976). "Kiln-stick thickness effects drying 2-inch western hemlock lumber," *Forest Products Journal* 26(3), 35-39.

Kumar, C., Faircloth, A., Leggate, W., and Redman, A. (2022). "Impact of continuous drying method on drying quality of southern pine sawn timber," *BioResources* 17(1), 574-591. DOI: 10.15376/biores.17.1.574-591

Majka, J., and Sydor, M. (2023). "Analysis of stress development during kiln drying of beech timber," *European Journal of Wood and Wood Products* 81, 1189-1200. DOI: 10.1007/s00107-023-01967-y

National Institute of Standards and Technology (NIST). (2020). American Softwood Lumber Standard, Voluntary Product Standard PS 20-20. Paragraph 2.7: Dry Lumber. Page 10.

Price, E. W., and Koch, P. (1981). "A note on the effects of stick thickness and air velocity on drying time of southern pine 2x4 and 2x6 lumber," *Wood and Fiber Science* 13(2), 115-119.

Rahimi, S., Nasir, V., Avramidis, S., and Sassani, F. (2023). "The role of drying schedule and conditioning in moisture uniformity in wood: A machine learning approach," *Polymers (Basel)* 15, article 792.

Steel, R. G. D., and Torrie, J. H. (1980). *Principles and Procedures of Statistics. A Biometrical Approach* (2nd ed.), McGraw-Hill, New York, NY.

Taylor, F. W., and Mitchell, P. H. (1987). "Drying pine lumber at very high temperatures and air velocities," *Wood and Fiber Science* 19(3), 239-245.

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