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WEATHERING EFFECTS ON THE DECAY RESISTANCE OF CREOSOTE-TREATED OAK

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Abstract: The resistance to decay of wood represents an important aspect of the functional durability of wood products. A standard soil block culture method ASTM [D 2017-81] was used to test the decay resistance of creosote-treated Oak crossties. Two types of crossties , naturally aged and accelerating (artificially) aged were used in the experiment. Creosote treated oak crosstie samples from service ages of 0, 5, 15, 20, 25, 30 and 40 years was infected by brown and white-rot fungi. Changes in some physical properties provided decay resistance bench mark for materials. Results show that brown-rot caused greater change in weight-loss and some physical properties in naturally aged samples than white-rot. Weight-loss of 43 to 47 percent, thickness-change from 2.35 to 17.83 percent, volume change from 6.89 to 28.51 percent and density change from 3.26 to 26.40 percent were observed. Naturally aged samples were found to be more susceptible to fungal attack as compared to artificially aged ones. Creosote content ranged from 3.41 pcf to 8.55 pcf. Type of fungus and number of cycles contributed significantly in the deterioration of the physical properties of wood. Relationship between the weight-loss and the creosote retention exists. On the basis of decay resistance, six cycles of this laboratory accelerated weathering or aging technique may be equivalent to more than 20 years of natural weathering on railroad track. This cyclic aging technique can be used as a quality control method in the development of oak crosstie products.

Keywords: Accelerated aging, Biodegradation; Brown-rot, Creosote Content; Decay White-rot; Red oak.

This is a refereed paper

Introduction

Wooden crossties occupy a significant place in timber usage throughout the world. They have been in service since 1831 (Bescher, 1977). Primarily they have been used in US either in the rail road industry or in the bridge construction. The chemically treated crossties account for more than 30 percent by volume of treated wood products which measures to 500 million cubic feet (14.16m3). It accounts for 1.46 billion dollars of merchandise annually. The major factors contributing to its degradation of treated oak rail road crossties are splitting, decay and other mechanical factors. Decay accounts for almost 12.2 percent of total ties removed every year. It is shown that the biological factors primarily fungi cause a significant effect on the service life of crossties (Bescher, 1977; Hope, 1983; Masters, 1982; USDA, 1973). Previous studies show that 43.6 percent of wood crossties were removed from track due to decay (Russel, 1986). Most of the fungi penetrate the material through a check associated with incision in the wood. Brown-rot and white-rot fungi are mainly associated with crossties decay.

Creosote constitutes as major preservative in treating rail road crossties and has been in use since 1838. Wide range of weight-loss among the samples infected by brown-rot fungi has been observed . It has been observed that brown-rot fungi like Lentinus lepidus and *Poria vaporaria* and *Coniophora cerebella* can grow in the presence of creosote (Cart-Wright et al., 1958). Wood having creosote less than 2 lbs per cubic foot is easily decayed by brown-rot (Hartley, 1958). Creosote content vaporizes with time in the natural environmental conditions (Reginald, 1972). Its content ranges from 4.4-13.6 Pcf for 15-20 years sample (Schmitz et al., 1937 and 1941). Creosote is also found to be biodegradable thereby making wood more susceptible to attack by fungi.

The objectives of this study were to compare the rate of decay of naturally-aged and artificially aged red oak (Quercus rubra) crossties against the brown and white-rot decay fungi. Secondly to estimate the amount of creosote present in these crossties.

Methodology

1. Materials and Methods

Red Oak (*Quercus Spp.*) railroad crossties were selected from Norfolk Southern Railroad track at Sadorus, Illinois and used for the experiment. These crossties represented service ages of 0, 5, 15, 20, 25, 30 and 40 years. The artificially accelerating-aged samples were taken from new red oak crossties which were pressure treated using creosote coal tar (60/40). The test samples were taken from each cycle of accelerated aging process. The artificial aging test consisted of six cycles, each cycle consisting of the following procedure (Chow et al., 1986 and 1987):

1. 30 minutes under water and 25 inch (63.5 cm) vacuum.
2. 30 minutes under water and 170 psi (1.75 kg/cm²) pressure.
3. 3 hours in a 0°F (-17.8°C) freezer.
4. 10 hours of steaming at 250°F (121°C) and 15 psi (103.4 kPa).
5. 9.5 hours of oven drying at 220°F (104°C), and
6. 22 hours of conditioning at 70°F or 21°C and relative humidity of 90 percent.

Test samples from each age group and cycle were taken from the top 50 mm section of these crossties. Samples with dimension 25x25x9 mm were taken from the clear, and defect free two locations, top (surface 0-25mm) and bottom (surface 25-50mm). The samples were air dried and after conditioning them to constant weight they were weighed accurately in the laboratory and then transferred into the test bottles maintained at 26.1±1°C and relative humidity of 70±4%. Two type of fungus, white-rot (*Polyporous versicolor* L.ex.Fr.) ATCC No. 12679 and brown-rot (*Postia placenta* (Fr). Cke. ATCC No. 11538 were used to study the efficacy of creosote against the decay. Standard method of accelerated laboratory test of natural decay resistance of wood (ASTM D2017-96) was used in the study (ASTM, 1996). Reference blocks were made of sweetgum. There were eight replications for each sample. The decay test was terminated after 14 weeks when the reference blocks obtained a weight-loss of 60 percent. Mycelium was brushed off and test samples were air dried and again conditioned to constant weight. The weight was recorded for each sample. The difference in weights of samples before and after the decay test gave the rate of decay in test samples.

2. Creosote Concentration

The creosote content in the test block was analyzed by using AWPA (American Wood Preserver's Association) standard A6-96, a method for the determination of oil type preservative and water in wood (AWPA, 1996). Test blocks weighing more than 5 grams were reduced to shaving chips or shivers and weighed accurately to 0.001gm. Xylene solvent was used to extract creosote. The samples were refluxed in a special apparatus for about 6 hours. The water present in the chips was collected in the water trap. Chips were dried for 90 minutes in oven at 125°C and weighed accurately. The difference in the weight of the test samples before and after refluxing and volume of water gave the amount of creosote present in the samples.

Results and Discussions

1. Weight-loss

Tables 1 and 2. show the weight-loss of naturally-aged and artificially accelerating-aged samples infected by both brown and white-rot fungi. It is clearly evident from the results that brown-rot attacks the creosote treated wood more vigorously than white-rot. The weight-loss was found to be higher for older aged samples. In Table 1, the average weight-loss for artificially accelerating-aged samples varied from 3.67 percent for cycle one samples to 11.48 percent for cycle six samples infected by white-rot. The brown-rot fungus caused an average weight-loss from 5.13 percent to 14.97 percent for the artificially aged samples. It was observed that the average weight-loss was slightly more for samples taken from bottom location of crosstie in white-rot test. However, Table 5 shows that the location did not significantly affect the weight-loss of samples according to the statistical analysis.

As shown in Table 2, the naturally-aged samples exhibited an average weight-loss from 6.83 to 47.38 percent. White-rot fungus caused weight-loss from 6.83 percent for 5 years old oak crosstie sample to 24.95 percent for 40 years old samples. In case of brown-rot, the average weight-loss ranged from 11.26 percent (5 year old) to 47.38 percent for 40 year old samples. However it was observed that the brown-rot infected 30 and 40 years old samples from bottom location showed greater weight-loss. It was noted that there was drastic change in weight-loss between 25 and 30 years old age samples. In the artificially-aged sample, the effect of both aging cycle and fungus type on weight-loss was significant as shown in Table 5. Table 6. shows that the crosstie age, fungus type, sample location and age x fungus interaction were found to be significant factors in influencing the weight-loss of naturally aged oak crosstie samples.

2. Thickness Change

Decayed wood exhibited a various degree in thickness change. The decay resistant wood generally shows a minimal thickness change. Fungus *Poria placenta* caused more change in thickness than *Polyporous versicolor*. Tables 3 and 4. show the mean change in the thickness of samples infected by fungus *Poria placenta* and *Polyporous versicolor*.

The naturally-aged samples showed more change in thickness as compared to the artificially-aged sample. For naturally-aged oak crossties, *Poria placenta* infected samples exhibited thickness reduction from 2.35% to 17.83% and *Polyporous versicolor* showed thickness change from 2.42% to 10.07%. The maximum change in thickness (17.80%) was observed in 40 years samples infected by *Poria placenta*.

Table 3. shows thickness reduction in artificially-aged sample. It varied from 0.38% to 8.06%. The maximum change in thickness was observed for sample representing cycle two (8.06%) infected by fungus *Polyporous versicolor*.

Brown-rot infected samples created more change in thickness than white-rot which was further supported by the other studies on the nature of decay by *Poria placenta* (Schmitz, 1945 and Schulze, 1948). In case of naturally-aged oak crossties thickness change was significant for Age, Fungus, Age x Fungus. Only Fungus and Fungus x Location were significant for artificially-aged crossties (see Table 5 and 6).

3. Volume Change

Decayed wood shows volume change or shrinkage in drying. The dimension changes were more pronounced for *Poria placenta* as compared to *Polyporous versicolor*. As wood is hygroscopic and sensitive to moisture. It was hard to get accurate measurement, as some of samples were found to be deformed, brittle and collapsed.

Tables 3 and 4. show the mean volume change in the samples attacked by fungi. The volume change for naturally-aged samples was considerably more than the artificially-aged sample. The *Poria placenta* infected samples exhibited more change in volume than the samples infected by *Polyporous versicolor*.

The naturally-aged samples, as shown in Table 4, had the average change ranging from 1.48% for 5 year to 28.51% for 40 year old samples. A drastic volume change from 25 year to 30 and 40 year old samples was observed. The *Poria placenta* was capable of reducing the volume of oak crosstie samples up to 28.51 percent whereas the *Polyporous versicolor* accounted for a maximum volume reduction of 16.08 percent for the naturally-aged oak crosstie samples.

In Table 3, the artificially accelerated-aged samples showed the volume change ranging from 1.00% to 10.18%. Samples subjected to 5 cycles of artificially aging and tested using *Poria placenta* showed a maximum change of 10.18%.

Table 5. indicates that the artificial aging cycle and fungus type were significant factors in affecting volume change for accelerated-aged samples whereas for the naturally-aged service age, fungus type, Age x Fungus and sample location were significant factors.

4. Density Reduction

Density changes were also recorded for all samples. Wood decay generally leads to the destruction of this woody mass and making it less dense. The destruction of this woody mass, leads to change in density. As density is a function of mass and volume hence the density change for samples infected by brown and white-rot varied. Tables 3 and 4, show the mean change in density of the samples. Naturally-aged samples showed density reduction in the range from 3.26% to 26.40% infected by fungus *Poria placenta* whereas in artificially-aged samples, the density was reduced from 2.48% to 7.26% by the same fungus. The density reduction for control samples was less than one percent.

It was observed that fungus *Poria placenta* reduced density of oak samples more than the *Polyporous versicolor*. Artificially-aged samples exhibited lower density change than the naturally-aged samples. Density was reduced drastically in naturally-aged from 25 years old sample onwards. Density change for artificially-aged samples didn't show much fluctuation. Only the aging-cycle number was found to be significant for accelerated-aged crossties whereas for naturally-aged crossties variables of Age, Fungus, and Age x Fungus were significant (Table 5 and 6).

5. Creosote Retention

Table 7. shows the amount of creosote present in the test samples. It ranged from 5.31 Pcf to 8.55 Pcf in the artificially accelerated-aged samples. There was a gradual decrease in the average creosote content from cycle one to cycle six. Cycle one samples from bottom location had an average of 8.12 Pcf of creosote content where as the bottom location of cycle five samples showed a 5.31 Pcf of creosote content. In case of naturally-aged samples, the average creosote content ranged from 3.41 Pcf to 8.60 Pcf. The 40 year old samples from the bottom location were found to have a 3.41 Pcf of creosote retention and 5 year samples from the top location had a 4.39 Pcf of creosote retention. It is clearly evident from Table 7. that creosote amount decreases with age and this can be attributed to the environmental and natural weather degradation of creosote with time. Moreover it was discovered that creosote content vaporizes with time (Reginald, 1972). From Tables 1, 2 and 7, a clear relationship can be established that the weight-loss is a function of the amount of creosote present in the oak crossties samples.

Conclusions

This study clearly demonstrates that naturally-aged samples are more susceptible to decay than artificially-aged samples. Brown-rot can cause considerable damage to creosote treated wood in the natural weathering with age on track service condition (47.38%). White-rot is observed to be less aggressive on the creosote treated oak crosstie. Weight-loss sharply increased after 25 years of on track service in naturally-aged samples. Similarly brown-rot fungus caused considerable thickness, volume and density reduction in naturally-aged samples as compared to artificially accelerating-aged samples. The process of laboratory artificial-aging did not significantly change the amount of creosote content present in the samples as much as that in naturally-aged samples in which the creosote decreased with time. There is a clear relationship between the weight-loss and the amount of creosote present in the samples. Furthermore, higher creosote content generally prevents samples from weight-loss in wood infected by wood deteriorating fungi.

Based on the data collected on the biodegradation or decay resistance (weight-loss), and the creosote retention in this study, six cycles of this laboratory accelerated aging technique may be equivalent to more than 20 years of natural weathering on rail road tracks. The results of this study agree to that of a previous study using mechanical properties to relate artificial accelerated and natural aging of oak crossties (Chow et. al., 1987). It can be concluded that this laboratory cyclic accelerated weathering technique can be adopted as a routine quality control method to predict the long term in service decay resistance performance of creosote treated oak crossties as well.

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SESSION CHAIRMAN BAXTER: Thank you, Dr. Chow.

Our next paper, today, is brought to us by Paul Morris. Dr. Morris comes to us from Forintek Canada Corp. He has fifteen years' experience in wood preservation research, since obtaining his Ph.D. from Imperial College of London University. His areas of expertise include International Wood Preservation Standards, treatability of Canadian wood species, laboratory and field test methodology, and factors affecting the durability of wood products. His paper, today, is entitled, "Beyond the Log Probability Model."

Table. 1

Mean Values of Percent Weight-loss of Artificially-aged samples by *Poria placenta* and *Polyporous versicolor*

	Poria placenta		*Polyporous versicolor*	
Artificial Aging Cycles	Bottom	Top	Bottom	Top
Control (0)	1.14	3.91	4.17	2.72
Cycle 1	5.13	6.41	4.51	3.67
Cycle 2	8.70	8.82	6.50	6.38
Cycle 3	9.43	12.28	7.70	6.77
Cycle 4	14.29	11.20	10.95	9.94
Cycle 5	14.97	12.82	11.48	10.65
Cycle 6	13.86	12.79	11.17	10.69

Note: Each value is an average for seven samples.

Table. 2

Mean Values of Percent Weight-loss of Naturally-aged samples by *Poria placenta* and *Polyporous versicolor*

	Poria placenta		*Polyporous versicolor*	
Natural Age	Bottom	Top	Bottom	Top
Control (0)	4.14	3.91	4.18	2.73
5 Year	11.26	14.32	6.83	8.12
15 Year	11.74	12.73	10.62	11.60
20 Year	14.57	14.89	11.93	12.79
25 Year	19.43	22.09	13.43	14.65
30 Year	40.21	30.83	10.97	14.64
40 Year	47.38	43.05	24.81	24.95

Note: Each value is an average for seven samples.

Table. 3
Mean Value of Percentage Change(Reduction) in Physical Properties of Artificially-aged Samples by *Poria placenta* and *Polyporous versicolor*

	Poria placenta						*Polyporous versicolor*					
	Thickness		Volume		Density		Thickness		Volume		Density	
Artificial Aging Cycle	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
Control (0)	1.31	1.80	1.74	2.27	2.36	1.68	7.69	1.46	2.06	1.77	2.13	0.89
Cycle 1	2.12	1.60	1.53	4.00	3.59	2.48	0.38	2.02	1.13	1.00	3.38	2.65
Cycle 2	2.19	3.80	3.76	4.98	5.10	4.01	8.06	1.61	2.70	2.22	3.92	4.23
Cycle 3	3.22	1.18	4.73	6.12	5.03	6.48	6.40	3.15	2.19	1.57	5.48	5.14
Cycle 4	1.01	3.69	7.48	5.19	7.26	6.30	3.99	4.72	5.20	3.09	6.07	6.76
Cycle 5	3.0	3.33	10.18	9.03	5.35	4.02	3.09	3.57	5.55	4.86	6.25	6.01
Cycle 6	1.98	2.82	9.43	7.38	4.76	5.68	2.80	4.51	5.16	5.36	6.20	5.60

Note:
Each value is an average for seven samples.

Table. 4

Mean Value of Percentage Change(Reduction) in Physical Properties of Naturally-aged Samples by *Poria placenta* and *Polyporous versicolor*

	Poria placenta						***Polyporous versicolor***					
	Thickness		Volume		Density		Thickness		Volume		Density	
Natural Age	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top	Bottom	Top
Control (0)	1.31	1.80	1.74	2.27	2.36	1.68	7.69	1.46	2.06	1.77	2.13	0.89
5 Years	3.84	2.35	8.24	9.61	3.26	5.14	2.95	2.85	1.48	3.02	5.21	5.23
15 Years	5.84	4.83	6.89	7.34	5.13	5.77	3.89	2.78	4.07	5.45	6.71	6.44
20 Years	5.14	4.45	8.10	9.19	7.02	6.19	5.55	7.45	5.14	5.93	6.85	6.69
25 Years	3.83	7.14	11.10	12.47	9.32	11.05	8.56	10.07	7.51	8.22	6.30	6.70
30 Years	11.90	6.30	22.76	17.29	22.59	16.45	3.45	2.42	3.61	6.18	7.51	8.86
40 Years	17.28	17.80	28.51	25.95	26.40	23.40	6.75	5.91	14.90	16.08	11.64	10.41

Note:
Each value is an average for seven samples.

Table. 5

Factorial Analysis for Artificially-aged Oak Crossties

Independent Variables	Dependent Variables			
	Weight-loss	Thickness Change	Volume Change	Density Change
Cycle No.(7)a	S [b]	NS[c]	S	S
Fungus(2)d	S	S	S	NS
Cycle No.x Fungus	NS	NS	NS	NS
Loc(2)e	NS	NS	NS	NS
Fungus x Loc	NS	S	NS	NS

a.- Aging cycle number was seven including control condition.
b-S- Significant at a five percent level.
c- Not significant at a five percent level.
d- Fungus- Two levels of fungus (*P.placenta* and *P.versicolor*).
e- Location- Two levels of location.

Table. 6

Factorial Analysis for Naturally-aged Oak cross-ties

Independent Variables	Dependent Variables			
	Weight-loss	Thickness Change	Volume Change	Density Change
Age(7)a	Sb	S	S	S
Fungus(2)c	S	S	S	S
Age x Fungus	S	S	S	S
Loc(2)d	S	NSe	S	NS
Fungus x Loc	NS	NS	NS	NS

a.- Actual crossties age level.
b-S- Significant at a five percent level.
c- Fungus- Two levels of fungus(P.placenta and P.versicolor).
d- Location- Two levels of location.
Not significant at a five percent level.

Table. 7

Estimation of Creosote for Naturally-aged and Artificially-aged Oak Crossties

Natural Service Age on track	Sample Location	Creosote Content Pcf a	Artificial Aging-Cycle	Sample Location	Creosote Content Pcf
Control	Top b	7.20	Control	Top	7.20
Control	Bottom	8.55	Control	Bottom c	8.55
5 Year	Top	4.39	Cycle 1	Top	7.00
5 Year	Bottom	6.13	Cycle 1	Bottom	8.12
15 Year	Top	8.60	Cycle 2	Top	7.25
15 Year	Bottom	6.34	Cycle 2	Bottom	6.59
20 Year	Top	6.84	Cycle 3	Top	7.91
20 Year	Bottom	4.52	Cycle 3	Bottom	7.21
25 Year	Top	5.13	Cycle 4	Top	6.01
25 Year	Bottom	5.03	Cycle 4	Bottom	6.56
30 Year	Top	5.00	Cycle 5	Top	6.38
30 Year	Bottom	4.02	Cycle 5	Bottom	5.31
40 Year	Top	3.82	Cycle 6	Top	5.53
40 Year	Bottom	3.41	Cycle 6	Bottom	6.59

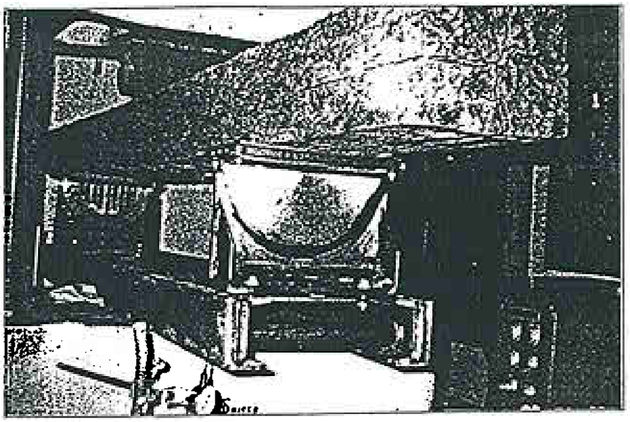
Note:

a - Pounds per cubic foot (Each value is an average of seven tests).

b - 0-25 millimeter from surface.

c - 25-50 millimeter from surface.

Proposed Strength Properties Tests For Wood Crossties



The static bending test indicates the structural capacity or the breakage of the tie and is important for track load capacity, deformation and surfacing.

By Poo Chow, - University of Illinois Urbana, Ill.; Albert J. Reinschmidt, David D. Davis, Kenneth Laine, John Choros and Semih Kalay - AAR, Chicago, Ill.

Since 1984, the Association of American Railroads, Chicago, and the Wood Engineering Laboratory in the Department of Forestry at the University of Illinois, Urbana-Champaign Campus, have developed test procedures to evaluate the mechanical performance of wood crossties. These tests are considered to be important to crosstie performance.

Objectives

These methods cover tests on full-size (7" x 9" x 9') specimens and/or 7" x 9" x 18" pieces from each tie specimen of wood that are made to afford:

A. Data for comparing the mechanical properties of various species, chemical or preservative treatments, drying methods, sources of supply, location and length of service in track,

B. Data for engineering design and for developing allowable stresses, and

C. Data for specific use in specifications for procurement and acceptance testing of new wood crosstie products.

Test Methods

The principal mechanical tests are static bending, compression perpendicular to grain, surface hardness, lateral spike resistance, and direct spike withdrawal.

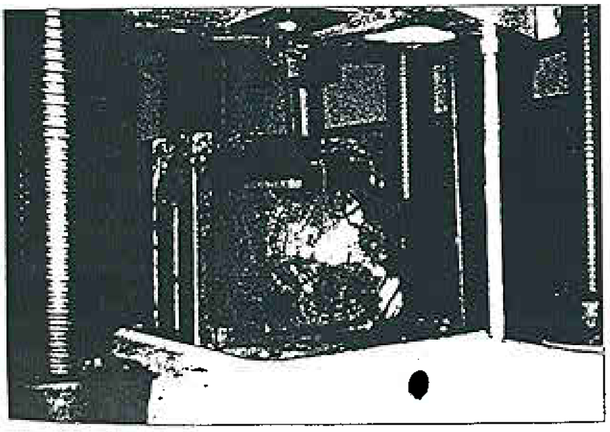
A. Conditioning of Specimens (18" section):

The physical and mechanical properties of wood depend on the moisture content at time of test. It is essential to condition the test specimen to constant weight so it is in moisture equilibrium under the desired outdoor track environmental condition prior to various tests. Therefore, 18" long tie specimens shall be conditioned to constant weight and moisture content in a conditioning chamber maintained at a relative humidity of 90 ±5 percent and a temperature of 68 ± 5F. If there is any departure from this recommended condition, it shall be so stated in the report.

B. Moisture Content and Density:

These two properties' determinations are required on each static bending test tie specimen. The moisture content shall be determined 1 inch below the surface near the tie-plate area using a resistance type of electronic moisture meter. Needle type electrodes shall be driven into the wood to 1 inch depth. A more accurate moisture content can be obtained from an increment bored wood sample or a coupon cut from each specimen.

The density shall be computed from the measurement of the length, width, thickness and weight of the tie specimen at time of test.



Spike resistance tests are used to indicate the rail gage and rollover restraint capacity of the tie spike drive-in force, the lateral spike resistance and spike withdrawal force.

C. Static bending test (Center Point Flexure Test).

It indicates the structural capacity or the breakage of the tie and is important for track load capacity, deformation and surfacing.

1. Specimen: Each test specimen shall be full-size (from 8 to 9 feet long).

2. Loading Span and Supports: Center loading and a span length of 60 inches shall be used to simulate a "center-bound" tie. Both supporting knife edges shall be provided with bearing plates (6" x 12") and rollers which are free to move in a horizontal direction. The knife edges (12" wide, a rocker type) shall be adjustable laterally to permit adjustment for light twist or warp in the tie specimen. The tie specimen shall be supported by two bearing plates (6" x 12") to prevent damage to the tie at the point of contact between tie and reaction support.

3. Loading Bearing: A 12" long steel pipe (6" diameter) shall be used for applying the load.

4. Speed of Testing: The load shall be applied continuously throughout the test at a rate of motion of the movable crosshead of 0.10 inch per minute.

5. Load-Deflection Curve: After a 200 pounds pre-loading, load-deflection curve shall be taken to the maximum load. Deflections of the neutral plane at the center of the length shall be taken.

6. Calculations.

a. Calculate the maximum bending stress or the modulus of rupture (MOR) for each specimen by the following equation:

$$\text{MOR (Psi)} = 3\ PL/2bd^2$$

b. Calculate the modulus of elasticity (MOE) for each specimen by the following equation:

$$\text{MOE (Psi)} = P_l L^3/4bd^3y_l$$

where

b = width of specimen, inches;
d = thickness (depth) of specimen, inches;
L = length of span, inches;
P = maximum load, pounds;
P_l = load at proportional limit, pounds;
y_l = center deflection at proportional limit load, inches.

D. Compression perpendicular to grain load (24,000 lbs.).

This test determines the crushing capacity of the wood in the critical plate areas. This is the area of the tie that is prone to failure in severe service environments.

1. Specimen Size: The test shall be made on the tie-plate area of the 18" long specimens.

2. Loading: A 24,000 lbs. load shall be applied through a movable crosshead and carried through a short section of 115 RE rail to a 7.75 by 13-inch tie plate and in turn to the upper surface of the crosstie specimen at equal distances from the ends and at right angles to the length.

3. Speed of Testing: The load shall be applied continuously throughout the test at a rate of motion of the movable crosshead of 0.024-inch per minute.

4. Load-Compression Curves: It shall be taken for all specimens up to 24,000 lbs. load. After which the test shall be discontinued.

5. Calculation: The modulus of elasticity in compression (MOE) shall be calculated using the following equation:

E(psi) = Compressive stress (PSI)/ Strain (in/in)
Compressive Stress (Psi) = P_l/A
Compressive Strain (in/in) = y_l/d

where

P_l = load at proportional limit, pounds;
A = net plate area, square inches;
y_l = compression at proportional limit, inches;
d = thickness or depth of tie specimens, inches.

E. Surface Hardness Test.

This test defines the plate cutting resistance and surface hardness of the tie specimen in the critical plate areas.

1. Specimen Size: The test shall be made on the tie-plate area of the 18" long specimens.

2. Loading: Use a steel ball "2-inch" in diameter as a loading head. A ball holding jig shall be made to restrain the ball from lateral movement.

3. Speed of Testing: The test shall be conducted at a speed of 0.25 inches of crosshead deflection per minute.

4. Load-Penetration Curve: It shall be

Test Results of 94 Newly Treated (Creosote) Oak Crossties (1985-1991)

University of Illinois and Association of American Railroads

Tie Specimen	Year	M.C.	Density	MOE Compression	Hardness	Bending MOR	Bending MOE	Spike Resistance Drive-in	Spike Resistance Out	Spike Resistance Lateral
		%	(lb./cu.ft.)	(psi)	(lbs.)	(psi)	(psi)	(lbs.)	(lbs.)	(lbs.)
1. Air dried (8)[1]	1985	20	34 (3)[2]	39,855 (28)	6,460 (13)	—	—	—	—	—
2. Vapor dried (8)[1]	1985	55	44 (5)	33,605 (10)	3,495 (13)	—	—	—	—	—
3. Boulton dried (8)[1]	1986	50	44 (3)	44,648 (10)	4,270 (23)	—	—	—	—	—
4. Boulton dried (8)[1]	1987	45	47 (5)	31,365 (18)	3,520 (14)	—	—	—	—	—
5. Boulton dried (8)[1]	1987	40	47 (4)	32,837 (19)	3,530 (23)	—	—	9,300 (7)	9,100 (5)	3,100 (10)
6. *Air dried (5)[3]	1988	37	47 (3)	33,165 (26)	4,130 (11)	7,450 (7)	967,000 (12)	9,895 (6)	9,060 (12)	3,160 (18)
7. *Boulton dried (5)	1988	37	47 (4)	32,830 (21)	4,400 (12)	7,660 (7)	920,000 (15)	9,650 (10)	8,700 (16)	3,400 (12)
8. Air dried (10)[1]	1988	28	44 (4)	42,730 (17)	4,455 (25)	—	—	7,525 (13)	8,485 (16)	2,895 (12)
9. Boulton dried (4)[3]	1989	60	58 (3)	38,485 (8)	3,930 (16)	7,215 (4)	1,327,300 (13)	7,215 (3)	7,990 (8)	3,300 (16)
10. Air dried (10)[3]	1991	22	60 (2)	32,520 (13)	3,650 (12)	8,630 (14)	1,043,770 (13)	10,660 (9)	8,540 (7)	3,460 (9)
11. Vapor dried (10)[3]	1991	40	67 (6)	28,500 (7)	4,385 (18)	7,355 (13)	842,820 (9)	8,735 (14)	7,405 (17)	2,660 (18)
12. Boulton dried (10)[3]	1991	42	66 (2)	30,170 (14)	4,490 (18)	8,145 (12)	638,860 (11)	9,335 (6)	7,865 (8)	2,970 (19)

[1] *Number of specimens (7" x 9" x 18")*

[2] *Coefficient of Variation (%)* + $\frac{\text{Standard Deviation}}{\text{Average}}$ *x 100*

[3] *Number of specimens (7" x 9" x 9')*

> *"The principal mechanical tests are static bending, compression perpendicular to grain, surface hardness, lateral spike resistance and direct spike withdrawal."*

recorded for all specimens until the steel ball being imbedded 0.25 inches into the surface of the tie specimen.

5. Calculations: The maximum load required to embed the "ball" to 0.25 inches into the specimen shall be the measure of surface hardness (lbs.). The slope of the straight-lien portion of the load-penetration curve in pounds per inch shall be the hardness modulus (lbs./inch).

Hardness Modulus (lbs./inch) = P_l/Y_l
where P_l = load at proportional limit, pounds,
Y_l = penetration at proportional limit.

F. Spike Resistance Tests.

These tests are used to indicate the rail gage and rollover restraint capacity of the tie spike drive-in force, the lateral spike resistance and spike withdrawal force shall be reported in this test.

A new 5/8" square and 6-1/2" long cut-spike shall first be inserted into the un-bored plate area of the tie specimen, so the resistance to withdrawal in plane normal to the tie surface can be measured.

1. Specimen Size: The test shall be made on the tie-plate area of the 18" long specimens.

2. Speed of Testing: (a) A cut spike shall be driven into the tie plate surface at a speed of 2 inches per minute. (b) The lateral spike resistance test shall be made at the speed of 0.1 inches per minute. (c) The direct withdrawal test shall be made at a speed of 0.3 inches per minute.

3. Load-Deflection Curve: (a) It shall be recorded for all tests as the spike head is being bent or displaced 0.2 inches laterally in the lateral spike resistance test, (b) It shall be recorded throughout the spike withdrawal perpendicular to the plane movement in the direct withdrawal resistance test.

4. Report: The following test results shall be recorded: (1) Maximum spike insertion load, (2) Maximum load produced a 0.20 inches lateral displacement of the spike head, (3) Maximum direct spike withdrawal force. ◆

Association of American Railroads Ⓐ Research & Test Department

REPORT BRIEF

The Effects of Weathering on Wooden Crossties

by David D. Davis, Poo Chow, and Roger Meimban

R-915

December 1997

The characterization of the existing condition of wood crossties is essential to forming effective tie-maintenance planning policy. This report details the results of mechanical testing of ties removed from lines across North America. A better understanding of tie-strength deterioration has been developed from this work. A strength-to-age relationship for ties has been developed for each of the following properties: bending modulus of elasticity, compression parallel to grain, hardness parallel to grain, spike insertion, spike pull-out resistance, and spike lateral stiffness.

These relationships may be used to estimate the properties of ties in track for modeling and maintenance-planning purposes.

Species that had sufficient samples, such as oak and hem-fir, were treated separately. As more data is collected, the same treatment can be given to additional species. The oak and hem-fir models provide examples of commonly used hardwoods and softwoods. The strength prediction models may be used in maintenance costing and planning predictions, such as AAR's Total Right of Way Analysis and Costing System (TRACS). Having ties that lose strength over time in a more realistic manner will improve the ability of TRACS or similar models to predict tie requirements and costs in the future.

In general, we found that tie strength decreases with age for all properties measured. There is an initial period of time when strength values remain near the new tie values. This period is from 5 to 15 years long, depending on average tie life. After this period, there is a rapid decline in strength. This is followed by another period of seemingly relatively stable strength values. This stability finding is likely a product of the way samples were collected. The sample of older ties consists only of the strongest survivors, not the entire population.

The development of a performance specification for wood crossties has been proposed. From the results of the AAR crosstie research work over the past decade, the baseline data is now available to develop such a specification. A specification has been proposed which uses the performance of the current population of crossties as the benchmark. Using accelerated weathering techniques and strength tests developed at the University of Illinois, new products may be evaluated uniformly for long-term performance in a few days.

To order this report, contact the Association of American Railroads, Publication Order Processing, 50 F Street, NW, 5th Floor COG, Washington DC 20001, Phone (202) 639-2211 Fax: (202) 639-2156. Prices: $10 members, $100 non-members postage paid within the USA. Checks payable to: Association of American Railroads, Visa and Mastercard accepted. A catalog of AAR reports is available upon request.

Exhibit 4.1. Strength Specifications of New Crossties

Species	Compressive MOE		Face Hardness		Modulus of Rupture	
	Sample Size	Mean (Std. Dev.)	Sample Size	Mean (Std. Dev.)	Sample Size	Mean (Std. Dev)
Oaks	71	34,725 (8,082)	70	4,284 (1,136)	52	7,809 (1,191)
	Max	52,220	Max	8,220	Max	10,340
	Min	17,583	Min	2,755	Min	5,300
Hem-Fir	20	26,626 (6,189)	20	2,051 (550)	20	5,051 (1,269)
	Max	39,621	Max	3,387	Max	7,709
	Min	15,142	Min	1,137	Min	3,293
Pines	46	25,418 (8,822)	46	2,072 (568)	40	5,123 (1,365)
	Max	44,078	Max	3,807	Max	7,197
	Min	6,229	Min	1,227	Min	2,418

Species	Spike Drive-in Load		Spike Lateral Resistance		Spike Withdrawal	
	Sample Size	Mean (Std. Dev.)	Sample Size	Mean (Std. Dev.)	Sample Size	Mean (Std. Dev)
Oaks	49	8,977 (1,402)	49	3,097 (481)	49	8,200 (1,035)
	Max	12,400	Max	4,355	Max	10,940
	Min	6,640	Min	2,090	Min	6,230
Hem-Fir	19	5,741 (1,233)	19	2,479 (612)	19	3,273 (949)
	Max	9,154	Max	3,444	Max	5,356
	Min	4,326	Min	1,071	Min	1,865
Pines	46	4,193 (1,056)	46	2,145 (565)	46	2,714 (1,132)
	Max	7,095	Max	3,292	Max	6,380
	Min	2,520	Min	1,270	Min	796

Note: MOE and MOR are in psi while all others are expressed in pounds.

Max = Maximum
Min = Minimum

Exhibit 1.10. Artificial Accelerated Aging Cycle

Six-Cycle Aging Schedule	
Condition	Exposure Period
Vacuum (25 inches) in water	30 minutes
Pressure (170 psi) in water	30 minutes
Freezing (0 F)	3 hours
Steaming(250 F, 15 psi)	30 minute warm-up + 10 hours
Oven Drying (220 F)	9.5 hours
Conditioning (70 F and 50-60% R.H.)	24 hours

2.0 TIE STRENGTH TEST RESULTS

The results of mechanical strength tests of ties removed from track are given below. These tests characterize the performance capabilities of ties in track at typical mainline sites. Comparison with new tie strengths provided strength deterioration-age-tonnage relationships for various locations.

Exhibit 2.17. Mechanical Test Results for Artificially Aged Ties

TEST: COMPRESSION (PSI)

TIE GROUP	NUMBER OF TIES	NUMBER OF AGING CYCLES						
		0	1	2	3	4	5	6
AIR	28	38842	30362	22469	19467	17005	15826	14616
		100	78	58	50	44	41	38
BOULTON	38	34898	28424	23276	18276	16540	14623	13484
		100	81	67	52	47	42	39
VAPOR	18	30770	23172	19295	16293	14188	12680	11660
		100	75	63	53	46	41	38
ALL:AVERAGE VALUE		35328	27945	22154	18248	16191	14607	13471
PERCENT OF NEW		100	79	63	52	46	41	38

TEST: HARDNESS (LBS)

TIE GROUP	NUMBER OF TIES	NUMBER OF AGING CYCLES						
		0	1	2	3	4	5	6
AIR	28	4712	3375	2365	2101	1595	1469	1385
		100	72	50	45	34	31	29
BOULTON	38	3978	2958	2380	1944	1772	1439	1295
		100	74	60	49	45	36	33
VAPOR	18	3989	2762	2220	1859	1349	1301	1181
		100	69	56	47	34	33	30
ALL:AVERAGE VALUE		4225	3055	2341	1978	1622	1420	1300
PERCENT OF NEW		100	72	55	47	38	34	31

TEST: SPIKE TEST (LBS)		DRIVE-IN		WITHDRAWAL		LATERAL	
TIE GROUP	NUMBER OF TIES	NUMBER OF AGING CYCLES					
		0	6	0	6	0	6
AIR	28	10660	3940	8538	1910	3460	1860
		100	37	100	22	100	49
BOULTON	38	8729	3588	7900	1332	3063	1143
		100	41	100	17	100	37
VAPOR	18	8735	3460	7405	1015	2660	860
		100	40	100	14	100	32
ALL:AVERAGE VALUE		9299	3654	7942	1409	3061	1218
PERCENT OF NEW		100	39	100	18	100	40

TECHNOLOGY DIGEST
Timely Technology Transfer

"PERFORMANCE PREDICTION AND SPECIFICATION OF WOOD TIES FOR REVENUE SERVICE"

by David D. Davis, Poo Chow,
and Roger J. Meimban

TD 96-010

Summary
To improve upon traditional wood crosstie service testing, which requires at least 5 to 10 years to reliably assess the technical and/or economic merits of products in their environments, the Association of American Railroads and the University of Illinois designed an accelerated test method. This method can "age" wood ties from new condition to 20 or 30 years equivalent in a few days. The strength properties of artificially weathered ties were compared with ties collected from revenue tracks across North America. From the field test data, we are able to construct a performance specification based on the current tie's strength vs age relationship. Candidate ties may be evaluated against this benchmark using the accelerated weathering technique developed. Test results, which have been used to calibrate the accelerated aging process reveal the following:

- Strength loss becomes significant as the crossties weather in track.
- Ties removed from revenue service had strength values as low as 50 percent of new tie strengths.
- New full-size crosstie strength values also differ from those published in the Wood Handbook, which presents values for small, clear specimens.
- A non-destructive test, such as plate area compression modulus, may be used to assess the acceptability of candidate ties.
- The weathering/artificial aging test may be used to evaluate the long-term durability of candidate ties.

Characterization of existing tie condition is essential to developing effective tie maintenance planning and policy. Rapid strength reduction in the field occurs during the crossties' first 5 to 15 years in service, after which, tie strength levels off to a lower stable value. The revenue track's climate index and rail traffic also contribute to tie deterioration. The effect, however, largely depends on the length of exposure to a given climate index and track traffic.

Suggested Distribution:
☐ Maintenance of Way
☐ Research and Development
☐ Track Maintenance
☐ Maintenance Planning

Association of American Railroads
Research and Test Department
April 1996

TIE PERFORMANCE IN REVENUE TRACKS

Results of statistical analysis showed that duration of exposure to a particular climate index and rail traffic tonnage is the main contributing factor to tie deterioration.

Exhibit 2 shows the compression modulus of elasticity (P_c) of the Red Oak crossties.

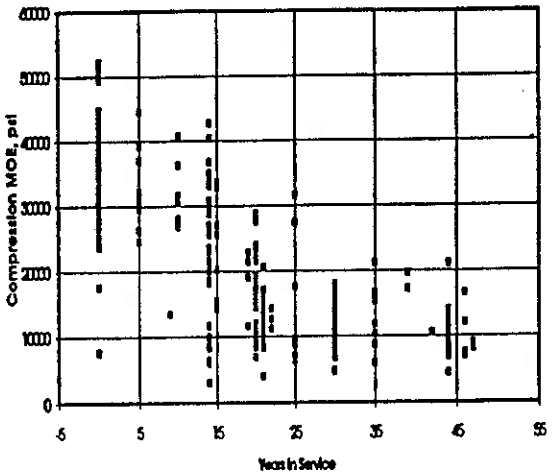


Exhibit 2. Compression MOE of Red Oak Crossties in Revenue Tracks

The best prediction equation derived was:

$$P_c = 35{,}700 - Age(9.57{*}CI + 13.2{*}Ton) \quad (1)$$

where CI=Climate Index, Ton=Annual Tonnage (MGT/Yr).

The equation has a regression coefficient of $R^2 = 0.66$. A much simpler linear equation of compression modulus (P_c = 34,123 - 711*Age) is equally promising with a regression coefficient of $R^2 = 0.60$.

ARTIFICIAL AGING OF CROSSTIES

Exhibit 3 presents the artificial weathering cycle used to accelerate crosstie aging in the laboratory. Up to six iterations of this artificial weathering were employed and the crosstie properties were measured at the end of each aging cycle.

Exhibit 3. Weathering Schedule for the Artificial Aging of Crossties

Activity	Duration	Conditions
Soaking under Vacuum	30 Minutes	25-inch
Soaking under Pressure	30 Minutes	170 psi
Freezing	3 Hours	0°F
Steaming	10.5 Hours	250°F and 15 psi
Oven Drying	9.5 Hours	220°F
Conditioning	22 Hours	70°F and 90 RH

Exhibit 4 shows the compression modulus of elasticity of aged Red Oak crossties. The compression modulus of naturally aged and artificially weathered ties are correlated, as also evident from the similarity in trends shown in Exhibits 2 and 4. For artificially aged ties, compression modulus declines rapidly during the first three cycles and levels off after the third cycle. As a result of this correlation, the service age equivalent of the number of artificial weathering cycles was established as follows:

$$\text{Service years} = 5.484 + 2.75 \times (\text{Cycles}) \quad (2)$$

PERFORMANCE PREDICTION OF NEW TIES

Exhibit 5 shows the strength retention of oak crossties after several years of exposure in railroad tracks. It appears that compression modulus in the plate area decreases more rapidly than the other properties as the ties age in service. The figure could provide a benchmark for how much crosstie strength is retained after several years, relative to its strength when new.

TECHNOLOGY DIGEST
April 1996

INTRODUCTION AND CONCLUSION

To improve upon traditional wood crosstie service testing, the Association of American Railroads and the University of Illinois designed an accelerated test method. In doing so, they also developed an artificial crosstie aging technique which is being used to compare strength-age-traffic relationships in wood ties collected from revenue tracks across North America.

Performance comparisons of the artificially "aged" ties with actual revenue service ties showed that a relationship between the two can be developed for some strength properties, in particular the compression modulus in the plate area.

Physical property tests on field ties showed that moisture content was generally higher (greater than 30 percent) 1 inch or more inside the materials. Mechanical tests further revealed that rapid strength loss in field ties occurred during the first 15 years of service.

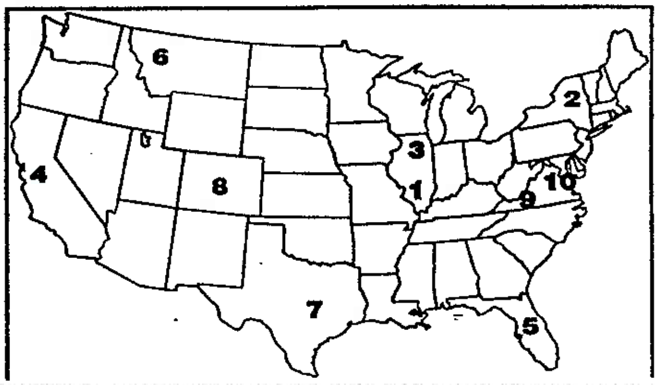
Strength properties tested include:

- bending modulus of elasticity,
- modulus of rupture,
- compression modulus perpendicular to the grain,
- face hardness and
- spike load resistance

Trends in the compression modulus of artificially weathered ties are consistent with those of revenue service. Rapid strength reduction occurred during the first three cycles of artificial weathering before gradually leveling off.

The results of this study can be used to predict crosstie performance, and to develop specifications for new ties for various track environments. The accelerated aging test could be used to qualify new ties by determining their long-term performance and the durability of treatments.

Sample crossties were collected from various test sites, as shown in Exhibit 1. The corresponding climate index, a measure of the potential for wood decay, is also listed for each site. The index is based on the number of days exhibiting warm moist conditions necessary for decay. The annual tonnage rate at each site and the number of ties used in the study are also indicated in the exhibit.



Site No.	No. of Ties	Tie Age (Years)	Hardwood/ Softwood	Climate Index (CI)	MGT/Yr (Ton)
1	71	5-40	HW	47	15
2	24	20	HW	52	25
3	41	21	HW	45	45
4	39	34	SW	15	14
5	27	10-40	HW	115	10
6	20	10-40	HW	26	35
6	19	10-40	SW	26	35
7	49	21	HW	50	45
8	30	14	Mixed	41	57
9	28	20-50	HW	64	4
10	13	20-50	HW	64	4

Exhibit 1. Test Specimen Collection Sites

TECHNOLOGY DIGEST
April 1996

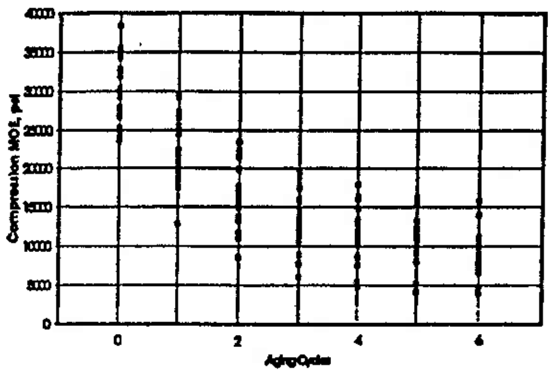


Exhibit 4. Compression MOE of Artificially Aged Oak Crossties

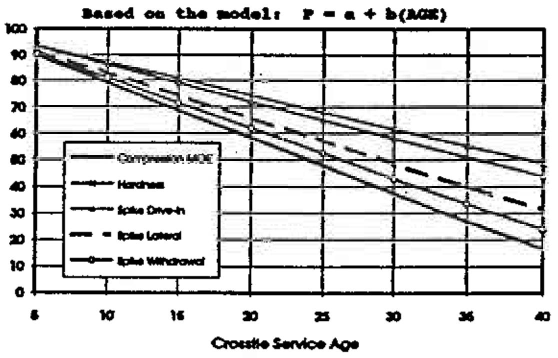


Exhibit 5. Strength Retention of Red Oak Crossties

Some of the prediction models developed in the study could be utilized to assess the property of a new crosstie for a given age-climate-traffic tonnage scenario. For bending modulus and compression modulus of elasticity, the following form of prediction equation could be used:

$$P_y = P_o - Age\,(b * CI + c * Ton) \qquad (3)$$

where b and c are the appropriate constants in Equation 1, P_y is the predicted property after y years of service, and P_o is the property of a new crosstie.

The artificial weathering test could also be used to estimate the property of a crosstie after some aging cycles. To establish the long-term performance of crossties, three aging cycles are sufficient.

STRENGTH SPECIFICATIONS OF NEW CROSSTIES

Among the goals of this project was the development of a performance specification for new crossties. Choosing the appropriate tests may depend on the location and load environment where the ties will be installed. A non-destructive test, such as the compression modulus in the plate area, should be conducted to assess the acceptability of candidate ties. Testing can be performed quickly and easily without destroying the test specimen.

Exhibit 6 provides a sample specification for the compression modulus test. Additionally, the weathering/artificial aging test can be used to assess long term durability of new ties. Test results will serve as indicator of wood quality and the durability of treatment.

Exhibit 6. Sample Crosstie Specification for Compression Modulus

Test Property:	Compression Modulus*
Species:	Oak
Sample Size:	15
New Tie Strength:	Average must meet or exceed 38,000 psi
Three Cycle Aging Strength:	** Average must meet or exceed 24,000 psi (63% of new tie strength)
* Loading must be applied as specified in AAR Report R-702. ** Accelerated Aging Test to be Performed in Accordance with AAR Report R-702.	

Contact David Davis at (719) 584-0754 with questions or comments about this document.

* MORE DETAILED REPORT, WHICH MAY CONTAIN REVISED INFORMATION, MAY BE AVAILABLE AT A LATER DATE THROUGH THE AAR, PUBLICATION ORDER

1987

Effects of Natural and Accelerated Aging on Oak Crossties[1]

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Judgements of the technical quality of wood crosstie products have been based on actual in-use performance. However, it takes at least 20 to 30 years to obtain results. New wood crosstie materials are at a severe market disadvantage due to the length of time necessary to prove their worth. Thus there is a need to develop a short-term test method which can be used to predict the long-term in-service performance of wood crossties. A cyclic accelerated aging technique that is adaptable as a routine quality control method in the manufacturing or developing of red oak crosstie products was developed. Six cycles of this accelerated aging technique may be equivalent to more than 20 years of natural aging depending on the property used to relate accelerated and natural aging. A 95 percent confidence interval of plus and minus three years borders this relationship. A curvilinear relationship is a better fit than a linear model in relating certain properties to tie-age, because these properties are decreasing their rate of change, i.e., leveling off with age. The MOE in compression is more sensitive than hardness modulus to the accelerated aging process. Various properties of selected creosote-treated red oak crossties were significantly affected by both the tie-age and the number of cycles of the developed aging technique.

Keywords: Accelerated aging, compression, creosote-treated, crosstie, hardness, modulus of elasticity, natural weathering, red oak.

Introduction

Wood crossties have been used in the United States since 1831 (Bescher, 1977). Creosote treated crossties account for more than 30 percent by volume of the treated wood products market; a market which utilizes more than 500 million ft^3 (14.16 million m^3) of standing timber and produces 1.46 billion dollars worth of merchandise annually (AWPA, 1982, USDA, 1981). It is apparent that the use of wood for crossties is an important segment of the forest products industry. However, wood crossties must remain competitive with alternative tie materials, such as concrete and steel, in order to maintain market share and prevent deleterious effects on the wood preserving and timber production industries.

Judgements of the technical success or failure of these crosstie products have always been based on actual in-use performance. This is the most accurate method of evaluation; however, it takes a long time to obtain results. The service life of treated wood ties on mainline track in the United States is typically 20 to 30 years and ranges up to 40 years (Bescher, 1977; Blum, 1942; Miller and Houghton 1981). Regardless of their potential, newly developed crosstie materials are at a severe market disadvantage due to the length of time necessary to prove their worth. For practical purposes, evaluation of these new tie products must be done through the use of accelerated aging tests which allow for the rapid evaluation of the resistance of crosstie materials to long-term service conditions. Thus there is a need to develop suitable short-term test methods and to establish correlations between these short-term test results and long-term in-service performance of wood crossties.

Table 1 lists those factors that may significantly affect the service life of a crosstie (Bescher, 1977; Hope, 1983; Masters, 1982; and USDA, 1973). Hinson (1985) and Hope (1983) reported that the relative importance of the degradation factors varies with the changing characteristics of rail traffic, environmental conditions, track characteristics, mainte-

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[1] This is a refereed paper.

nance, quality of preservative treatment, and crosstie species. In the past, failure of crossties has generally been due to biological decay. Since the advent of the diesel locomotive and sealed roller bearings, rail traffic has become more severe; that is a greater tonnage carried per year, larger and longer cars, increased axle loads, and higher speeds. The failure of crossties in a mechanical (non-biological) mode has become more common. Bescher (1977) also found that the reasons for tie failure are different for different species. Over 60 percent of the oak ties were removed because of splits while only 5 percent of the pine ties failed due to splits. Mechanical failure, primarily splitting or checking, is the cause for removal of the majority of the hardwood crossties.

It is important to realize that reasons for removal of ties from track are determined on the basis of visual appearance and decay presence. Ties are removed from track because of the suspicion of poor performance based on the experience of the tie inspector. There is no efficient method of determining tie failure based on measured mechanical properties. It is desirable to compare mechanical properties of accelerated aged ties with those of naturally aged ties; however, there is no data on the mechanical

Table 1.
Degradation Factors Affecting the Service Life of Crossties

I. Weathering Factors
  A. Temperature (elevated, cyclic + depressed)
  B. Water
  C. Temperature-Moisture Interactions (i.e. freeze-thaw)

II. Biological Factors (primarily fungi)

III. Stress Factors
  A. Abrasion and Compression due to ballast
  B. Impact Compression due to vertical rail loads
  C. Impact Bending due to vertical rail loads
  D. Spike loading due to lateral rail loads

IV. Incompatibility Factors
  A. Chemical degradation due to presence of rusting metal and high concentrations of acidic salts
  B. Physical degradation due to particulate matter under tie plate during loading

V. Use Factors
  A. Quality and Frequency of Maintenance (i.e. spike removal, adzing, type of ballast)
  B. Track geometry (i.e. curves, ties per mile)
  C. Accidents (derailment, dragging equipment, spills)

properties of naturally aged ties. There is a need to determine the mechanical properties of crossties at various ages.

The most important properties for ties that are sensitive to the aging process and indicative of the serviceability would be side hardness and compression perpendicular to grain. These properties have been shown to be sensitive to wood degradation to a degree reported by Thompson (1980). Chow (1977, 1983) also found hardness of wood is affected by moisture changes. MacLean (1932, 1953, 1954) found that dry heat is generally not as severe as moist heat, but steam heating is more severe than heating in water; and also found heating to be more severe on hardwoods than softwoods and attributed it in part to the higher acetic acid content in hardwoods. Acetic acid accelerates the disintegration of wood.

Plate-cut, season-checks and split created by repeated wetting and drying of the wood surface from rain, dew, snow, and high humidity have been considered the principal causes of crosstie failure. A preliminary study (Chow et al., 1986) indicates that a cyclic artificial aging test appeared to be an effective way of reducing the modulus of elasticity (MOE) in compression perpendicular to grain and hardness modulus of 2 by 2 by 6 in. (5 by 5 by 15 cm) red oak blocks. Each cycle of aging test consists of the following procedure:

1. 30 minutes under water and 25-inch (10 cm) vacuum,
2. 30 minutes under water and 170 psi (1.75 kg/cm^2) pressure,
3. 3 hours of steaming at 250°F (121°C) and 15 psi (103.4 kPa),
4. 16.5 hours of oven drying at 220°F (104°C), and
5. 3 hours in a 0°F (17.8°C) freezer.

The 6-cycle aging test found that the rapid deterioration which occurred in the small red oak blocks was not occurring in the full-size, 7 by 9 by 18 in. (18 by 23 by 46 cm) creosote-treated red oak ties. A longer steaming portion of the cycle was necessary to achieve an adequate level of damage on the full-size crossties. Tests also found that the steel tie plate inhibits movement of heat and moisture into the crosstie. For this reason, further accelerated aging tests should be conducted on crossties without a tie plate attached.

Objectives

The major objectives of this study were as follows:

1. To determine the effects of aging, both accelerated and natural, on the surface appearance, modulus of elasticity (compression perpendicular to grain), side hardness and hardness modulus of red oak crossties.
2. To establish a relationship between short-term and long-term aging of red oak crossties in terms of the following properties:
   a. Compressive load perpendicular to grain
      (1) Modulus of elasticity (MOE)
      (2) Maximum deflection
      (3) Load at 0.04 in. (0.1 cm) deflection
   b. Side Hardness
      (1) Hardness
      (2) Hardness modulus
   c. Total area of surface checks (surface quality)

Materials

1. Naturally Aged Red Oak Crossties:

With the aid of the Norfolk Southern Railroad Company, 38 red oak crossties were selected from a 0.2 mile (0.32 km) long section of track at Sadorus, Illinois in June of 1985. This section was a mainline running east-west with a single line of track. The line carried 11-12 MGT per year at a maximum speed of 50 miles per hour (80.5 km/hr.) over a grade that varied from 0.188 to 0.590 feet per 100 feet (0.06 to 0.18 m/30,5 m). This traffic generally consisted of 10 to 12 trains per day with 100 to 150 cars per train. The heaviest car and engine weights were estimated at 130 tons over four axles and 300 tons over six axles, respectively. The line was tangent (straight) and consisted of 115 lb. (52 kg) continuously welded rail placed on 13 by 7.75-in. (33 by 19.7 cm) steel tie plates. Two spikes per tie plate were used to secure the rail and tie plates to the crossties, which were supported by ballast.

The crossties were 7 by 9 in. (18 by 23 cm) in cross section and 8.5 ft. (2.6 m) in length when installed. The ties were supplied to the railroad by three creosote-coal tar treating plants over the last 45 years. The treating plants were located in Madison (Illinois), Kansas City (Missouri), and Indianapolis (Indiana). The most recent ties were believed to be from the Madison plant and Boulton-dried before treatment. Most of the older ties were thought to have been air dried before treatment.

Table 2 shows that selected ties were assigned to seven different age groups, A through G, based on visual appearance and any identifying marks. The oldest of the ties selected was 44 years old as determined by a date nail. Ties were selected mainly on the basis of visual appearance. The ages of 12 ties were obtained in the field by the presence of date nails and date stamps. The ages of 6 more ties were determined after removal from the track by the presence of date stamps.

Table 2.
Naturally aged red oak crossties specimens.

Age Group	A	B	C	D	E	F	G	
Years	0-5	6-10	11-15	16-20	21-25	26-30	31+	Total
First part	4	7	5	6	5	2	9	38
Second part	2	0	1	0	1	2	0	6
Total	6	7	6	6	6	4	9	44

Six red oak ties were desired in each of the seven age classes. As red oak ties could not be differentiated from white oak ties in track, more than six ties were selected for each class in hopes of obtaining the desired number of red oak ties. A total of 71 ties were taken from the track. In the laboratory, red oak ties were separated from white oak ties by the use of a solution of sodium nitrite on a fresh-cut, untreated surface from the center of the tie. This has proven to be a reliable method for separating red oak and white oak (Miller et al., 1985).

Each tie was cut into two pieces, with one piece gong to the Association of American Railroads' Laboratory in Chicago and the other piece going to the Wood Science Laboratory at the University of Illinois in Urbana, Illinois. Each piece contained a tie plate area. One piece from each crosstie was used in this study. From Table 2, it can be seen that groups A, C, E, and F each had less than six red oak ties. The second piece from two red oak ties in group A, one red oak tie in groups C and E, and the two red oak ties in group F were also included in this study to bring the number of red oak specimens per age class up to six. This provided for at least six specimens in each age class except for group F, which had only four specimens. Thus a total of 44 specimens from 38 naturally aged red oak crossties were used.

2. Accelerated Aging Red Oak Crossties:

Twenty-four new red oak crossties which were pressure treated to 7 pounds per cubic foot (112 kg/m^3) with 60/40 creosote-coal tar preservative were obtained. These crossties were separated into three groups based on the method by which they were seasoned. Eight ties were air-dried, eight ties were vapor-dried, and eight ties were Boulton-dried. The crossties were provided by the Norfolk Southern Railroad Company. Each crosstie measured approximately 7 by 9 by 18 in. (18 by 23 by 46 cm).

Procedures

1. Naturally Aged Crossties:

Moisture content readings were taken with a resistance type moisture meter at a penetration of 1 in. (2.54 cm) at various locations on the ties at the time of removal from the track. Moisture content readings were also taken when the ties were tested at about 70°F (21°C) room temperature.

Compression perpendicular to grain tests were performed on the tie plate area of the tie. The load was applied through a movable crosshead of the universal testing machine and carried through a short section of 115 lb. (52 kg) rail to a 13 by 7.75-in. (33 by 19.7 cm) tie plate and in turn to the crosstie. Because the ends of the tie plate were rolled, the length of the plate was considered to be 12.875 in. (32.7 cm) when calculating the bearing area of the load. The area of the spike holes, which totalled 4.234 in.^{2} (27.3 cm^2) was subtracted from the tie plate area. This left a bearing surface of 9.547 in.^{2} (616.4 cm^2). The compression tests were conducted at a speed of 0.024 in. (0.061/cm) of crosshead deflection per minute and were carried out to a load level of 24,000 lb. (10,886 kg) which created a stress level of about 250 psi (1723.7 kPa) on the wood bearing surface.

95.47 in^2

In a previous study Chow et al. (1986) found that the ASTM D-143 hardness test, by using a steel ball that was only 0.444 in. (11.28 mm) in diameter, did not provide a reliable hardness value for the treated-crosstie. If the test was conducted on a knot or just above a hidden check or split cavity, the results obtained would over or under estimate the proper test values. These problems could be solved by increasing the size of the steel ball used so as to "average out" any variation of surface hardness in localized areas of the crosstie. For these reasons, hardness tests were performed using a 2-inch (5.1 cm) steel ball that was imbedded into the surface of the side of the tie at the plate area. The load was transferred from the crosshead to the steel ball using a steel plate with a circle cut into it to accommodate the ball. The hardness tests were conducted at a speed of 0.25 in. (0.635 cm) of crosshead deflection per minute and were conducted until the steel ball was imbedded 0.25 in. (0.635 cm) into the crosstie.

A hardness testing apparatus was constructed that held the steel ball, prevented it from moving laterally, and was able to measure the penetration from the surface of the wood. It was decided to test the plate area of the tie in hardness since hardness is best suited to indicate the tie's resistance to plate cutting, which occurs only under the tie plate.

Properties calculated from compression tests included modulus of elasticity (MOE), load at 0.04 in. (0.1 cm) deflection, and maximum deflection. For selected ties, the area of surface checks was measured. By subtracting the area of the surface checks from the bearing area, a reduced bearing area was determined. This was used to determine an MOE based on reduced bearing area.

Properties determined from hardness tests were hardness (maximum load) and hardness modulus. Hardness modulus is equal to the load under the proportional limit divided by the depth of penetration (Chow et al., 1983).

Ties were conditioned to the moisture contents near the level of the fiber saturation point of red oak. Variation in moisture content under the fiber saturation point is known to affect the mechanical properties of wood.

2. Accelerated-Aging of Crossties:

The eight ties from each of the three seasoning groups were processed through six cycles of the following accelerated aging schedule as shown in Table 3.

One cycle is approximately 48 hours. Due to limitations in the size of the processing equipment, the ties were processed in sets of two. The ties were tested before and after the completion of every cycle. Testing consisted of performing compression perpendicular to grain, hardness tests, measuring the dimensions of the tie, and the length and width of all surface checks on the top of the specimen. The measuring of the surface checks was done with a ruler to the nearest eighth of an inch for both width and length.

All compression and hardness tests were carried out in the same manner as those for the naturally aged tie specimen with the exception that hardness tests were performed on the bottom surface of the

Table 3.
Laboratory Aging Schedule

Condition	Exposure Period	Purposes
Vacuum soaking (25 in. or 63.5 cm. Hg., room temp.)	30 minutes^1	Maximum swelling occurs in wood
Pressure soaking (170 psi or 1,172 kpa, room temp.)	30 minutes^1	Maximum swelling occurs in wood
Freezing (0°F or 17.8°C)	3 hours	To simulate winter temperature
Steaming (250°F or 121°C, 15 psi or	30 minute warmup + 10 hours	Thermal degradation of wood fibers
Oven drying (220°F or 104°C)	9.5 hours	Shrinkage occurs to create checks.
Conditioning (70°F or 21°C, ~~50-60%~~ R.H.) 90%	about 22 hours	

crossties so as not to affect the bearing area for future compression tests.

RESULTS AND DISCUSSION

1. Naturally Aged Crossties:

The moisture contents at the time of removal were generally above the fiber saturation point. The moisture contents one inch below the top surface of the tie under the center of the tie plate area were virtually all above the fiber saturation point (about 25 percent moisture content). Exceptions were some ties in group G, where moisture contents under the tie plate varied down to 23 percent. Several ties in groups D through G varied all the way down to 17 percent moisture content but the averages for all groups were close to or above the fiber saturation point. The ties that had moisture contents that were below the fiber saturation point were in the older age groups. It is thought that the increased number and size of checks in older ties enable them to dry out more rapidly than younger ties.

Moisture content readings at testing, under the tie plate area on the side of the tie at mid height, varied at or near the level of fiber saturation point. Average values for each group are shown in Table 4. Table 4 shows that the older ties had lower moisture content at the time of testing. Since the older ties had lower moisture content when removed from the track, it may be appropriate to consider the lower moisture content as a part of the natural aging process. This would provide a better estimate of strength in service than if the moisture contents were adjusted.

The values for each mechanical property were plotted against age group and curves were fit to the data using ordinary least squares linear regression. Two curves were determined for each property, one being P, the mechanical property as a linear function of years, and the other being Log (P) as a linear function of years (Steel et al., 1980). Each tie was assigned the midpoint of the group age range as its age i.e., group A ties were 3 years old, group B—8 years old, . . . group G—33 years old. In addition to the seven age groups that consisted of crossties taken out of track, an eighth group of new crossties, representing an age of zero, was also included. This group consisted of the 24 ties that were to be used for the accelerated aging procedure. Table 5 gives regressions of various properties on ages of naturally aged red oak ties. Figures 1 through 3 are examples of scatter plots showing the data values and the regression line that was fit to this data. Each property has two scatter plots, one for the linear model, $P = a + b$ (Cycles), and one for the log-linear model, $\text{Log}(P) = a + b$ (Cycles).

Table 4.
Average moisture contents at testing.

Group	Average moisture content	Range
A	27	23-29
B	27	24-31
C	26	21-30
D	25	17-34
E	24	22-27
F	23	19-30
G	18	8-24

All of the regressions in Table 5 are significant at the one percent level. The coefficient of determination, R^2, can be used to determine the goodness-of-fit of the regression line to the data. The coefficient of determinatin for the regressions varies from 0.24 for the log-linear model for hardness modulus as function of cycles up to 0.74 for the log-linear models for maximum deflection, MOE, and MOE using a reduced bearing area as a function of cycles. For some properties, the rate of change of the property appears to be nonlinear. The rate of reduction in MOE and load at 0.04 in. (0.1 cm) deflection decreases while the rate of change in maximum deflection in compression seems to increase. For these properties, the log-linear model has the better fit. Generally, the R^2 values were higher for the log-linear model than for the linear model except the hardness modulus and surface check properties.

Those regressions involving properties pertaining to compression accounted for more of the variation in the dependent variable than did those regressions involving hardness properties. All the intercepts and coefficients possess non-zero values at the one percent level of significance.

2. Accelerated Aging of Crossties:

The values for each mechanical property were plotted against number of aging cycles for each seasoning group. Ordinary least squares regression was used to fit two curves to the data. One curve was of the form $P = a + b$ (Cycles) and the second was of the form $\text{Log}(P) = a + b$ (Cycles), where P represents the mechanical property (Steel et al., 1980). Separate regression curves were determined for each seasoning group. These curves are shown in Table 6 and Figures 4 through 6. Table 6 gives the dependent variables, the model used, the estimates of the parameters, the significance of the parameters, and the coefficient of determination for each regression. Figures 4 through 6 each show the three regression equations determined for a specific property and model. The three lines in each figure are identified by the letters A, V or B. A stands for air-dried, V stands for vapor-dried, and B stands for Boulton-dried.

Table 6 shows that all models are significant at the 1 percent level. With the exception of the regression coefficient in the linear model for hardness modulus of air-dried ties, all intercepts and regression coefficients possess non-zero values at the one percent level of significance.

Most of the regressions show that the rates of mechanical degradation due to accelerated aging between the air-dried ties and the vapor-dried ties were very similar. The comparisons show that the only significant differences between the ties from

Table 5.
Regressions of Properties on Ages of Crossties

Property & Model	Equation	Significance[a] of: Model	Intrcpt	Coeff	R^2
MOE:[b]					
linear	P=36395-978(Yrs)	**	**	**	0.71
log-linear	Log(P)=4.554-0.0207(Yrs)	**	**	**	0.74
max. deflection:[c]					
linear	P=0.092+0.0098(Yrs)	**	**	**	0.62
log-linear	Log(P)=-1.015+0.020(Yrs)	**	**	**	0.74
load at 0.04 inches:					
linear	P=3834-121.7(Yrs)	**	**	**	0.53
log-linear	Log(P)=3.56-0.0327(Yrs)	**	**	**	0.68
hardness:[d]					
linear	P=4656-75.9(Yrs)	**	**	**	0.35
log-linear	Log(P)=3.652-0.0095(Yrs)	**	**	**	0.38
hardness modulus:[e]					
linear	p=18294-245(Yrs)	**	**	**	0.30
log-linear	Log(P)=4.273-0.011(Yrs)	**	**	**	0.24
reduced bearing area:[f]					
linear	P=95.320-0.49(Yrs)	**	**	**	0.35
log-linear	Log(P)=1.98-0.0028(Yrs)	**	**	**	0.34
MOE using reduced area:					
linear	P=39485-1129(yrs)	**	**	**	0.60
log-linear	Log(P)=4.587-0.0215(Yrs)	**	**	**	0.74

a-** denotes significance at the p=0.01 level.

[b] In psi, 1 kPa = 0.145 x psi.

[c] In in., 1 cm = 0.393 x in.

[d] In lb., 1 kg = 2.205 x lb.

[e] In lb./in., 1 N/cm = 0.571 x lb./in.

[f] In in.^{2}, 1 cm^2 = 0.155 in.^{2}.

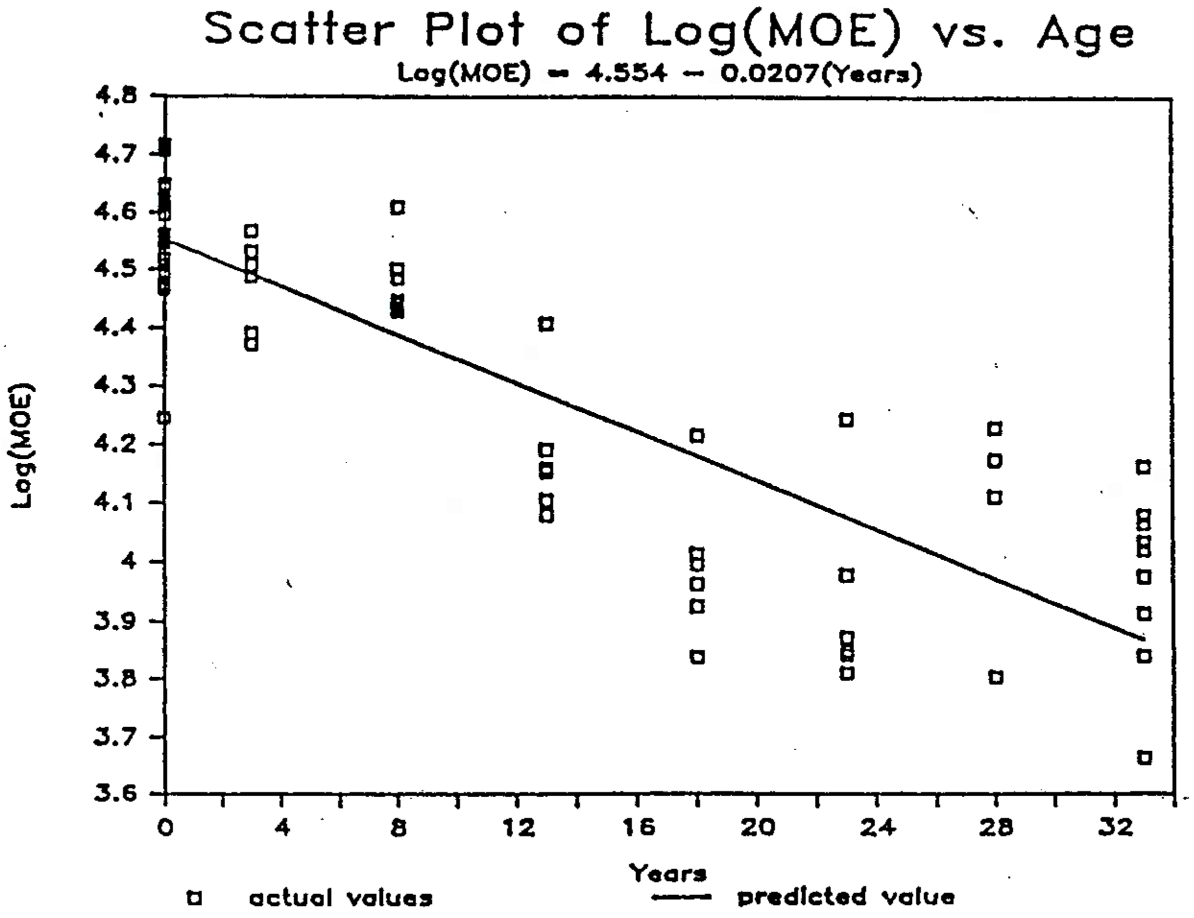

Figure 1—The effect of natural-aging on the MOE (psi) in compression of red oak crossties (semi-log form), 1 kPa = 0.145 × psi.

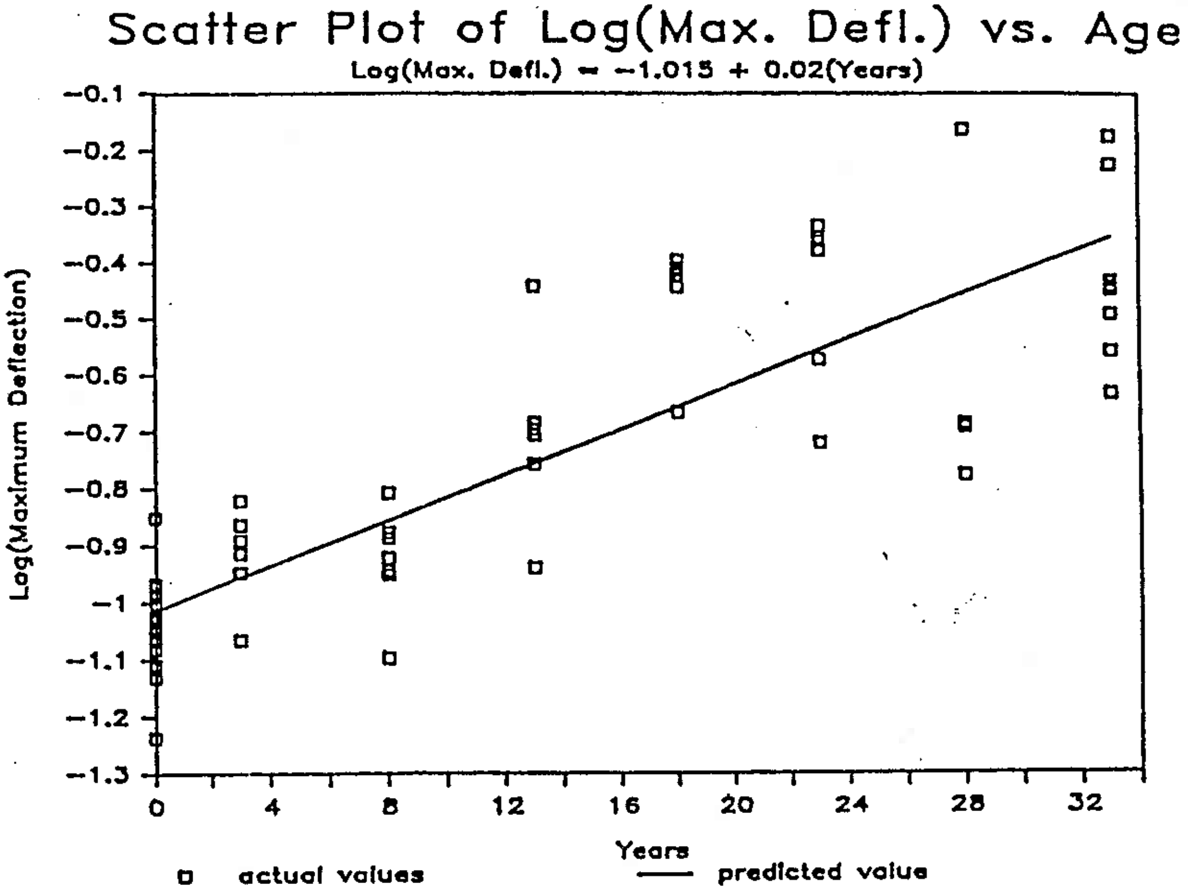

Figure 2—The effect of natural-aging on the compressive deflection (in.) of red oak crosstie (semi-log form), 1 cm = 0.394 × in.

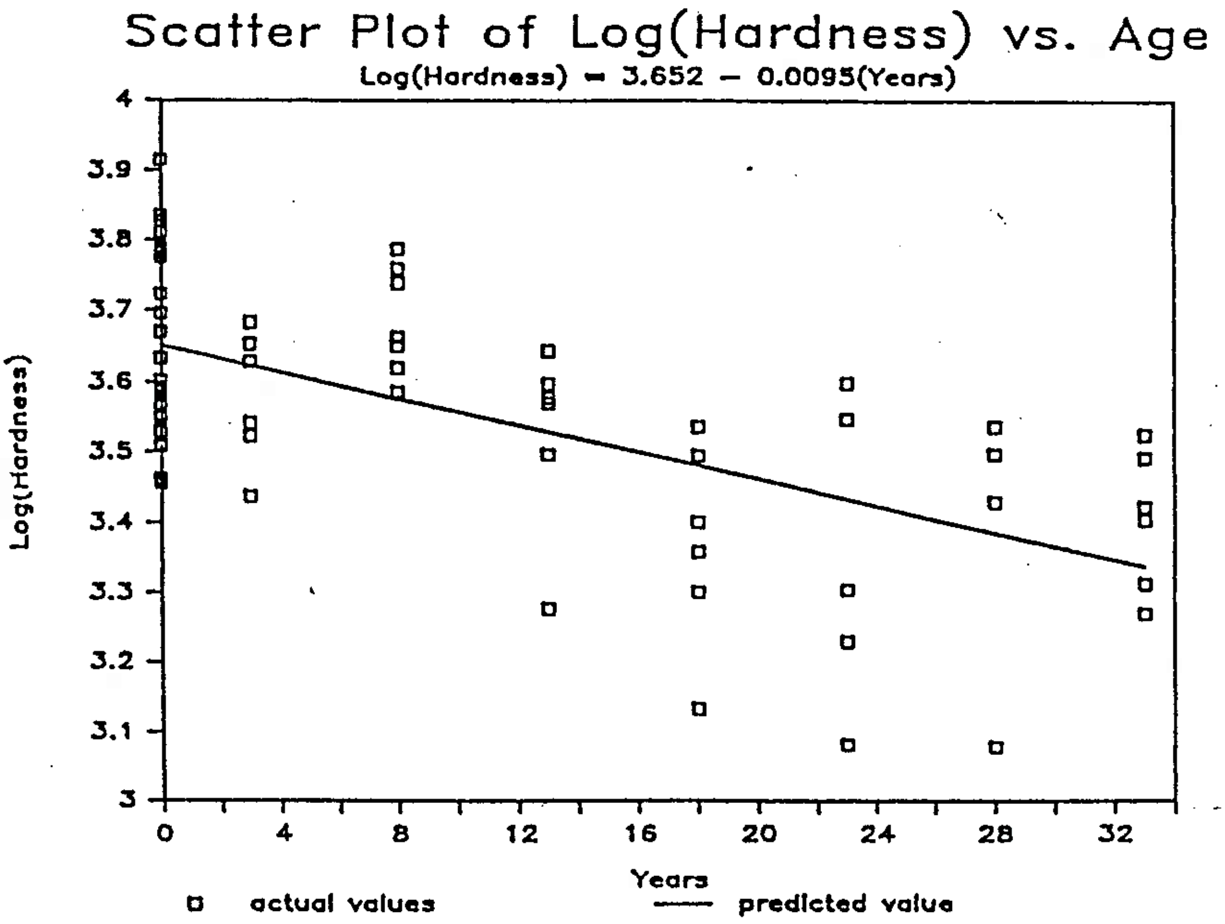

Figure 3—The effect of natural-aging on face hardness (lb.) of red oak crossties (semi-log form), 1 kg = 2.204 × lb.

Table 6.
Linear Regressions of Properties on Number of Aging Cycles

Property, Model & Seasoning Group	Regression Equation	Significance[a] of:			
		Model	Intrcpt	Coeff	R^2
Modulus of Elasticity:[b]					
linear:					
air dry	P=34433-3378(Cycles)	**	**	**	0.47
vapor dry	P=31163-2547(Cycles)	**	**	**	0.64
boult. dry	P=43074-3988(cycles)	**	**	**	0.67
log-linear:					
air dry	Log(P)=4.523-.0568(Cycles)	**	**	**	0.45
vapor dry	Log(P)=4.497-.0468(Cycles)	**	**	**	0.67
boult. dry	Log(P)=4.640-.0562(Cycles)	**	**	**	0.67
Maximum Deflection:[c]					
linear:					
air dry	P=.1001+.0128(Cycles)	**	**	**	0.34
vapor dry	P=.0973+.0102(Cycles)	**	**	**	0.50
boult. dry	P=.0772+.0100(Cycles)	**	**	**	0.59
log-linear:					
air dry	Log(P)=-1.004+.0419(Cycles)	**	**	**	0.39
vapor dry	Log(P)=-1.005+.0337(Cycles)	**	**	**	0.50
boult. dry	Log(P)=-1.099+.0392(Cycles)	**	**	**	0.63
Load at 0.04" Deflection:					
linear:					
air dry	P=4039-415.5(Cycles)	**	**	**	0.27
vapor dry	P=3819-248.7(Cycles)	**	**	**	0.18
boult. dry	P=5035-435.3(Cycles)	**	**	**	0.49
log-linear:					
air dry	Log(P)=3.581-.0627(Cycles)	**	**	**	0.35
vapor dry	Log(P)=3.591-.0453(Cycles)	**	**	**	0.26
boult. dry	Log(P)=3.716-.0566(Cycles)	**	**	**	0.53
Hardness:[d]					
linear:					
air dry	P=5346-720(Cycles)	**	**	**	0.63
vapor dry	P=3212-304(Cycles)	**	**	**	0.63
boult. dry	P=4323-402(Cycles)	**	**	**	0.43
log-linear:					
air dry	Log(P)=3.716-.089(Cycles)	**	**	**	0.74
vapor dry	Log(P)=3.505-.056(Cycles)	**	**	**	0.61
boult. dry	Log(P)=3.636-.058(Cycles)	**	**	**	0.47

Table 6. (continued)

Property, Model & Seasoning Group	Regression Equation	Significance[1] of:			R^2
		Model	Intrcpt	Coeff	
Hardness Modulus:[e]					
linear:					
air dry	P=11371-696(Cycles)	**	**	--	0.18
vapor dry	P=13529-1359(Cycles)	**	**	**	0.63
boult. dry	P=17877-1867(Cycles)	**	**	**	0.54
log-linear:					
air dry	Log(P)=4.054-.033(Cycles)	**	**	**	0.17
vapor dry	Log(P)=4.130-.061(Cycles)	**	**	**	0.60
boult. dry	Log(P)=4.252-.067(Cycles)	**	**	**	0.58
Reduced Bearing Area:[f]					
linear:					
air dry	P=95.005-.766(Cycles)	**	**	**	0.74
vapor dry	P=95.539-.507(Cycles)	**	**	**	0.33
boult. dry	P=95.343-.603(Cycles)	**	**	**	0.38
log-linear:					
air dry	Log(P)=1.978-.0036(Cycles)	**	**	**	0.73
vapor dry	Log(P)=1.980-.0024(Cycles)	**	**	**	0.33
boult. dry	Log(P)=1.979-.0028(Cycles)	**	**	**	0.37
MOE w/Reduced Area:					
linear:					
air dry	P=34992-3320(Cycles)	**	**	**	0.44
vapor dry	P=31238-2460(Cycles)	**	**	**	0.62
boult. dry	P=43300-3858(Cycles)	**	**	**	0.63
log-linear:					
air dry	Log(P)=4.532-.0546(Cycles)	**	**	**	0.41
vapor dry	Log(P)=4.497-.0444(Cycles)	**	**	**	0.64
boult. dry	Log(P)=4.641-.0533(Cycles)	**	**	**	0.63

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[a] ** denotes significance at the p=0.01 level,
-- denotes no significance.

[b] In psi, 1 kPa = 0.145 x psi.

[c] In in., 1 cm = 0.393 x in.

[d] In lb., 1 kg = 2.205 lb.

[e] In lb./in., 1 N/cm = 0.571 x lb./in.

[f] In in.^{2}, 1 cm^2 = 0.155 in.^{2}.

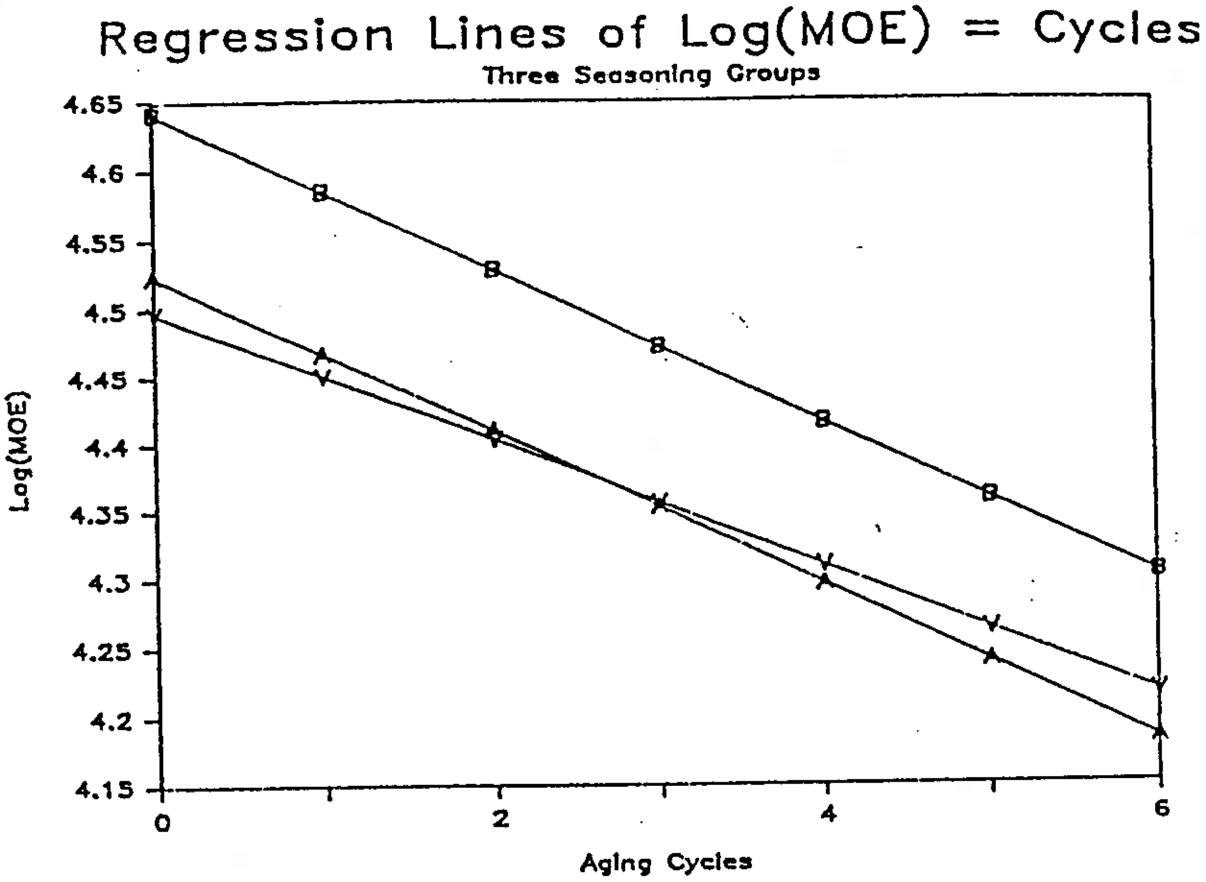

Figure 4—The effect of accelerated-aging cycle on compressive MOE (psi) of red oak crossties (A = air-dried, V = vapor-dried, B = Boulton-dried), 1 kPA = 0.145 × psi.

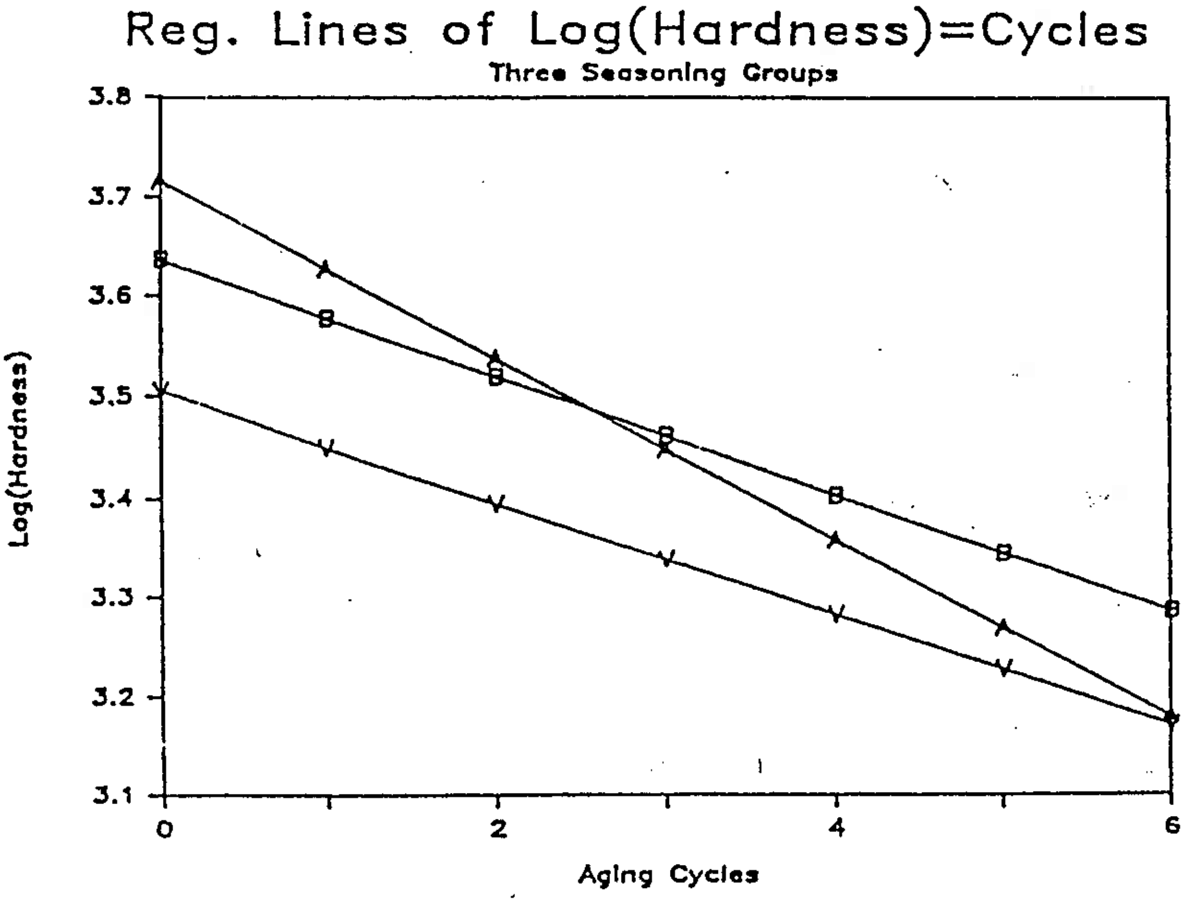

Figure 5.—The effect of accelerated-aging cycle on face hardness (lb.) of red oak crossties (semi-log form) (A = air-dried, V = vapor-dried, and B = Boulton-dried), 1 kg = 2.205 × lb.

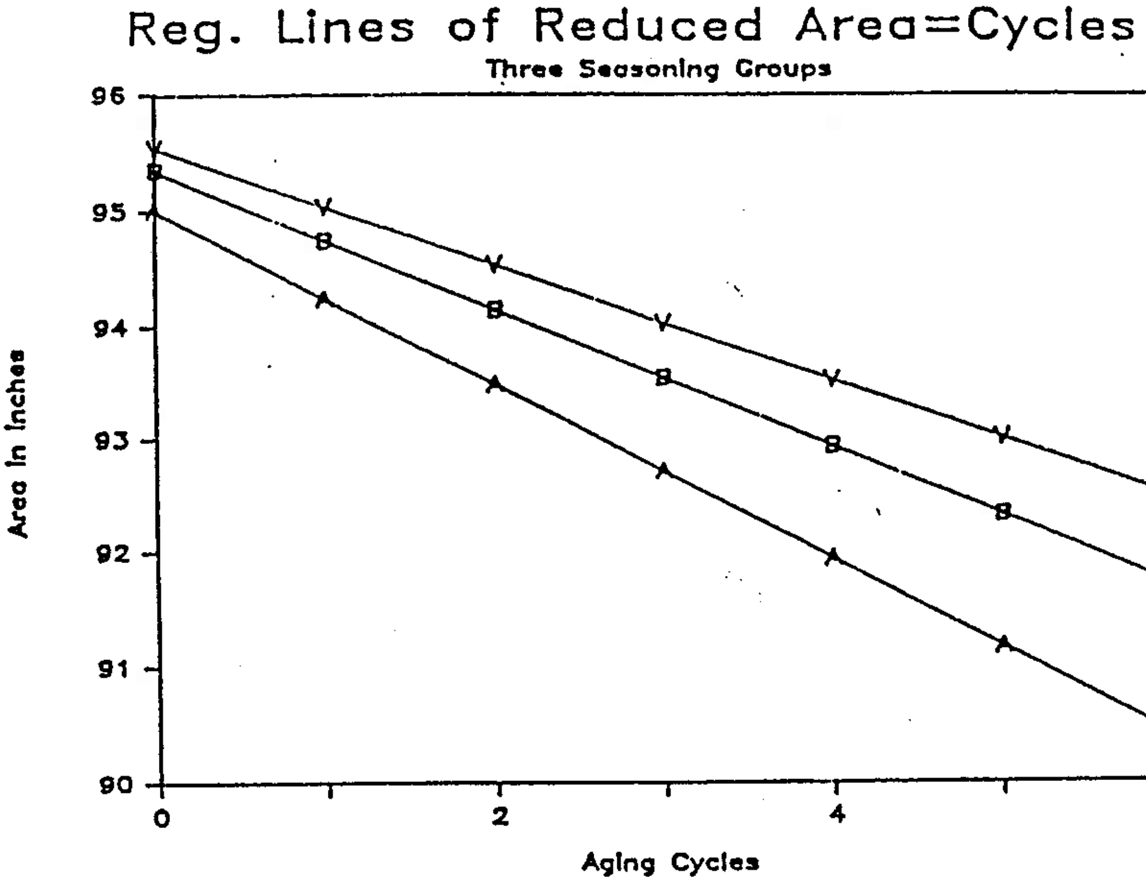

Figure 6—The effect of accelerated-aging cycle on reduced tie-plate area (in^2) of red oak crossties caused by checks and splits (linear regression form), 1 cm^2 = 0.155 × in^2.

these two seasoning methods were the rate of increase in surface checking (shown by differences in the regression coefficient), and the original value (intercept term) and the rate of change (regression coefficient) in hardness. Boulton-dried ties show significant differences in intercept terms for all properties from the air-dried and vapor-dried ties. However, the rate of change in the property is similar for all three groups for MOE, maximum deflection, and load at 0.04 in. (0.1 cm) deflection.

As should be expected, the intercept term for reduced bearing areas for all groups was similar since initially all ties had very few if any checks. The air-dried ties had the largest regression coefficient for reduced bearing area while the vapor-dried ties had the smallest. It is likely that the increase in checking is similar between the various groups of ties but the size of checks may differ considerably. The air-dried ties tended to have at least one or more large checks while the other groups may have had the equivalent area of checks but in much smaller checks.

3. Relationship of Accelerated Aging to Natural Aging:

a. Correlation:

The intent of this study was to numerically relate accelerated aging to natural aging and thus determine a quantitative measure of durability. A relationship in the form of:

Years of Natural Aging = f (Accelerated Aging Cycles) was desired. This relationship was determined by algebraically solving the two independent regression equations:

$P = f_1$ (Cycles)................................[1]

Years $= f_2$ (P)................................[2]

Years $= f_2 [f_1$ (Cycles)]........................[3]

The symbol "P" denotes a mechanical property. The results shown in Table 6 gave equations f_1. The regressions of accelerated aging were calculated again with the dependent variable being years instead of P. The linear regression equations from both types of aging were combined. These gave equations of the form:

Years = a + b (Cycles)

Table 7 presents equations 1 and 2 and the resulting equation 3 for each property, model, and seasoning group. In Table 7 "Y" represents years, "C" represents accelerated aging cycles, "P" represents the property or log of the property used to relate cycles to years. Also "AD" represents air-dried, "VD" represents vapor-dried, and "BD" represents Boulton-dried.

b. Confidence Level of Predicting Models:

Table 7 provides equations relating accelerated aging cycles to years but does not provide a measure of how accurate this relation is. It is possible to predict a confidence interval about any point in these equations. A 95 percent confidence interval about these equations would denote that based on the data collected in this study, the confidence interval would have a 95 percent probability of including the true value at any one point.

Ninety-five percent confidence intervals for the expected value of years from each equation were determined as outlined below (Steel et al., 1980).

The two independent equations below were used to calculate the variable "years".

$P_i = a + b\,(\text{Cycles}_i)$ from accelerated aging ..[4]

$\text{Years}_j = m + n(P_j)$ from natural aging........[5]

The variance of the estimate of years, V (Y), is equal to the variance of estimated years due to equation 4, V_1, plus the variance of estimated years due to equation 5, V_2. V_1 and V_2 were calculated as follows:

$V_1 = [x_0' (x'x)^{-1} x_0] n^2 * \text{MSE1}$ ....[6]

where x_0 = the matrix containing the desired values of the independent variables, i.e., 1 and Cycles—1 representing the intercept term and Cycles varying from 0 to 6.

x_0' = the transpose of matrix x_0

$(x'x)^{-1}$ = the inverse of a matrix containing the sum of squares of x for equation 4

n = the estimated coefficient from equation 5.

MSE1 = the mean square error from equation 4.

$V_2 = [P'(X'X)^{-1}P] * \text{MSE2}$ ....[7]

where P = the matrix containing the desired values of the independent variable, i.e., 1 and predicted P—1 representing the intercept and predicted P corresponding to the desired value of cycles.

P' = the transpose of matrix P

$(X'X)^{-1}$ = the inverse of a matrix containing the sum of squares of x for equation 5.

MSE2 = the mean square error from equation.

The variance of the estimate of years can be used to determine the confidence interval in the following manner.

Limits on the Confidence Interval = estimated years $\pm\, t(V[Y])^{0.5}$.

where t = tabulated t statistic for the appropriate degrees of freedom and probability level. In this case, p = 0.025 and there are 66 degrees of freedom, from published t-tables, t = 2.0.

Table 7.
Relation of aging cycles to years.

Property	P=f (Cycles) Equation 1	Years=f (P) Equation 2	Years=f (Cycles) Equation 3
MOE (Compression perpendicular to grain):[a]			
Linear:			
AD	P=34433-3378 (C)	Y=29.975-.00073 (P)	Y=4.82+2.47 (C)
VD	P=31163-2547 (C)	same as above	Y=7.21+1.86 (C)
BD	P=43074-3988 (C)	same as above	Y=1.49+2.91 (C)
Log-linear:			
AD	P=4.523-.0568 (C)	Y=166.3-35.84 (P)	Y=4.16+2.04 (C)
VD	P=4.497-.0468 (C)	same as above	Y=5.09+1.68 (C)
BD	P=4.640-.0562 (C)	same as above	Y=-.04+2.01 (C)
Maximum Deflection:[b]			
Linear:			
AD	P=.1001+.0128 (C)	Y=-1.433+63.808 (P)	Y=4.95+0.82 (C)
VD	P=.0973+.0102 (C)	same as above	Y=4.78+0.65 (C)
BD	P=.0772+.0100 (C)	same as above	Y=3.49+0.64 (C)
Log-linear:			
AD	P=-1.004+.0419 (C)	Y=40.71+37.08 (P)	Y=3.48+1.55 (C)
VD	P=-1.005+.0337 (C)	same as above	Y=3.45+1.25 (C)
BD	P=-1.099+.0392 (C)	same as above	Y=-0.03+1.45 (C)
Hardness:[c]			
Linear:			
AD	P=5346-720 (C)	Y=29.29-.00478 (P)	Y=3.74+3.44 (C)
VD	P=3212-304 (C)	same as above	Y=13.94+1.45 (C)
BD	P=4323-402 (C)	same as above	Y=8.63+1.92 (C)
Log-linear:			
AD	P=3.716-.089 (C)	Y=154.94-40.56 (P)	Y=4.20+3.61 (C)
VD	P=3.505-.056 (C)	same as above	Y=12.76+2.27 (C)
BD	P=3.636-.058 (C)	same as above	Y=7.45+2.35 (C)
Hardness Modulus:[d]			
Linear:			
AD	P=11371-696 (P)	Y=32.13-.00125 (P)	Y=17.88+0.87 (C)
VD	P=13529-1359 (P)	same as above	Y=15.17+1.70 (C)
BD	P=17877-1867 (P)	same as above	Y=9.72+2.34 (C)
Log-linear:			
AD	P=4.054-.033 (C)	Y=107.0-22.71 (P)	Y=14.95+0.75 (C)
VD	P=4.130-.061 (C)	same as above	Y=13.22+1.39 (C)
BD	P=4.254-.067 (C)	same as above	Y=10.40+1.52 (C)

[a] In psi, 1 kPa = 0.145 x psi.

[b] In in., 1 cm = 0.393 x in.

[c] In lb., 1 kg = 2.205 x lb.

[d] In lb./in., 1 N/cm = 0.571 x lb./in.

The confidence interval varies with x. The further x is from the average x used to determine the confidence interval, the wider the confidence interval. Examples of confidence intervals are given in Figures 7, 8, and 9. These confidence intervals are about the equations determined by combining the linear regression equations that involve the modulus of elasticity in compression. These are the first three equations in Table 7. The graphs show the confidence interval becoming wider at the ends of the known values for cycles.

Table 8 shows the range of the confidence interval for each property, seasoning group, and type of model. All values in Table 8 are for 95 percent confidence intervals.

For the properties determined from the compression perpendicular to grain tests, the confidence interval is ±2 to 3 years. The confidence intervals for hardness properties have a wider range, from ±3 to 5 or 6 years. The compression properties gave more consistent values, with intercepts ranging from 0 to 7 years with most being between 3 and 5 years. According to the equations constructed from the regressions involving MOE, 6 cycles of accelerated aging is equal to 16 to 20 years of natural aging depending on the seasoning method. The 95 percent confidence interval for x = 6 cycles is less than ±3 years for the equation obtained by solving the linear regressions involving MOE. The compression perpendicular to grain properties seem to provide a better and more consistent relationship between accelerated aging and natural aging.

The reduced bearing area criteria provides a very consistent confidence interval between ±2.8 years.

Summary and Conclusions

This study involved the testing of naturally aged and accelerated aged 7 x 9-in. (18 by 23 cm) cross-

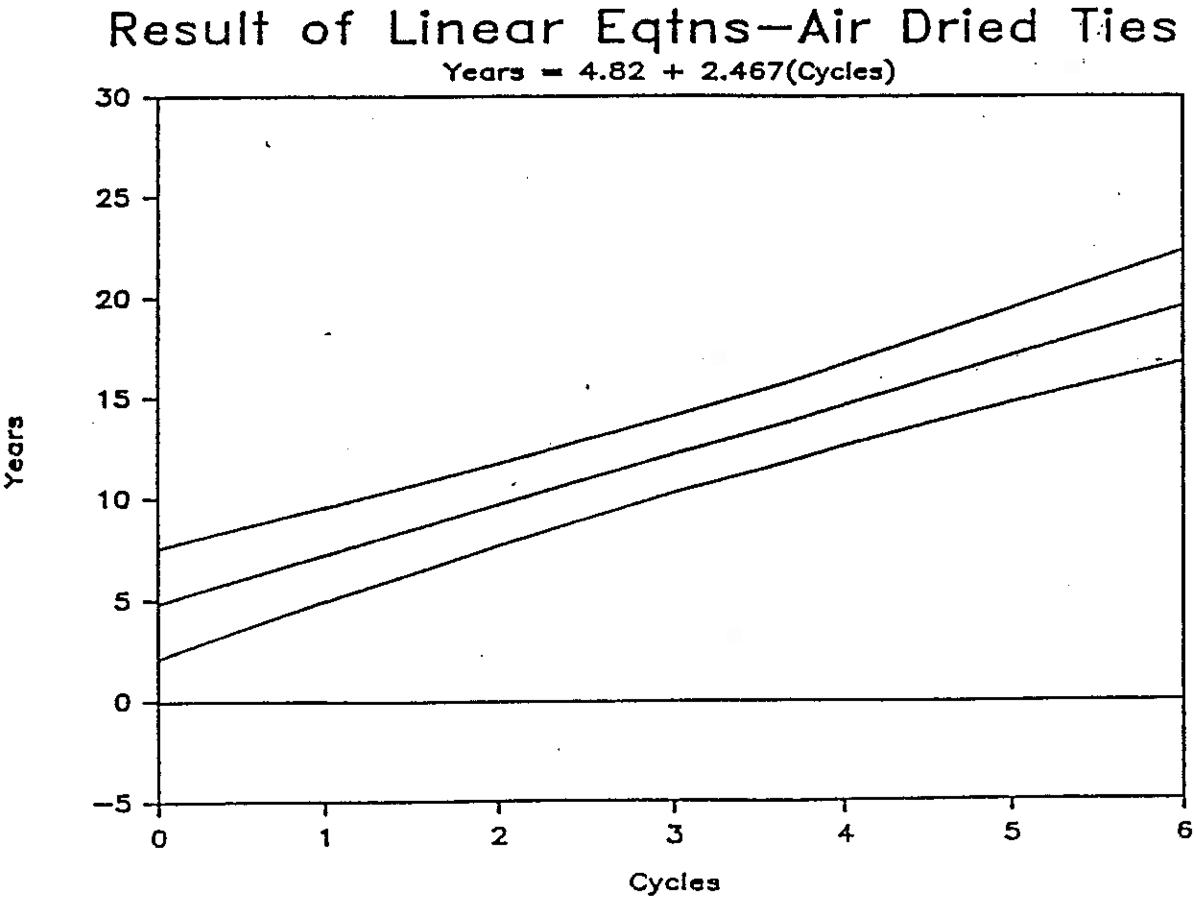

Figure 7—Prediction of tie age by using the number of cycle of accelerated aging test in term of MOE (psi) in compression (based on tests data of air-dried red oak crosstie specimens), 1 kPa = 0.145 × psi.

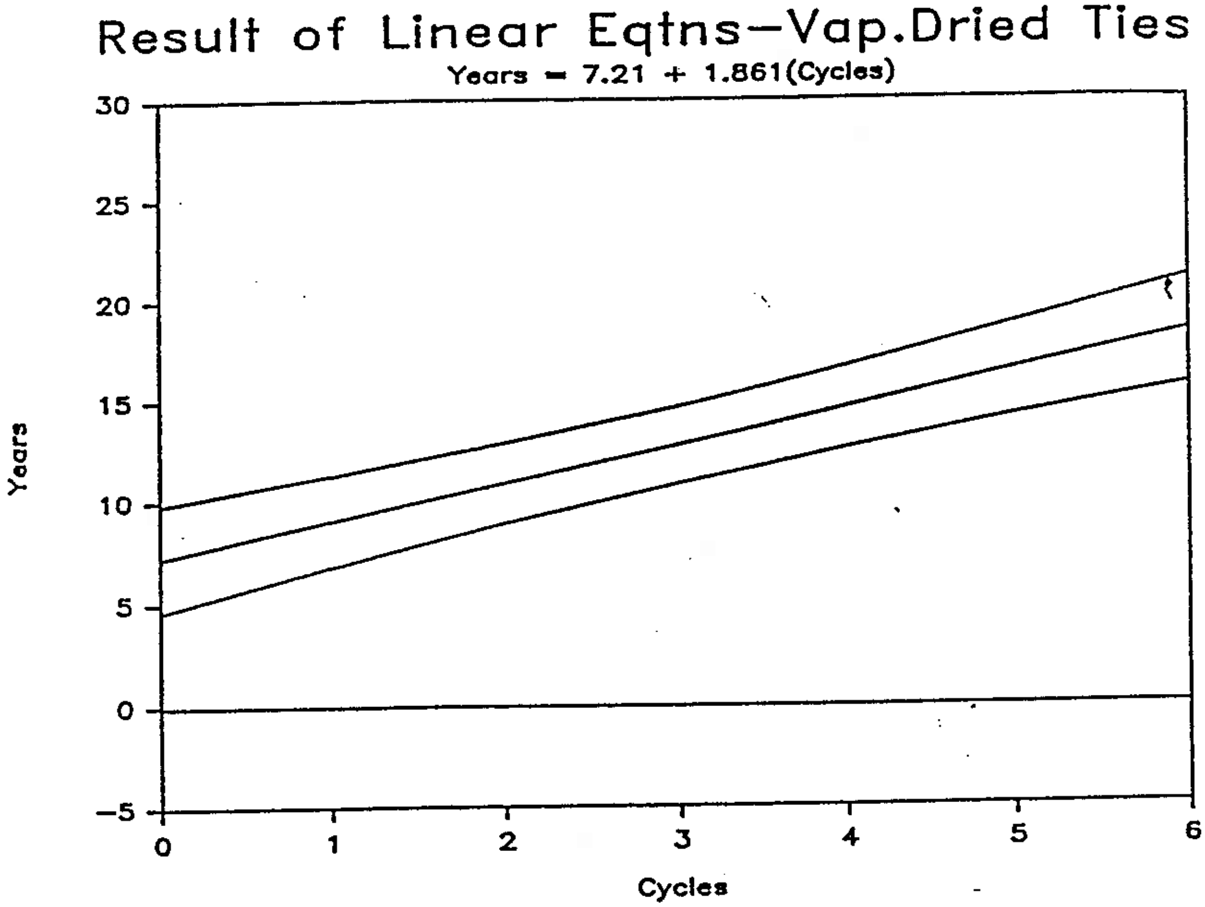

Figure 8—Prediction of tie age by using the number of cycle of accelerated aging test in term of MOE (psi) in compression (based on test data of vacuum-dried red oak crosstie specimens), 1 kPa = 0.145 × psi.

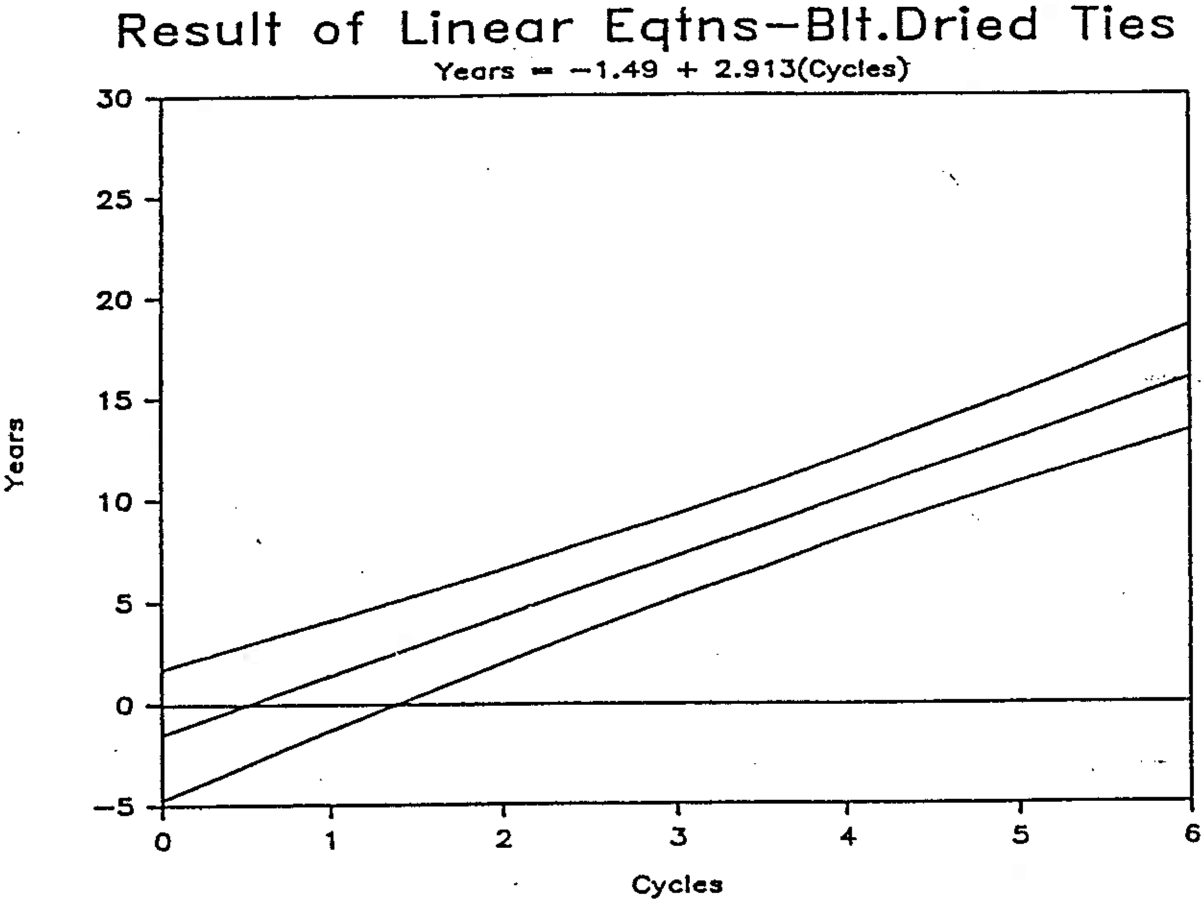

Figure 9—Prediction of tie age by using the number of cycle of accelerated aging test in term of MOE (psi) in compression (based on test data of Boulton-dried red oak crosstie specimens). 1 kPA = 0.145 psi.

section pressure treated red oak crossties. Conclusions that can be drawn from this study include:

1. The elastic properties in compression perpendicular to grain and surface hardness properties are significantly affected by cyclic accelerated aging and natural weathering.
2. The modulus of elasticity in compression perpendicular to grain is more sensitive than hardness or hardness modulus to accelerated aging treatments of heat and moisture.
3. Simple linear regression can account for up to 74 percent of the variation in compression perpendicular to grain properties, including mod-

Table 8.
Confidence Intervals About the Equations Relating Accelerated Aging to Natural Aging.

Property & Seasoning Group	Confidence Intervals consist of: Estimated Y ± the values in this table. Linear Equations	Log-linear Equation
Modulus of Elasticity:		
air dry	1.90-2.77	1.74-2.44
vapor dry	1.91-2.70	1.74-2.38
boult. dry	2.00-3.23	1.87-2.76
Maximum Deflection:		
air dry	1.96-2.34	1.75-2.37
vapor dry	2.02-2.35	1.79-2.37
boult. dry	2.12-2.50	1.93-2.66
Load at 0.04" Deflection:		
air dry	2.40-3.45	1.95-2.60
vapor dry	2.46-3.36	2.05-2.62
boult. dry	2.61-4.01	2.17-2.88
Hardness:		
air dry	2.62-5.33	2.60-5.56
vapor dry	3.12-4.87	3.05-5.66
boult. dry	2.66-4.26	2.63-4.50
Hardness Modulus:		
air dry	3.53-4.89	3.02-4.02
vapor dry	3.13-5.61	2.91-4.71
boult. dry	2.93-5.09	2.80-4.04
Reduced Bearing Area:		
air dry	2.72-3.01	2.75-2.91
vapor dry	2.73-2.87	2.75-2.87
boult. dry	2.72-2.85	2.74-2.85
MOE w/Reduced Area:		
air dry	3.05-5.04	2.08-3.36
vapor dry	3.20-4.88	2.12-3.21
boult. dry	2.75-4.48	1.93-2.75

ulus of elasticity and maximum deflection in naturally aged crossties.

4. Certain properties, including modulus of elasticity, maximum deflection, and load at 0.04 inches show a better fit when a curvilinear relationship is used. This indicates that these properties are leveling off with age.
5. There is more variability in measurement of hardness properties than in compression perpendicular to grain properties.
6. There are differences in the mechanical properties of red oak crossties that have been seasoned by different methods. However, the rate of change of these properties due to accelerated aging may be consistent between seasoning treatment groups.
7. A relationship has been determined between the six-cycle accelerated aging process and natural aging. Confidence intervals of approximately ± three years border this relationship. Six cycles of accelerated aging may be equivalent to more than 20 years of natural aging depending on the property used to relate accelerated and natural aging.
8. The mechanical properties of some selected in-service red oak crossties obtained from track in the Midwest has been determined.
9. The aging and degradation of a wood crosstie appears to be an extremely complex process involving many factors and interactions. This study demonstrates that the weathering of red oak crossties may be as important a factor of degradation as biological deterioration and stress.

Acknowledgment

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Discussion

HARRY GREAVES: Did you find that any of your accelerated aging regimes caused an increase in the mobility of the creosote in the treated ties. I am particularly thinking of the steaming, oven drying and conditioning phases.

MR. CHOW: It is very interesting to know the condition in Australia and I think in the United States. We are also going in the same direction as what you say. Your question about loss of creosote due to accelerated aging, is true. Especially the first and second cycle in the autoclave where we are steaming the creosote treated ties. We try to simulate the rains and the sun. We determine some of the creosote content after each cycle. But after six cycles there is still quite a lot of creosote left in the ties.

JEFF BROADFOOT: What plans do you have to incorporate mechanical damage into your overall picture. I noticed that wasn't included in the accelerated aging process and its relationship to tie life (i.e., is there any relationship between mechanical damage aspect in your accelerated tie aging process?)

MR. CHOW: The question was whether or not the mechanical damage on the tie was included in the lab accelerating test. One of the slides show that the left half of each tie went to the Association of American Railroads lab. They are planning to do some impact and dynamic test in their lab in Chicago. That is part of the purpose. We only conduct the static test at the University of Illinois. I am only responsible for this end in the lab and I don't know their plan. Mr. Victor Shafarenko of AAR is here and you may be able to get some answers from him. He is the representative of the Association of American Railroads.

J. N. R. RUDDICK: This study and the conclusion developed do not take into account the influence of decay. Would you like to comment on the effect of decay on limiting tie life?

MR. CHOW: In the past I think the tie inspectors removed the tie based on the appearance and decay which are major factors to remove the tie from the track. In this study we only tried to isolate the decay factor. Right now we just study the weathering effect. In the later phase of the study we shall include decay or fungi effect in the same kind of tests.

All of the tests we conducted on red oak ties had the tie ages from brand new up to 30 years old. Ties deteriorate in a kind of similar rate annually. When ties reach 20 years old, decay or fungi may start to grow in them. This is just my guess. We are planning to study this topic using a different kind of fungus species in the future.

SESSION CHAIRMAN ROU: Thank you very much, Dr. Chow: Our next paper is entitled "Recent Research on Alkylammonium Compounds in the U. S." by A. F. Preston, P. J. Walcheski, P. A. McKaig and D. D. Nicholas. Alan Preston will present the paper.

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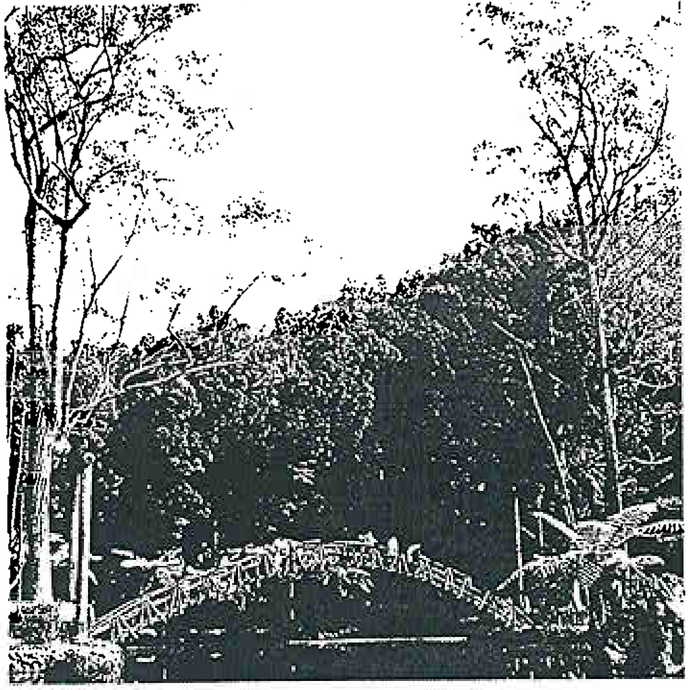

PROCEEDINGS

Edited by Dr. Song-Yung Wang and Dr. Min-Chyuan Yeh

The Forest Products Association of R.O.C. Bulletin N0.16

DIMENSIONAL STABILITY AND DECAY RESISTANCE OF COMPOSITE FIBERBOARD MADE FROM PLANTATION-GROWN SOUTHERN YELLOW PINE

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[ABSTRACT] The objective of this study was to investigate the influence of the phenol-formaldehyde resin content level-(3 percent and 7 percent), and three fungi species (Poria Placenta, Gleophyllum trabeum, and Polyporus versicolor) on the dimensional stability and decay resistance of high density composition boards made from plantation-grown southern pine chips. A standard ASTM method was used to evaluate weight loss and thickness change. The linear shrinkage and expansion of each species were also determined. All specimens were exposed to decay chambers for 16 weeks. Test results indicated that the main factors significantly influence the thickness and length changes and the decay resistance of the high density southern pine composition boards.

1. INTRODUCTION

When composition board becomes wet, it swells mostly in thickness and in length, and considerable bonding degradation occurs. Phenolic resin bonded boards are preferred in building construction for protection against water and high humidity. However, fungal attack in the phenolic bonded board was as severe as that in the urea bonded board [2 and 4].

Weight loss during the mycological testing of particleboard and fiberboards was reported as a good measure of decay resistance [3]. However, in the United States, little information concerning the dimensional stability of wood-base composites such as dry-process hardboard made from plantation-grown southern pine is available in spite of the rapidly expanding use of these materials often in areas of potentially high decay hazard. There is a need to provide the public with general information in the areas of the effects of resin content and fungal species on the dimensional stability and decay resistance of the composition boards.

2. MATERIALS AND PROCEDURE

Wood fiber composition boards approximately 279-by 279-mm were made from steam-pressure refined fibers. The wood chips were obtained from the juvenile plantation-grown southern pine. All fibers were produced from chips, steamed for 2 to 5 minutes at about 7.5 MPa, disk refined, and dried at 150 to 160° C in a rotation drier. Two levels of phenol-formaldehyde adhesive content were used: 3 and 7 percent (based on resin solids content and ovendry fiber weight).

Table 1. Design for the experiment.

No.	Fungus Type	Resin (%)	Replication
1	Poria	3	8
2	Poria	7	8
3	Gleophyllum	3	8
4	Gleophyllum	7	8
5	Polyporus	3	8
6	Polyporus	7	8

Composition boards with a specific gravity of 1.0 and a thickness of 3.2 mm were produced for two resin contents. All boards were pressed on a steam-heated press at about 190°C for 8 minutes at a maximum pressure of 7.24 MPa for all boards.

Forty-eight board specimens approximately 25 mm square by 3.2 mm thick were cut from the experimental boards made from plantation-grown southern pine fibers. After conditioning at a temperature of 26.7°C and 70% relative humidity for 4 weeks, all specimens were weighed and calipered.

All specimens were tested according to ASTM Method D2017 [1] using cultures of three common rot fungi (two brown rots and one white rot); *Poria placenta* (Fr.) Cook (ATCC 11538), *Gleophyllum trabeum* (ATCC 11539), and *Polyporus versicolor* (L. ex. Fr.) (ATCC 12679). The second brown cubical rot often causes decay in millworks and wood situated aboveground. A replicate of eight specimens of each fungus and resin content condition were used. Each cylinderical 225 cm^3 culture bottle contained one specimen of the board. After 16 weeks exposure to fungus specimens were removed from the test bottles, reconditioned, reweighed, and recalipered to measure the weight loss and dimensional changes.

3. RESULTS

Statistical analysis indicates that the average dimensional stability and decay resistance values for all specimens were significantly (5% level) influenced by major factors of resin content and the decay species. The effect of resin content on the thickness change of the board specimens was found not to be significant as shown in Table 2.

Table 2. Factorial analysis

Factor	SGR[a]	TC[b]	WL[c]	LC[d]
Fungus (3)	S[e]	S	S	S
Resin Content (2)	S	N[f]	S	S

[a] SGR = Specific gravity reduction
[b] TC = Thickness change
[c] WL = Weight loss
[d] LC = Linear expansion or shrinkage
[e] S = Significant at 5% level
[f] N = Not significant at 5% level

Table 3. Average specific gravity reduction, thickness change, and weight loss of plantation-grown southern pine composition boards.

Fungus Type	3 Percent Resin Content[a]	7 Percent Resin Content
	SPECIFIC GRAVITY REDUCTION	
GT[b]	-31.6	-29.4
Pp	-28.3	-21.7
PV	-23.4	-24.0
	THICKNESS CHANGE (%)	
GT	+8.2	+8.9
PP	-7.1	+7.6
PV	+24.7	+16.7
	WEIGHT LOSS (%)	
GT	-44.6	-36.9
PP	-50.0	-34.3
PV	-18.1	-21.3

[a] Phenol – formaldehyde resin
[b] PP = *Poria placenta*, GT = *Gleophyllum trabeum*, PV = *Polyporus versicolor*

Table 3 shows the average specific gravity reduction (SGR), thickness change (TC), and weight loss (WL) of specimens exposed to three wood decay fungi for 16 weeks. Table 4 shows the effects of resin content and fungi species on the linear change (LC) of specimens. It indicates that a moisture content incrfease did occur to the majority of the specimens after they were exposed to three common rot fungi.

Table 4. Average Linear expansion

Fungus Type	3 Percent resin content[a]	7 Percent resin content
	LINEAR CHANGE (%)	
GT[b]	-0.255	+0.223
PP	-0.354	-0.161
PV	+0.453	+0.334

[a] Phenol-formaldehyde
[b] PP = *Poria placenta*, GT = *Gleophyllum trabeum*, PV = *Polyporus versicolor*

4. SUMMARY

The following conclusions can be made from this study:

1. The effects of differences in adhesive content and type of decay fungi on dimensional change and decay resistance of hardboards made from plantation-grown southern pine were statistically significant at 5 percent level. The phenolic resin content level did not play an important role in influencing the thickness change of the specimens.
2. As increased resin content from 3 to 7 percent caused a significant reduction in SGR, WL, and LC values in specimens.
3. Specimens appeared to have more resistance to *Polyporus versicolor* (a white rot fungus) than two other brown-rot fungi.
4. Most of the specimens swelled in dimension except that the thickness and length shrinkage occurred in many specimens after the decay exposure.

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6. ACKNOWLEDGMENT

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ASSOCIATION OF AMERICAN RAILROADS | RESEARCH AND TEST DEPARTMENT | REPORT BRIEF

DURABILITY OF WOOD CROSSTIES
(PHASE 1)

R-702 (1987)

The durability and longevity of wood crosstie products are well known in the railroad industry. Wood products dominate the crosstie market, today. Yet, there is a lack of basic information on the wood tie strength-age relationship in railroad service.

Due to the relatively long life of the wood tie, service testing of new products is impractical for current purchasing decisions. An accelerated, but realistic testing method is required.

This report discusses the development of an accelerated aging technique for treated timber crossties. This process can be used for quality control in manufacturing or developing treated timber products.

A cyclic accelerated aging technique that is adaptable as a routine quality control method in the manufacturing or developing of wood crosstie products was developed. Six cycles of this accelerated aging technique may be equivalent to more than 20 years of natural aging depending on the property used to relate accelerated and natural aging. Ninety-five percent confidence intervals of plus and minus three years border this relationship.

Testing of crossties removed from track has been used to calibrate the aging process. These results have also been used to develop strength-age relationships for crossties in one service environment. Several tests were conducted in order to characterize the properties essential to tie performance. Among these are bending stiffness, plate area hardness and stiffness, lateral spike resistance, and vertical spike withdrawal resistance. Of these, bending stiffness and plate area stiffness showed the best correlations to tie age.

The applicability of the accelerated aging process was demonstrated in a comparison test of air-dried, boulton-dried, and vapor-dried ties. Boulton-dried ties appear to be stiffer than air-dried or vapor-dried ties. However, the normalized strength loss rates of the three groups are very similar.

Copies of the AAR Report: "Durability of Wood Crossties (Phase 1)", are available from the Document Distribution Center, Chicago Technical Center, 3140 South Federal Street, Chicago, Illinois 60616. The AAR report number is R-702; the price is $10.00 for member railroads and $30.00 for nonmembers. The cost includes taxes and surface mail postage if mailed within North America. There will be a surcharge for any overseas mail. Checks should be made payable to the Association of American Railroads. This report was issued in October,1987. A report list is available upon request.