

EFFECT OF DISTANCE ABOVE GROUND DURING AIR SEASONING ON FLEXURAL PROPERTIES OF BLACK GUM AND RED OAK TIES

Leon Rogers

Former Graduate Research Assistant

E-mail: leon.rogers@oregonstate.edu

Jed Cappellazzi

Senior Faculty Research Assistant

Department of Wood Science & Engineering

Oregon State University

Corvallis, OR 97331

E-mail: jed.cappellazzi@oregonstate.edu

*Jeffrey J. Morrell**†

Director and Professor

National Centre for Timber Durability and Design Life

University of the Sunshine Coast

Brisbane, Queensland, Australia

E-mail: jeff.morrell@oregonstate.edu

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Abstract. Stacks of red oak (*Quercus rubra*) and black gum (*Nyssa sylvatica*) railroad ties were seasoned 150, 200, or 300 mm above the ground to investigate the effect of height on fungal colonization and timber properties. Decay fungi became increasingly abundant as seasoning time increased. Decay fungi were more abundant on black gum than red oak ties, but fungal isolation frequency did not differ with variation in seasoning sill height. Similarly, neither MOR nor MOE differed with seasoning height. The results indicate that decreasing the tie seasoning height by 150 mm had no significant effect on either fungal colonization or timber properties.

Keywords: Railway ties, air seasoning, decay, red oak, black gum, MOR, MOE.

INTRODUCTION

Creosote-treated wood railroad ties remain the backbone of the North American railroad network providing long, reliable service life under a range of conditions (Webster 1992; Webb et al 2016). Tie preparation generally involves an air-seasoning period to remove moisture from wood before preservative treatment (Taylor et al 2015). Exposing untreated timber for long periods increases the risk of fungal attack and wood decay (Zabel and Morrell 2020). National standards require practices during seasoning to reduce decay, including using seasoning sites that expose

ties to maximize airflow and expedite drying, removing woody debris from the seasoning yard, and creating well-drained sites to avoid standing water (Taylor et al 2013; AWP 2017; AREMA 2019). These standards also mandate that seasoning yards must minimize the risk of direct soil contact by seasoning ties a minimum of 300 mm above the ground on preservative-treated or durable stickers (sills). Two timbers are typically required to achieve the 300-mm sill height. The first timber can be placed mechanically, whereas the second is typically placed manually, creating the risk of worker injury when lifting (Reinach and Gertler 2001). There has been an industry desire to decrease worker injury by reducing sill heights, but doing so could increase the risk of fungal attack during seasoning. Although increased separation between

* Corresponding author

† SWST member

seasoning timbers and soil should be intuitively beneficial, there are few studies examining the effect of distance above the ground during seasoning on timber properties. Railroad ties in storage were the subject of many early studies on decay (Humphrey and Richards 1939), and results were used to develop seasoning recommendations (Mathewson 1930; Mathewson et al 1949), but studies on the effects of seasoning on fungal colonization and tie wood properties are limited (Taylor et al 2013). Air seasoning has been studied using other wood species and applications. Air-seasoned Douglas fir poles were found to be colonized by a variety of fungi over a 3-yr period, but the fungi had no negative effect on flexural properties (Smith et al 1987). Subsequent studies showed that decay fungi rapidly colonized wood but were slow to induce changes in flexural properties (Smith et al 1992). This contrasts with previous reports showing dramatic strength loss at very early stages of fungal attack (Wilcox 1978; Winandy and Morrell 1993); however, context is important. Most laboratory studies create ideal conditions for fungal attack, resulting in rapid wood property losses. Proper air seasoning, conversely, should create an ever-diminishing habitat for fungal attack. Thus, colonization may not immediately translate into substantial timber property changes, and it is this premise that allows for air seasoning of larger timbers before preservative treatment. The effect of distance above the ground on the risk of fungal colonization and changes in timber properties remains unclear. The purpose of this study was to examine the effects of sill height during air seasoning on fungal attack and flexural properties in ties of two commonly used wood species.

MATERIALS AND METHODS

One hundred freshly cut ties of red oak (*Quercus rubra* L.) and black gum (*Nyssa sylvatica* Marsh.) (175-mm by 225-mm by 2.55-m long—one of the most common tie dimensions) were obtained from an area near Guthrie, KY. Black gum is classified as nondurable, whereas red oak has slight resistance to decay (Scheffer and Morrell 1998). The ties were graded according to the Railway Tie Association grading requirements (Webb

et al 2016). Two ties of each species were rejected because of defects, whereas the remaining 98 were included in the study. The degree of initial fungal colonization was assessed by removing increment cores from the center of one wide face and locations 450 mm inward from both ends of each tie.

Increment cores were placed in plastic straws, labeled with the tie number and location, then stapled shut to minimize the entry of other fungi. Increment core holes were plugged with tight-fitting, creosoted wood dowels. The 125- to 150-mm-long increment cores were surface-flamed to minimize the growth of contaminating fungi and placed on 1% malt extract agar amended with benomyl. Benomyl retards the growth of ascomycetes, allowing us to selectively isolate basidiomycetes (Carey and Hull 1989). Whereas some ascomycetes can cause wood decay, most of the important wood decay fungi are basidiomycetes (Zabel and Morrell 2020). For the purposes of this report, references to decay fungi represent basidiomycetes, although we also recognize that not all fungi in this group cause substantive wood decay. The plated cores were examined for evidence of fungal growth over a 1-mo period. Basidiomycetes growing from wood were segregated by growth morphologies and the presence of hyphal clamp connections for later identification to genus and, where possible, species (Rogers 2019).

Ten ties of each species were removed from the seasoning study immediately after the initial fungal sampling and used to assess baseline flexural properties. These ties were shipped to Oregon State University, where small, clear beams (25 by 25 by 400 mm long) were cut from each tie, conditioned to constant weight at 65% RH and 23°C, and tested to failure in four-point loading. These data were used to determine the initial MOR and MOE according to ASTM Standards D143-14 and D4761-18 (ASTM 2017a, 2017c). Beams were tested at loading rates of 4 mm/min and 3 mm/min for black gum and oak, respectively.

Stacking Procedures for Seasoning

The remaining 88 ties of each species were placed into normal German-style seasoning stacks with treated sills that kept ties a minimum of 150, 200, or

300 mm off the ground. The ties were placed in courses of five test ties between two nontest ties at each side within a layer to minimize edge effects and to match normal German-style stacking with 9 ties in a layer (Mathewson et al 1949; Webster 1992; Taylor et al 2013). Only the first three layers above the treated sill received test ties because this was perceived to be the zone where proximity to the ground would have the greatest effect on moisture conditions. Nontest ties were then placed on the top of the first three layers to create a full stack containing approximately 204 ties. Two stacks of each species were set at each sill height, creating 12 stacks in total. The stacks were located in a section of yard near a creek and riparian area that would be more likely to have high humidity and, therefore, foster fungal growth. RH/temperature sensors attached to the underside of ties in the first and third layer of one stack at each sill height showed that there were no noticeable differences in humidity or temperature within the stacks at different sill heights (see Rogers 2019).

The test site is located in American Wood Protection Association (AWPA) Deterioration Zone 4 (but close to Zone 3) and is representative of many tie seasoning sites in the region (AWPA 2017a; Kirker et al 2017). Ties were exposed between June 2017 and April 2018. The gum stacks were disassembled and sampled after 3 mo of air seasoning using the same increment core procedures described earlier, whereas the oak ties were not sampled until 6 mo, as this species requires a longer seasoning period (Connors 2008; AREMA 2019). Ties were returned to the same position in a stack after sampling.

The gum ties were removed from the test after 6 mo when they had reached a MC suitable for treatment. These ties were transported to Corvallis, OR, where a third set of increment cores was removed for fungal sampling. The oak ties were seasoned for an additional 5 mo and similarly shipped to Oregon for sampling.

Beam Preparation

Ties were tested for strength by 4-point bending of small clear beams cut from each tie according to ASTM D143-14 (ASTM 2017a). Beams were

cut to 25.5 mm × 25.5 mm × at least 406 mm in length so that they would be 25 by 25 mm after drying to 12% MC. Each beam was assessed for grain and defects. Signs of decay deemed to have been present as heart rot in the living tree, as well as insect galleries, and open decay pockets were rejected from initial testing, but beams with visual signs of incipient decay such as mycelial growth or melanin deposits (zone lines) characteristic of white-rot decay, as well as any fungal pigmentation (spalting) from other fungi were included in the tests. Visual indicators of fungal growth were retained in testing to capture the potential variations in strength caused by decay fungi. There were no obvious decay pockets or decayed regions noted that could not be attributed to decay present at the time the trees were felled. The most common causes to reject small beams were knots or grain defects. Two different sampling schemes were implemented for black gum and oak ties. Black gum ties were sampled with the intention of correlating intra-tie strength variations with core sample positions so that strength could potentially be related to the distance from the presence of a decay fungus.

Black gum ties were initially sampled at a rate of 12 beams per tie. Four planks (32 mm thick by 178 mm wide) were cut across the narrow end of each black gum tie. The remainder of each tie was retained in case additional beams were required. The endmost 280 mm of each plank as well as the top incised plank and outer 25-30 mm incised surfaces were discarded because these zones were more likely to have drying defects, such as splits or checks, that would complicate testing. The remaining plank portions were cut into 406-mm-long segments labeled A, B, C, D, or E, with segment A matched to core A. Segments were cut to beams of 25 mm × 25 mm and 406 mm length. Selecting 12 beams per gum tie resulted in 1056 small clear beams, labeled according to depth and position within ties (Fig 1).

Although the black gum beams provided a wealth of test data, isolation of decay fungi and flexural properties were poorly correlated. The first unseasoned red oak ties were processed in the same

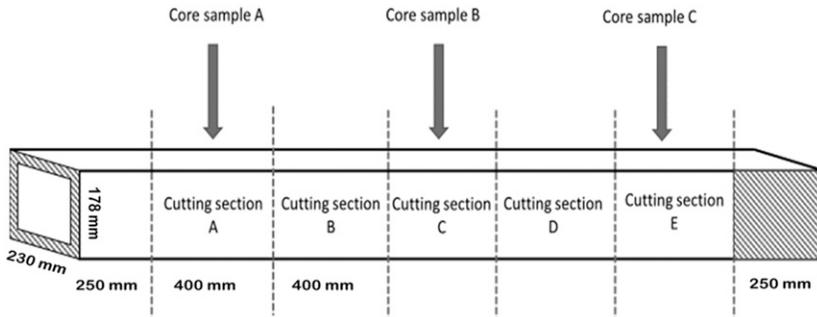


Figure 1. Cutting and sampling locations from a rail tie. Core samples were taken from the wide face. All outer surfaces and the endmost 250 mm were excluded from beam cutting. Black gum beam samples were taken from all sections A-E, whereas oak beams were taken only from section A.

manner as described for the black gum, but fungal isolation frequencies from the oak ties were much lower than those from the black gum ties, and because initial tests suggested that the wood properties were less variable, the beam cutting pattern for air-seasoned oak ties was reduced.

Beams were cut from all red oak ties, but only beams from the ties in layers (tiers) closest to and furthest from the ground were tested (tiers 1 [closest] and 3 [farthest]). Beams were obtained from tie ends closest to core C positions (or southwesterly facing ends of stacks) and were cut from the area 280 mm to 775 mm inward from the end and from depths of 50 mm to 130 mm on the narrow (178 mm) face. The endmost 280 mm and all incised outer portions were again avoided to minimize edge effects. Ties were always cut with the pith on center. This resulted in essentially all beams being cut from heartwood, but the sampling pattern avoided the most juvenile wood at the pith in as much as the heartwood orientation allowed. Ties sampled at the beginning of the air-drying period to establish baseline measurements were an exception to this sampling method.

Beams were conditioned to constant weight at 65% MC and 20°C before testing. Black gum beams were at 12% MC and oak beams were 15% MC at the time of testing. MC was verified by oven drying and weighing random samples at 50°C for 72 h.

Flexural Testing

Strength and flexibility, expressed as MOR and MOE, were determined using a 4-point bending test according to the secondary test method described in ASTM Standard D143-14 (ASTM 2017a). The 4-point loading produced a wider stress area than 3-point and increased the likelihood that any decayed wood would be included in the stressed region while minimizing potential shear forces.

The conditioned beams were tested to failure on an Instron 5982 universal testing machine (Instron, Illinois Tool Works, Norwood, MA) with downward force applied at two points, dividing the entire span into 11.85-cm thirds and 25 mm of overhang beyond each side of the testing apparatus. The suggested loading rate from ASTM D143-14 of 1.3 mm/min was adjusted so that beams achieved ultimate stress in around 5 min (Gerhards 1977). Black gum beams were tested at a loading rate of 4 mm/min, whereas oak beams were tested at 3 mm/min. These test speeds were similar to loading rates previously used for small wood beams (Davis et al 2012; Babiak et al 2018). All beams were loaded with the pith side oriented upward as the bearing surface.

Load and deflection were continuously recorded to the point of failure, and these data were used to calculate MOE and MOR in MPa. Results were compared with previous reports for each species (FPL 2010; ASTM 2017b; Webb et al 2016) and

baseline tests conducted on ties of the same batch that were not air seasoned. In all cases, MOE was determined using the most linear portion of the load deflection curve.

A total of 686 small beams cut from 88 air-seasoned black gum ties were tested to failure, whereas 306 red oak beams from 57 air-seasoned ties were tested. Five red oak beams were tested from each tie from the first and third tiers in the seasoning stacks, avoiding 28 ties from the second tiers. This facilitated direct comparison of strength measures in the bottom

tiers across all treatments and effects from height within each stack.

Data Analysis

The isolation data were summarized by species, location in a stack (i.e. distance above ground), and seasoning time. Flexural data were summarized and compared with previously published values for each wood species, and results were compared with seasoning conditions to determine whether sill height affected flexural properties for each species.

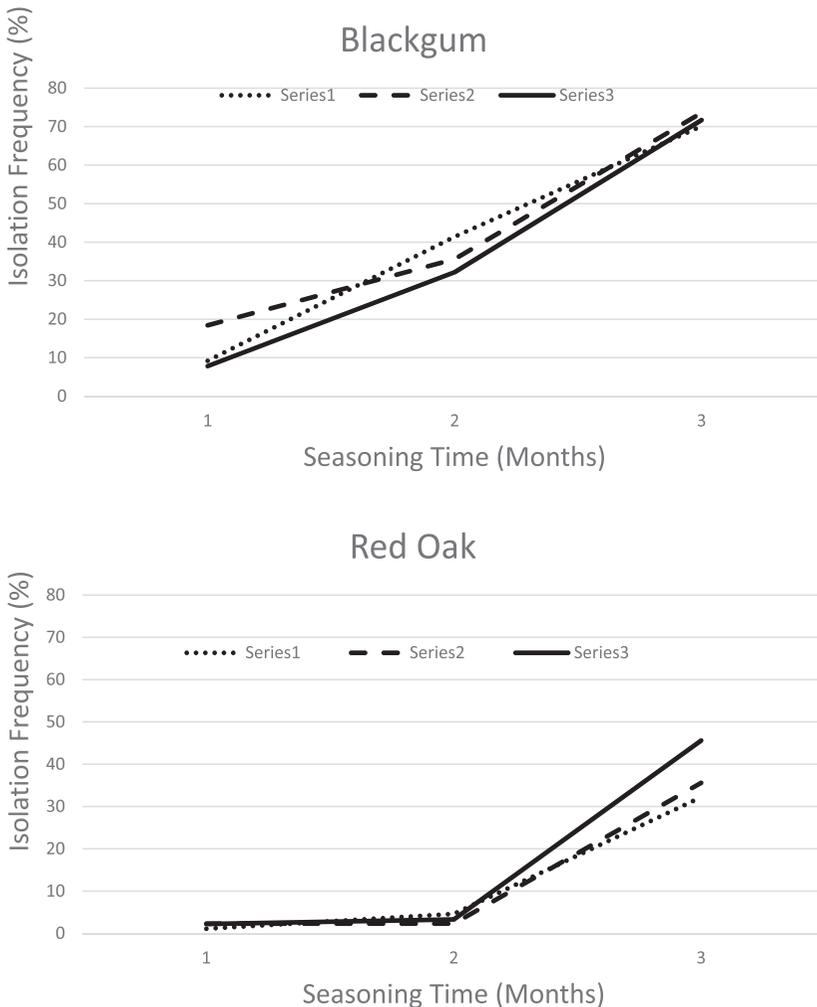


Figure 2. Isolation frequencies of decay fungi over time from black gum and red oak ties seasoned on sills 150, 200, or 300 mm off the ground.

Flexural data were subjected to an analysis of variance (ANOVA) and Tukey’s test of means for MOR and MOE ($\alpha = 0.05$). Pairwise comparisons were not corrected for multiple comparisons, and we expected some type I errors, given the number of comparisons (Neyman et al 1933; Parchami et al 2008).

Flexural properties were ultimately calculated as an average of all beams from each tie. The matter of weighted averages per tie was resolved by considering all ties as complete and equal sample units.

Isolate counts at each height were compared using the multiresponse permutation procedure (MRPP), a nonparametric technique that allows for comparison of groups by distance (dissimilarity) in multiple variables at the same time (Biondini et al 1991; McCune et al 2002). The

MRPP provides a *p*-value to evaluate differences and an *A*-value (−1 to 1) of chance corrected within group agreement, that is, the size of the effect between two or more groups. The MRPP allowed for comparisons of fungal community composition and size (isolate counts) similar to permutational multivariate ANOVA but avoided any assumptions of normality (Biondini et al 1991).

RESULTS AND DISCUSSION

Environmental Monitoring

RH and temperature changed seasonally, but there were no noticeable differences in conditions related to sill height, suggesting that altering height by 150 mm did not markedly change the environment for fungal colonization (data not shown; see Rogers 2019).

Table 1. MOR and MOE of black gum and red oak beams cut from freshly cut ties or from ties that had been air seasoned for 6 or 11 mo.^a

Species	Sill height (mm)	Layer	N ^a	MOE (MPa)	MOR (MPa)	Isolate count
Black gum (seasoned 6 mo)	Not air seasoned	—	8 (225)	10,989 (1346)	80.21 (10.19)	3
		150	1	10 (64)	10,067 (1633)	68.12 (14.21)
	200	2	10 (71)	10,607 (1780)	75.23 (14.4)	33
		3	9 (69)	10,384 (1190)	76.46 (14.33)	37
		Average		10,353 (1534)	73.27 (14.31)	
		1	10 (87)	10,040 (1545)	75.88 (14.66)	39
		2	10 (60)	9758 (1201)	74.99 (9.24)	38
		3	10 (99)	10,818 (1093)	80.9 (11.04)	34
		Average		10,205 (1279)	77.26 (11.65)	
	300	1	10 (103)	9110 (1440)	64.87 (13.78)	41
		2	10 (75)	10,806 (1116)	77.32 (14.05)	37
		3	9 (58)	11,392 (1409)	81.63 (16.46)	22
		Average		10,436 (1322)	74.61 (14.76)	
	USDA values		—	8300	66	
Red oak (seasoned 11 mo)	Not air seasoned	—	9 (315)	11,646 (1050)	79.65 (7.13)	0
		150	1	9 (47)	10,662 (964)	75.85 (8)
	200	3	9 (51)	11,502 (1630)	82.25 (10.01)	8
		Average		11,082 (1297)	79.05 (9)	
		1	10 (52)	10,407 (1713)	77.62 (10.28)	8
		3	10 (58)	11,701 (2135)	81.4 (13.2)	4
	300	Average		11,054 (1924)	79.51 (11.74)	
		1	10 (52)	11,037 (1039)	78.61 (10.56)	10
		3	9 (46)	11,002 (990)	78.68 (6.54)	6
	Average		11,020 (1015)	78.64 (8.55)		
	USDA values		—	10,300	75	

^a Values represent number of ties, while figures in parentheses represent the number of beams examined.

Differences between sensors were constant but could be better attributed to sensor aspect and facing more than they could be related to height. Differences in sensors did not indicate a height gradient.

Fungal Isolations

Decay fungi were isolated from 11.7% of cores removed from freshly cut black gum ties before air seasoning (Fig 2). These fungi were likely in the trees before cutting, although they may have also invaded in the time between harvest and sampling (Hepting 1971; Schwarze et al 2013). Decay fungi were only isolated from 1.9% of the red oak ties, indicating that these ties were relatively free of fungal presence.

Fungal colonization increased sharply in gum ties after 3 mo of seasoning, but there were no significant differences between ties seasoned on stacks at different sill heights. The MRPP did not indicate any difference in isolate counts or community composition related to sill height ($\alpha = 0.05$). Isolation frequencies in black gum continued to increase with an additional 3 mo of seasoning with 71.6% of cores yielding decay

fungi; however, once again, sill height had no significant effect on isolation frequency. Isolate counts were nearly identical among seasoning heights and sill heights after 6 mo of seasoning (Fig 2).

Isolation frequencies in red oak ties increased minimally after 6 mo of seasoning, with slightly more decay fungi isolated from ties on 150-mm sills, but the differences were not significant. Isolation frequencies increased markedly with an additional 5 mo of seasoning, with isolates recovered from 37.8% of all cores. Although isolation frequencies were highest from ties on 300-mm sills, the differences between sill treatments were not significant and had no relationship to height. Decreasing the sill height from 300 to 150 mm had no effect on the incidence of decay fungi as indicated by culturing. Although culturing is not necessarily a direct measure of decay nor is it capable of recovering all fungi present in a substrate, it provides a measure of relative decay risk (Winandy and Morrell 1993; Schwarze et al 2013). The results also highlight the importance of ensuring ties are subjected to sterilization at some point between the end of seasoning and placement in track.

Table 2. One-way analysis of variance results for MOR and MOE values of beams cut from red oak and black gum ties seasoned on 150-, 200-, or 300-mm-high sills. Oak ties were compared using the first and third tier of stacks. Replicates (n) represent the number of ties sampled. p -values indicate evidence of any difference between groups.

		Sill height			Total	
		150 mm	200 mm	300 mm		
Red oak	MOR (MPa)	<i>N</i>	18	20	19	57
		Mean	79.04	79.50	78.64	79.07
		SD	988.86	1229.38	912.98	1038.69
		<i>p</i> -value	0.97			
	MOE (Mpa)	D.f	56.00			
		Mean	11,082.26	11,053.85	11,020.48	11,051.70
		SD	1444.28	2093.37	1044.41	1572.03
		<i>p</i> -value	0.99			
		D.f	56.00			
Black gum	MOR (MPa)	<i>N</i>	29	30	29	88
		Mean	73.15	77.25	74.36	74.95
		SD	15.04	12.35	16.66	14.69
		<i>p</i> -value	0.55			
	MOE (Mpa)	D.f	87.00			
		Mean	10,351.60	10,205.41	10,402.98	10,318.70
		SD	1609.61	1392.87	1671.36	1544.91
		<i>p</i> -value	0.75			
		D.f	87			

Flexural Properties

Average MOE values for beams cut from black gum and red oak ties before air seasoning were above the previously reported values for each species (Table 1) (FPL 2010). MOE values for beams from ties seasoned at varying heights ranged from 9727 to 11,356 MPa for black gum and 10,370 to 12,623 MPa for red oak. There were no significant differences between MOE values for beams before and after seasoning or between beams cut from ties seasoned in stacks with different sill heights, except for black gum beams of tier 1 in stacks with 300-mm-high sills, which had lower MOE and MOR than beams cut from ties from baseline testing (MRPP; $p = 0.04$, $A = 0.10$) (Table 1).

Average MOR values for beams cut from black gum and red oak ties before air seasoning were also near or above the previously reported values for each species, regardless of sill height or position in the seasoning stack (Table 1) (FPL 2010). MOR values for black gum ties seasoned at varying heights ranged from 64.67 to 81.37 MPa, whereas those for red oak ranged from 74.54 to 85.29 MPa. As with the MOE, neither sill height nor location in a seasoning stack had a significant effect on the MOR for either species (Table 2). The results indicate that reducing the sill height by 150 mm had no significant effect on RH or temperature conditions, frequency of isolated decay fungi, or flexural properties of either species. Tier 1 of black gum ties at 300 mm was the only group that did not exceed published strength values (FPL 2010). We could not draw any correlation between flexural properties and either height or isolate counts.

CONCLUSIONS

Air-seasoned black gum and red oak ties were colonized by an array of potential decay fungi over the course of 6 or 11 mo of exposure; however, there were no significant effects on flexural properties of either red oak or black gum. Reducing the sill height from 300 to 150 mm above the ground also had no significant effect on fungal colonization or flexural properties of either

species. The results indicate that altering the sill height within the range tested would have no noticeable negative effect on tie properties.

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