Toughness of Loblolly Pine (*Pinus taeda*) Salvaged after 0 to 6 Months on the Ground

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Abstract

Recovering value, mainly as lumber, from windthrown trees is important. Toughness has been shown to be an early indicator of deterioration. To investigate, approximately 38-year-old loblolly pine trees, from the same forest stand, were felled. From these fallen trees, five trees were removed at 0, 3, 4, 5, and 6 months. Toughness specimens were prepared and tested from this material. Bending modulus of rupture (MOR) and modulus of elasticity (MOE) of cross-laminated timber specimens from this same material (reported elsewhere) showed no significant differences. Results indicated that toughness decreases in response to time on ground were statistically significant. This finding suggests that within the 0-to-6-month interval toughness declined but no changes in MOR and MOE were not detectable.

Decay or deterioration in wood necessarily reduces its utilitarian properties. Small amounts of decay, as measured by weight loss, can cause large losses of strength and stiffness. Wilcox (1978) noted the strength properties that most severely and rapidly diminished by the onset of decay are toughness and impact bending (subtly different ways of measuring the same fundamental properties). The southern pine belt runs from Texas to Virginia (Franca et al. 2018). The land associated with this geographical distribution is within 200 miles of either the Gulf of Mexico or the Atlantic Ocean. As such, much of the pine timberland is susceptible to strong coastal storms as well as inland tornadoes particularly at the Western half of the southern pine belt. Climate change may increase the severity and/or frequency of storms and other high-wind events. As a result of such storms, timber is often windthrown. In the best case the trees remain standing but may have slight internal damage such as that of ring shake. In severe cases, large acreages may be blown down and/or broken. For example, in September 1989, Hurricane Hugo struck South Carolina with 135 mile-per-hour winds. Subsequent forest inventory indicated that 4.5 million acres of timberland, about 37% of South Carolina's timberland, sustained damage (Sheffield and Thompson 1992). To minimize the negative financial implications of these losses, salvage logging may be used after such storm events. Salvaging timber can be a difficult task for landowners following a disaster event. As a result, damaged wood can remain unutilized on the landscape leading to potential wildfires and pest outbreaks in addition to lost revenue (Gordon et al. 2018). There is however a time limit during which salvage logging may be effective. If too much time elapses between wind throw and processing, then significant loss of production yield and/or wood properties occurs. For felled pine trees fungal type stain, beetle infestation (Sellers 1985), and ultimately decay is the result of increasing time on the ground. Therefore, the objective of this research was to compare the toughness of wood specimens recovered from pine trees that were felled and remained in the forest for 0, 3, 4, 5, and 6 months.

Materials and Methods

To simulate wind-throw conditions candidate pine trees were selected and felled. Loblolly pine (*Pinus taeda*) trees from a single stand were selected. Twenty-five trees were felled on the same day. This date was considered time zero. Trees were approximately 38 years old and were approximately 15-in (38 cm) diameter at breast height. Trees were from similar growing stock but were not clones. After

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felling the trees were left on the ground. Tops were left intact in order to simulate the conditions after a windthrow event. At time zero, five trees were taken to the laboratory for processing. Subsequently at times 3, 4, 5, and 6 months five trees from each time were taken to the laboratory for processing. In this manner, the wood under consideration was analogous to that of a salvage logging operation. Further description of the tree felling, and nondestructive analysis of resultant lumber, and pictures of the resultant CLT is given in Khademibami et al. (2024). Processing consisted of bucking the stems into logs, sawmilling the logs into 2×6-in. (5×15 cm^2) lumber, kiln drying and planning the lumber, nondestructively evaluating the lumber, and manufacturing demonstrative cross-laminated timber (CLT) panels from the lumber. At this time, that demonstrative work is in preparation for publication. Following that demonstration, clear straight-grain toughness specimens were recovered either from extra lumber that was not used in the CLT panel demonstration or from the intact ends of the CLT panels. In sum, approximately 70 toughness specimens were considered for each of the five-time treatments (0, 3, 4, 5, or 6 months). Lumber and CLT raw materials were stored outside under a protected roof. It was estimated that equilibrium moisture content (EMC) conditions were in the range of 10–15%. Once machined, toughness specimens were returned to an exterior environment that was protected from rain. This action likely resulted in an equilibrium moisture content situation near, but not necessarily at, 12% as called for by ASTM D143 (2017). This moisture conditioning scenario was favored as lumber and CLT panels from the same parent stock were equilibrated at these same moisture conditions. Figure 1 illustrates a stack of toughness specimens, from time 0, after machining and awaiting testing. As such, this action was thought to facilitate more direct comparisons between the toughness results and other mechanical and nondestructive testing results. Additionally, because in this case the toughness tests are meant to be comparative across times within this experiment, as long as all the specimens were conditioned in the same environments the comparisons should be valid.

Toughness testing was conducted per ASTM D143 (2017). The pendulum type testing device used herein is described in FPL No. 1308 (1961). In short, the pendulum imparts a fixed amount of energy into each specimen and the extent to which the specimen interrupts the pendulum's swing is measured via a degree Vernier. To the extent possible, growth ring orientation was alternated such that the load was applied to either the radial or tangential face in subsequent specimens. The toughness tester employed a 50-pound (23 kg) weight, and the 20.25-in. (51 cm) long pendulum was set with an initial angle of 45 degrees. The 11 in. (28 cm) long specimens were loaded across a 9.47-in. (24 cm) span. After testing, an approximately 2-in. (5 cm) long section was crosscut from the one end of each specimen. The section was weighed, measured, oven dried, and reweighed for moisture content (MC) per ASTM D4442 (2017) and specific gravity (SG) per ASTM D2395 (2017) determination. Moisture content (MC) was considered on a dry basis, that is, weight of the water divided by the oven-dry weight of the wood. SG was considered as oven-dry mass divided by volume at the MC during testing.

Figure 1.—Toughness specimens from time 0 after machining and before toughness testing.

Once complete, data for toughness, SG, and MC were analyzed via statistical ANOVA with alpha level of significance at 0.05.

Results

The results of the toughness, MC, and SG are shown in Tables 1 to 3. For reference, the Wood Handbook (Senalik and Farber 2021, Table 5-9) lists the average SG_{12} for loblolly pine as 0.51, the mean radial and tangential toughness values as 160 and 260 in.-lbf (18.1 and 29.4 Nm), respectively, and Table 5-6 lists the toughness coefficient of variation as 34%. SG_{12} is the specific gravity at 12% MC; calculated as

$$SG_{12} = M_{od}/V_{12}$$

where

M_{od} = Mass oven-dry,
V_{12} = Volume at 12% MC.

Table 1.—Summary statistics for toughness (in.-lbf) across the five post-felling time-on-ground treatments. Means with the same letter were not found to be statistically different at the a = 0.05 level. P value ≤ 0.0001.*

	Months				
	0	3	4	5	6
N	68	71	69	71	72
Mean*	146^{a}	130^{ab}	132^{ab}	115^{b}	92^{b}
Median	142	118	143	126	82
St Dev	61.5	53.3	58.9	50.7	35.7
COV	42%	41%	45%	44%	39%
Min	30.5	36.5	36.5	21.5	18.5
Max	276	296	276	241	216

*: [a and b] Treatment mean within the same column within effect without common superscripts are significantly different (P value < 0.05).

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Table 2.—Summary statistics for MC (percent, dry basis) across the five post-felling time-on-ground treatments. Means with the same letter were not found to be statistically different at the a = 0.05 level. P value = 0.0023.*

	Months				
	0	3	4	5	6
N	68	71	69	71	72
Mean*	8.6%[c]	8.8%[bc]	9.0%[ab]	9.2%[a]	8.8%[bc]
Median	8.7%	9.0%	9.0%	9.2%	8.6%
St Dev	1.1%	0.7%	0.7%	0.9%	0.9%
COV	13%	7%	8%	10%	10%
Min	1.7%	6.3%	7.8%	7.1%	6.3%
Max	10.3%	10.2%	12.1%	11.4%	10.6%

*; a-c Treatment mean within the same column within effect without common superscripts are significantly different (P value < 0.05).

Table 3.—Summary statistics for SG across the five post-felling time-on-ground treatments. No statistically significant differences were detected at the a = 0.05 level across the differing time-on-ground treatments. P value = 0.0943.

	Months				
	0	3	4	5	6
N	68	71	69	71	72
Mean	0.46	0.47	0.48	0.48	0.46
Median	0.45	0.46	0.48	0.48	0.43
St Dev	0.06	0.05	0.08	0.07	0.07
COV	13%	10%	16%	15%	15%
Min	0.34	0.38	0.33	0.35	0.36
Max	0.59	0.58	0.82	0.65	0.66

Figure 2 illustrates the data points across the time treatments.

Conclusions

The toughness of this material appeared to decrease over time. Overall, these differences were statistically significant at the a = 0.05 level. The p-value for this analysis was < 0.0001. Toughness values were highly variable hence the relatively weak correlation is shown in Figure 2.

The toughness values developed herein appear to be lower than those listed for loblolly pine in the Wood Handbook. However, the SG as measured herein was also lesser than that reported for the same species in the Wood Handbook.

The COV values for toughness ranged from 39 to 45%. These COV values were slightly higher than those reported in the Wood Handbook. This increase may be attributed to the fact that the specimens evaluated herein were recovered from sawn lumber some of which may have had slight slope of grain.

The mean MC% at the time of testing for all of the specimens across all time treatments was approximately 9%. This finding suggests that the moisture equilibration before testing was effective. Overall, differences among these MC % values were statistically significant at the $\alpha = 0.05$ level. The p-value for this analysis was 0.002. That said, average MC values ranged from 8.7% to 9.2%. These MC% differences were of no practical significance and could very likely be ignored. It seems highly unlikely that additional environmental conditioning time would have further reduced MC% variation. As such, it is considered that MC was not an influential factor with respect to observed differences in toughness at the varying time periods.

The SG values the time of testing for all of the specimens across all time treatments ranged from 0.46 to 0.48. No clear trend (downward) was noted for the specimens as time increased. This finding suggests that from 0 to 6 months after-felling, the SG did not trend downward. Overall, the differences among SG values were not statistically significant at the a = 0.05 level. The p-value for this analysis was 0.09943.

The work described herein is part of a parent demonstration project in which CLT was produced and tested from this same raw material. In that work, currently in preparation for publication, when the CLT was destructively tested in bending, no statistically significant differences were

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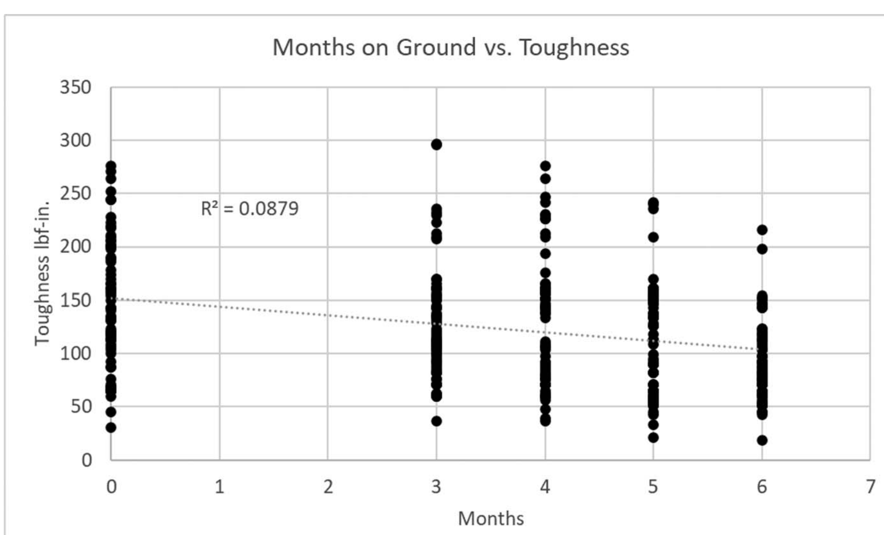

Figure 2.—Time (months) when the felled trees were on the ground in the forest vs. toughness.

found across the different time periods for MOE (p-value 0.5438) or for MOR (p-value 0.1564). The findings developed herein corroborate that reported by Wilcox (1978) which reported that toughness is an early indicator of deterioration as compared to other methods.

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