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.

Keyword= **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' (14.16 million mn) 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 cross ties 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 finspector. 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 cross tie 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") 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
        (I) 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 130,5 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			D	E	F	G	
Years	0-5	6-10	11 ⁻ 15	16-20	21-25	26-30	31+	Total
First part		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 Ted 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 / nr') 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') was subtracted from the tie plate area. This left a bearing surface of 9.54 m. 6.4 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 el., 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 perforthing 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. Mg., room temp.)	30 minutes'	Maximum swelling occurs in wood
Pressure soaking (170 psi or 1,172 kpa, room temp.)	30 minutes'	Maximum swelling occurs in wood
Freeting (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, PO:=60% R.H.)	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 I 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, Log (P) = a + b (Cycles).

Table 4.
Average moisture contents at testing.

Group	Average moisture content	Range
A	27	23-29
	27	24-31
C	26	21-30
D	25	17-34
E	24	22-27
F	23	19-30
	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 his 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 Log = 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

		Significance[a] of:			
Property & Model	Equation	Model	Intrcpt	Coeff	
MOE:					
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)=-1.015-1-0.020(Yrs)	**	**	**	0.74
load at 0.04 inches:					
linear	[illegible] 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:					
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.

In in., 1 cm = 0.393 x in.

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

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

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

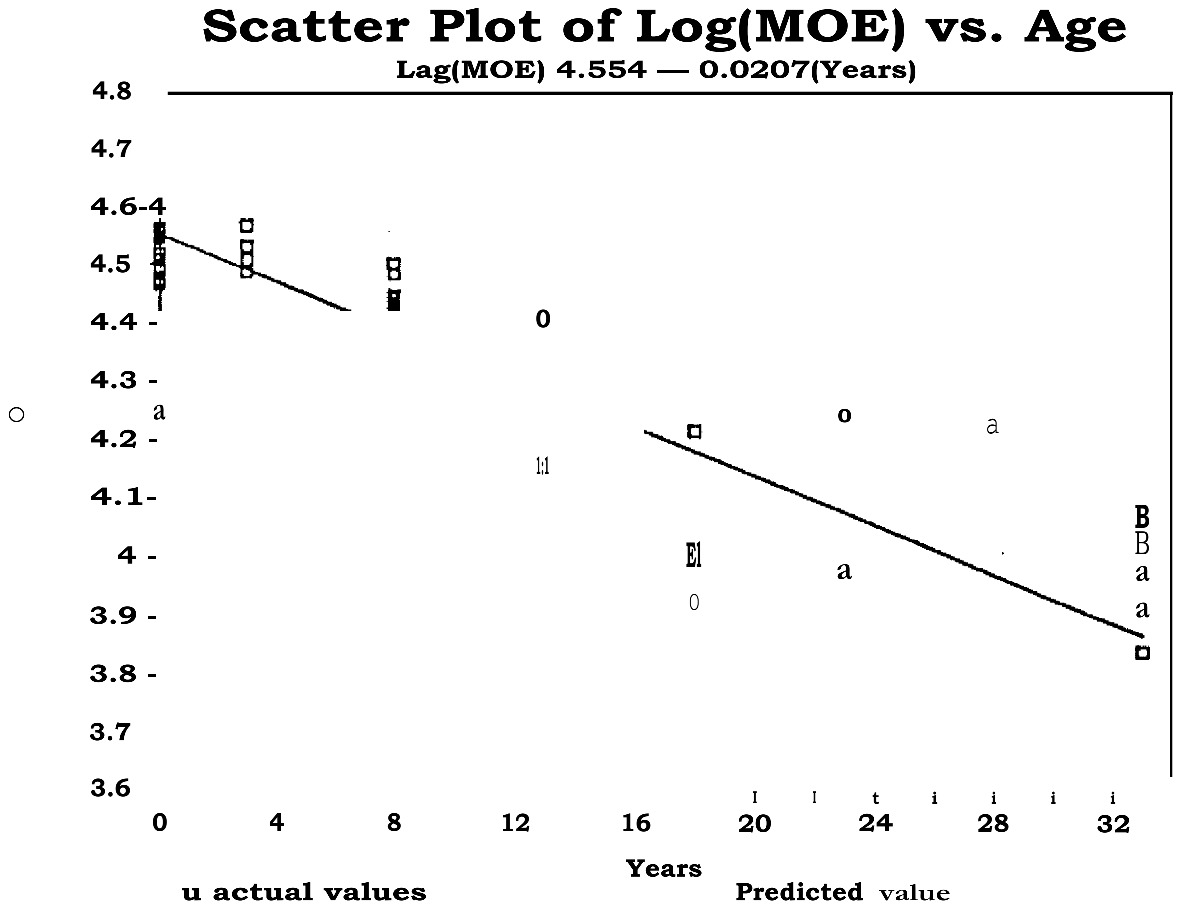

Figure 1—The effect of natural-aging on the MOE (psi) in compression of red oak crossties (semi-log form), 1 &Pa -= 0.145 X psi.

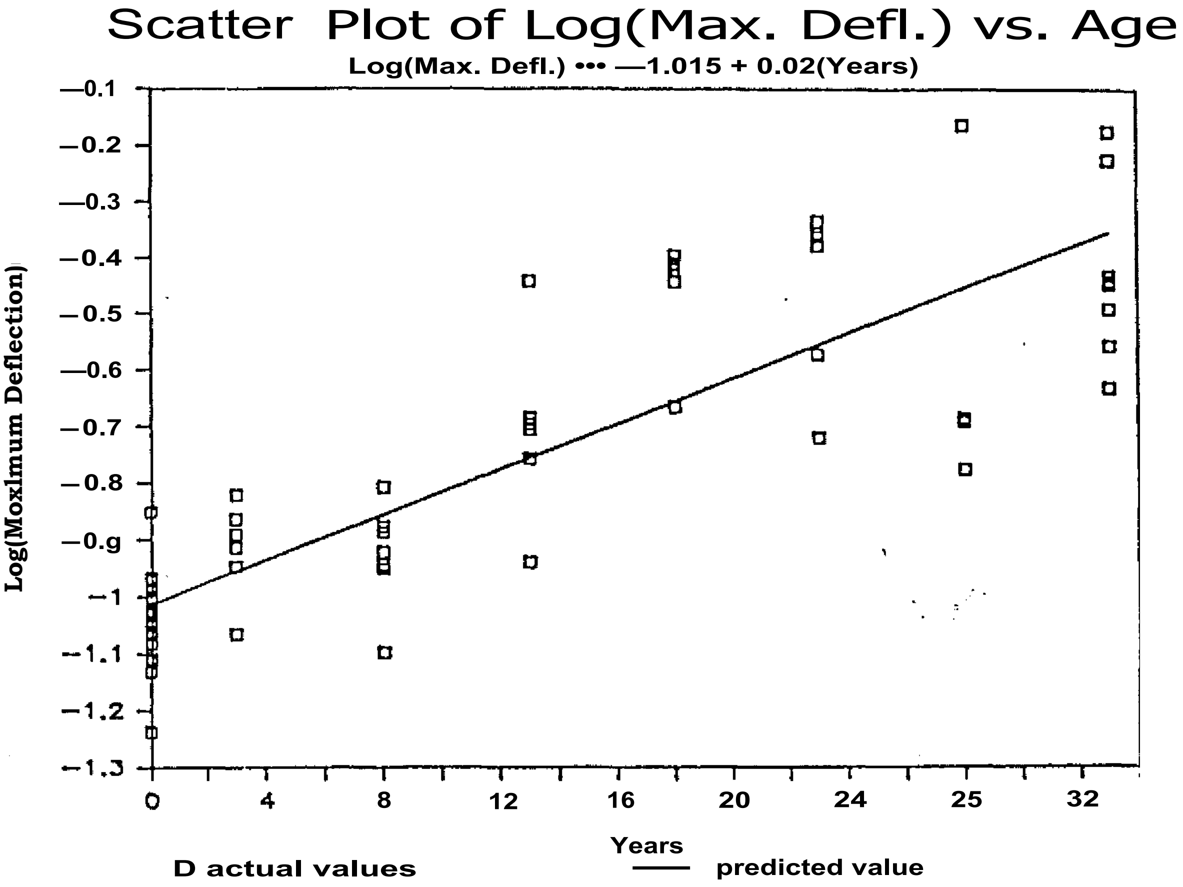

Figure 2—The effect of natural-aging on the compressive deflection (in.) of red oak crosstie (semi-log form), 1 cm =-- 0.394 x in.

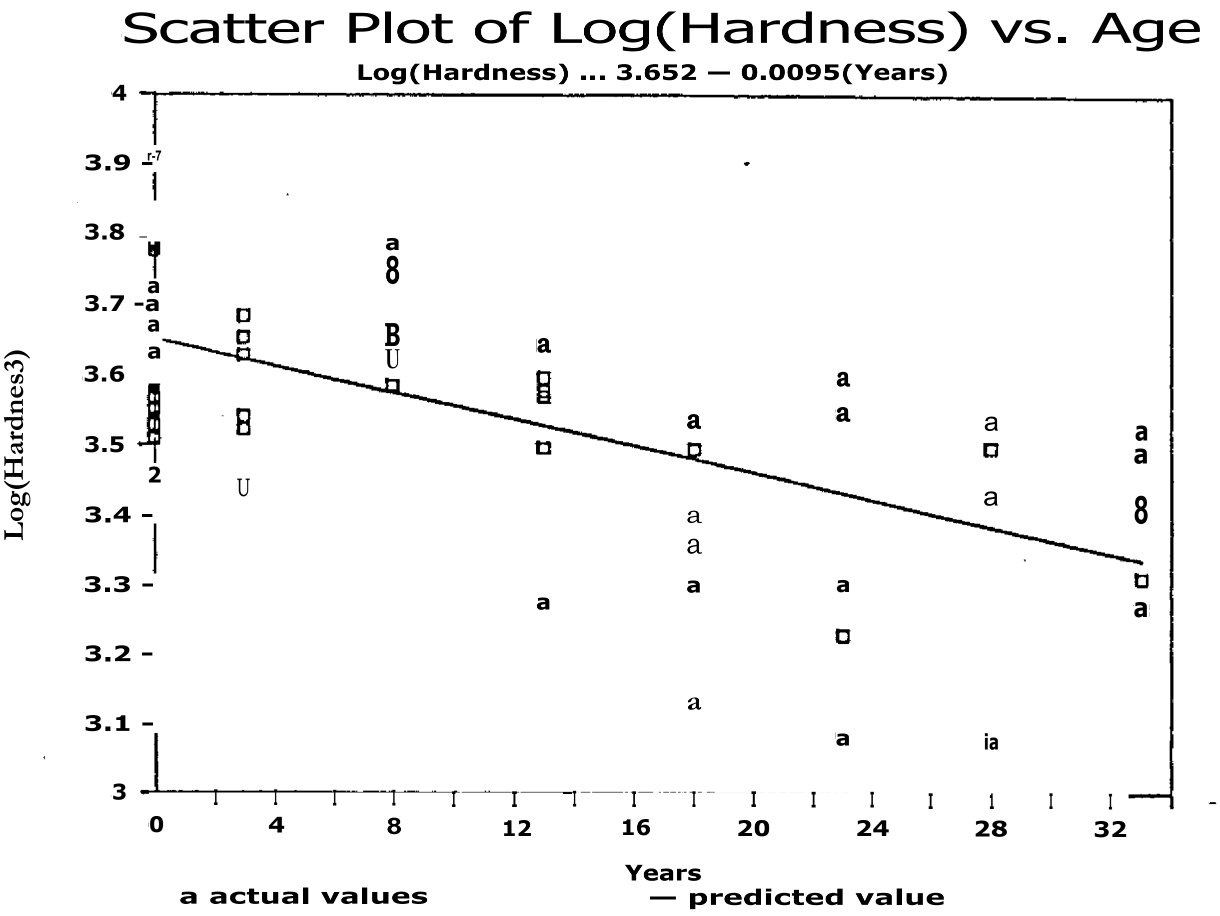

Figure 3—The effect of natural-aging on face hardness (lb.) of red oak crossties (semi-log form), 1 kg = 2.204 x lb.

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

Property, Model & Seasoning Group	Regression Equation	Significance[a] of:			R^2
		Model	Intrcpt	Coeff	
Modulus of Elasticity:[b]					
linear:					
air dry	1^3 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)i=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	Pi.,.0772+.0100(Cycles)	**	**	**	0.59
log-linear:					
air dry	Log(P)p--1.004+.0419(Cycles)	**	,**	**	0.39
vapor dry	Log(P).-1.0051-.0337(Cycles)	**	**	**	0.50
boult. dry	Log(P)**-1.099+.0392(Cycles)	**	**	**	0.63
Load at 0.04" Deflection:					
linear:					
air dry	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)1-13.59r-.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	4323-402(Cycles)	**	**	**	0.43
log-linear:					
air dry	Log(P)3.716-.089(Cycles)	**	**	**	0.74
vapor dry	Log(P)n3.505-.056(Cycles)	**	**	**	0.61
boult. dry	Log(P)3.636-.058(Cycles)	**	**	**	0.47

Table 6. (continued)

Property, Model & Seasoning Group	Regression Equation	Significance) of: Model	Intrcpt	Coeff	R^2
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(F)J-4.252-.067(Cycles)	**	**	**	0.58
Reduced searing Area:					
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

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

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

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}.

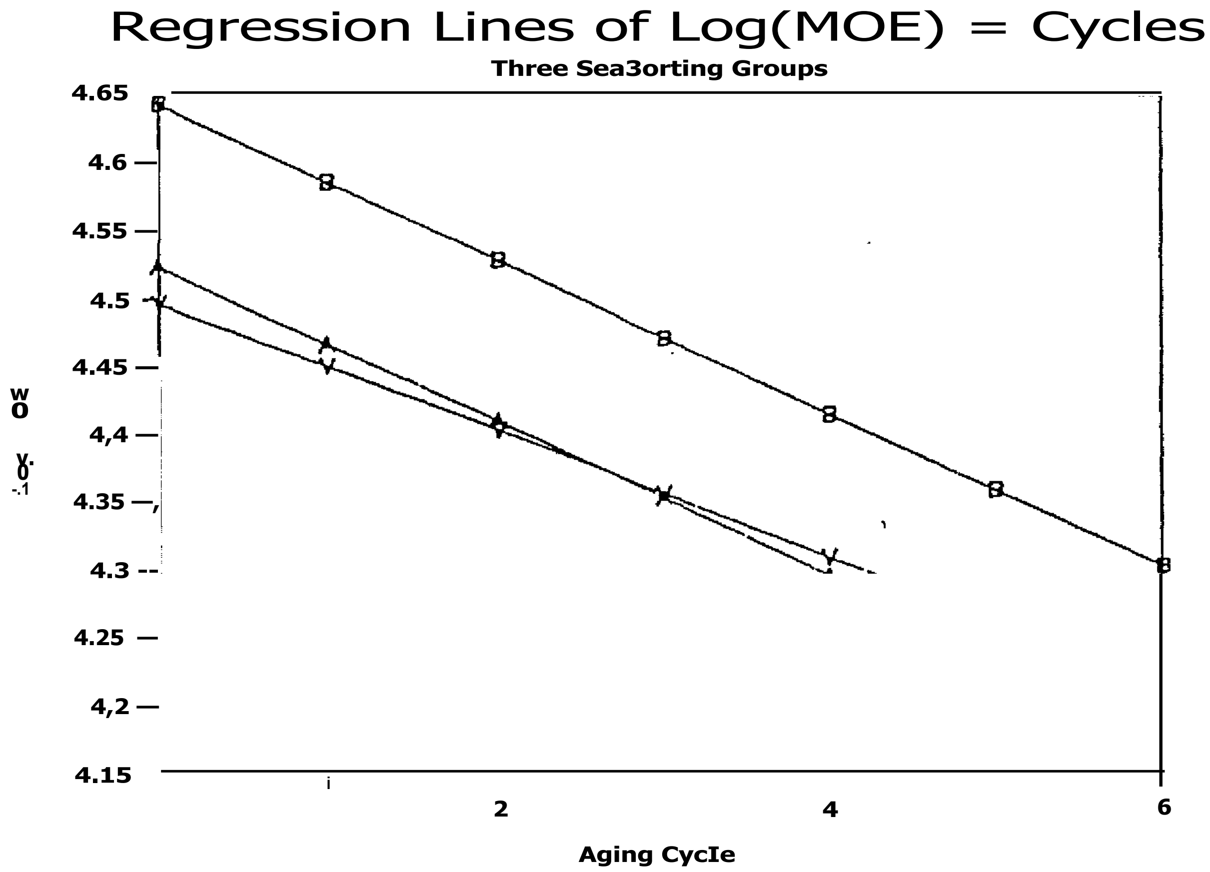

Figure 4—The effect of accelerated-aging cycle on compressive MOE (psi) of red oak crossiies (A --= air-dried, V = vapor-dried, **B =** Boulton-dried), I kPA = 0.145 X psi.

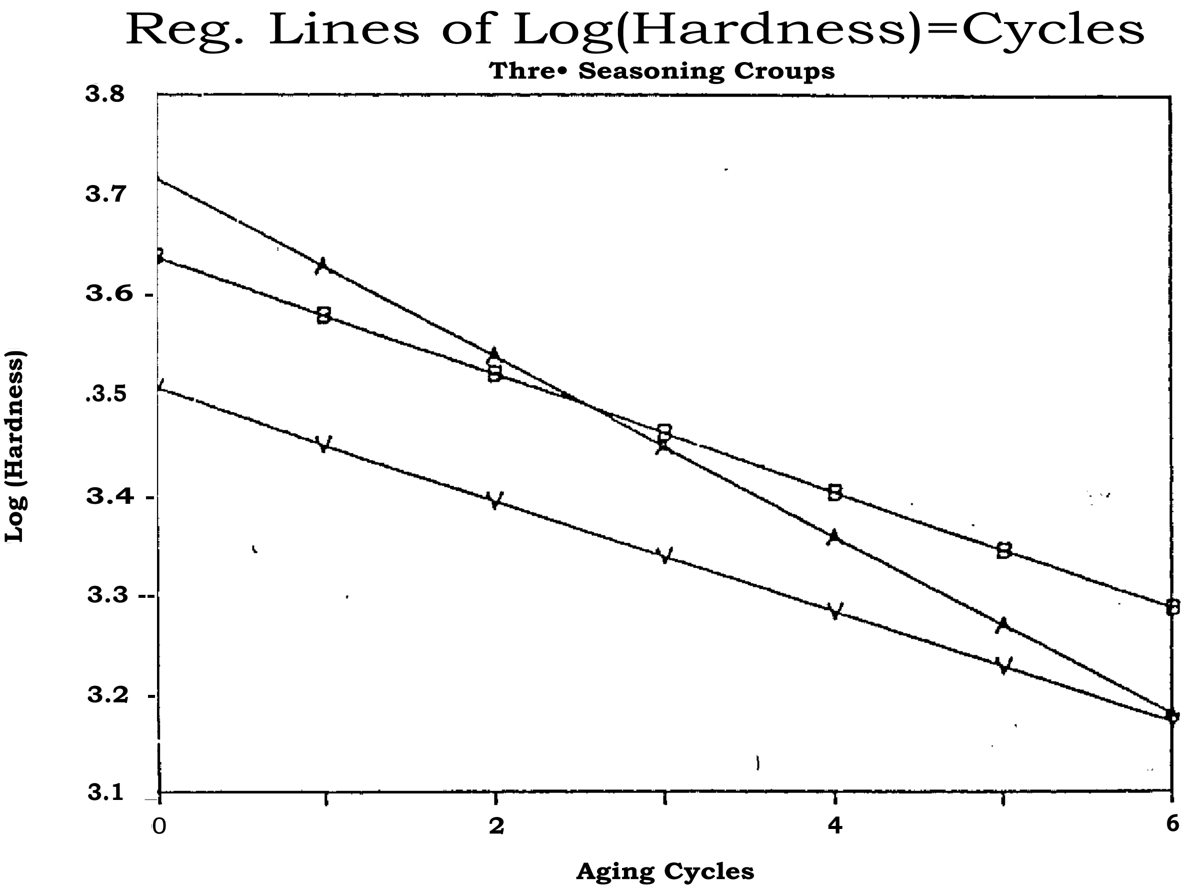

Figure 5.—The effect of accelerated-aging cycle on face hardness (lb.) of red oak crossties (semi-log form) (A = air-dried, V = vapor-dried, and B = Boulton-dried), 1 kg = 2.205 X lb.

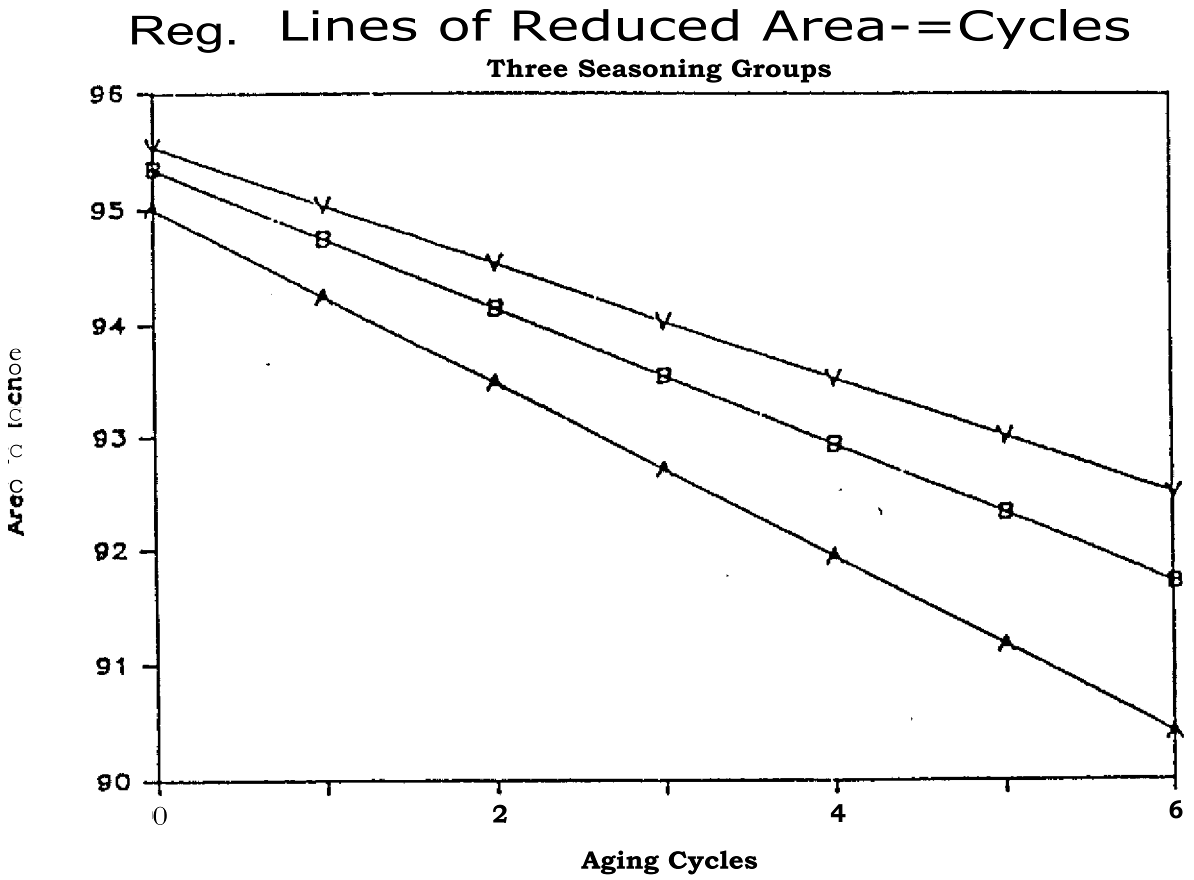

Figure 6—The effect of accelerated-aging cycle on reduced tie-plate area (in') of red oak crossties caused by checks and splits (linear regression form), 1 cm' = 0.155 X in'.

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:

$P = f_l$ (Cycles) .... [I]
Years = f_2 (P) .... [2]
Years = f_2 [f, (Cycles)] .... [^{3}]

The symbol "P" denotes a mechanical property. The results shown in Table 6 gave equations f_l. 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 resuiting 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_l = a b (Cycles,) from accelerated aging .. [4]
Years, = rn n(P,) 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, **V2. V1** and **V2** were calculated as follows:

V_1 = [x_0' (x'x)$^{-\prime}$ix_o]n^{2}4MSE1 .... [6]
where x_o = the matrix containing the desired values of.the independent variables, i.e., 1 and Cycles—I representing the intercept term and Cycles varying from 0 to 6.
X_0' = the transpose of matrix x_o
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 = [1^{31}(X'X)$^{-}$'P]oNISE2 .... [^{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.
= the transpose of matrix P
(rX)$^{-1}$ = 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 ± t(V[Y])os.

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)	1=29.975-.00073 (P)	Y=4.82+2.47 (C)
VD	P=31163-2547 (C)	same *as* above	1=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	1=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=-I.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)	1=3.48+1.55 (C)
VD	P=-I.005+.0337 (C)	*same* as above	Y=3.45+1.25 (C)
BD	P=-1.099+.0392 (C)	same as above	1=-0.03+1.45 (C)
Hardness:			
Linear:			
AD	P=5346-720 (C)	Y=29.29-.00478 (P)	1=3.74+3.44 (C)
VD	P=3212-304 (C)	same as above	1=13.94+1.45 (C)
BD	P=4323-402 (C)	same as above	1=8.63+1.92 (C)
Log-linear:			
AD	P=3.716-.089 (C)	Y=154.94-40.56 (P)	1=4.20+3.61 (C)
VD	P=3.505-.056 (C)	same as above	1=12.76+2.27 (C)
BD	P=3.636-.058 (c)	same as above	1=7.45+2.35 (C)
Hardness Modulus: [d]			
Linear:			
AD	P=11371-696 (P)	Y=32.13-.00125 (P)	Y=I7.88+0.87 (C)
VD	P=13529-1359 (P)	same as above	1=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)	1=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)
ED	P=4.254-.067 (C)	same as above	Y=I0.40+1.52 (C)

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

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

In lb., I kg = ,2.205 x lb.

In lb./in., 1 N/cm = 0.571x 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-

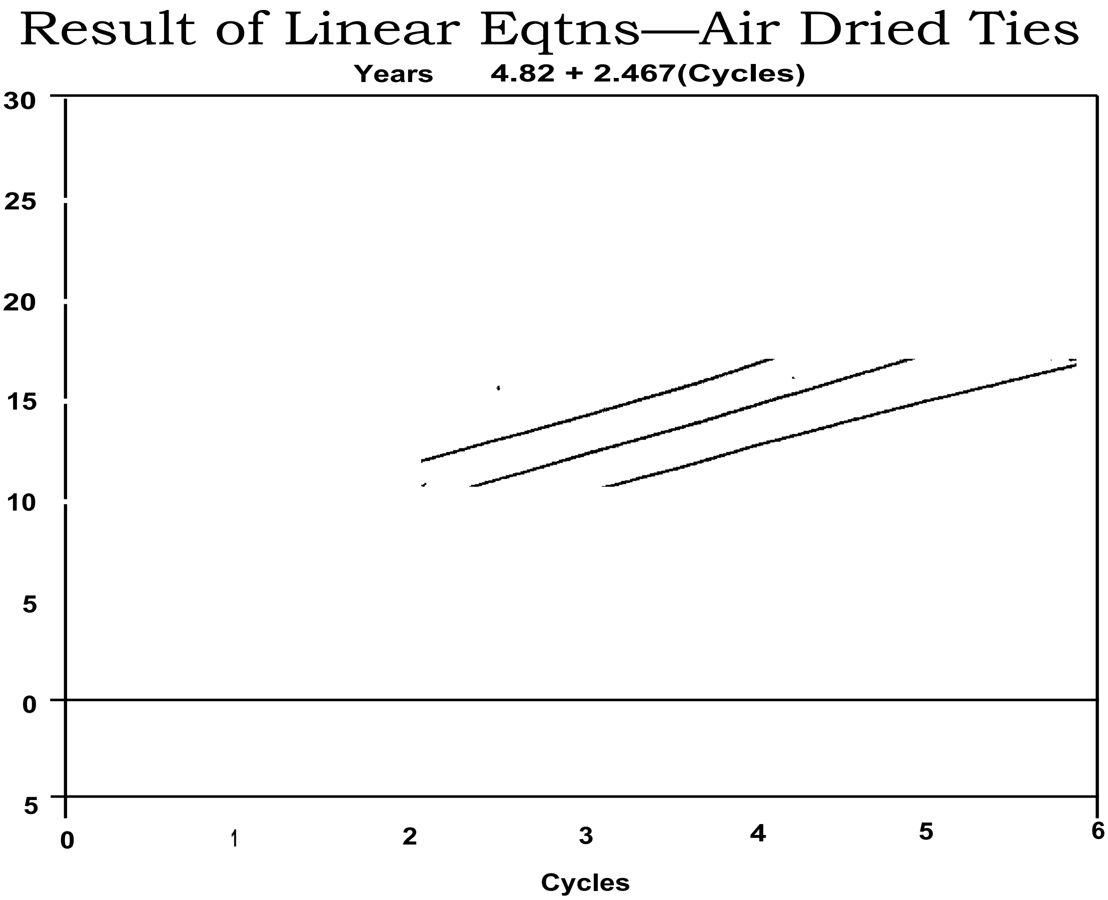

Figure 7—Prediction of tie age by using the number of cycle of accelerated aging test in term of MOE (psi) in compression - (based on tests data of air-dried red oak crosstie specimens), 1 kPa = 0.145 x psi.

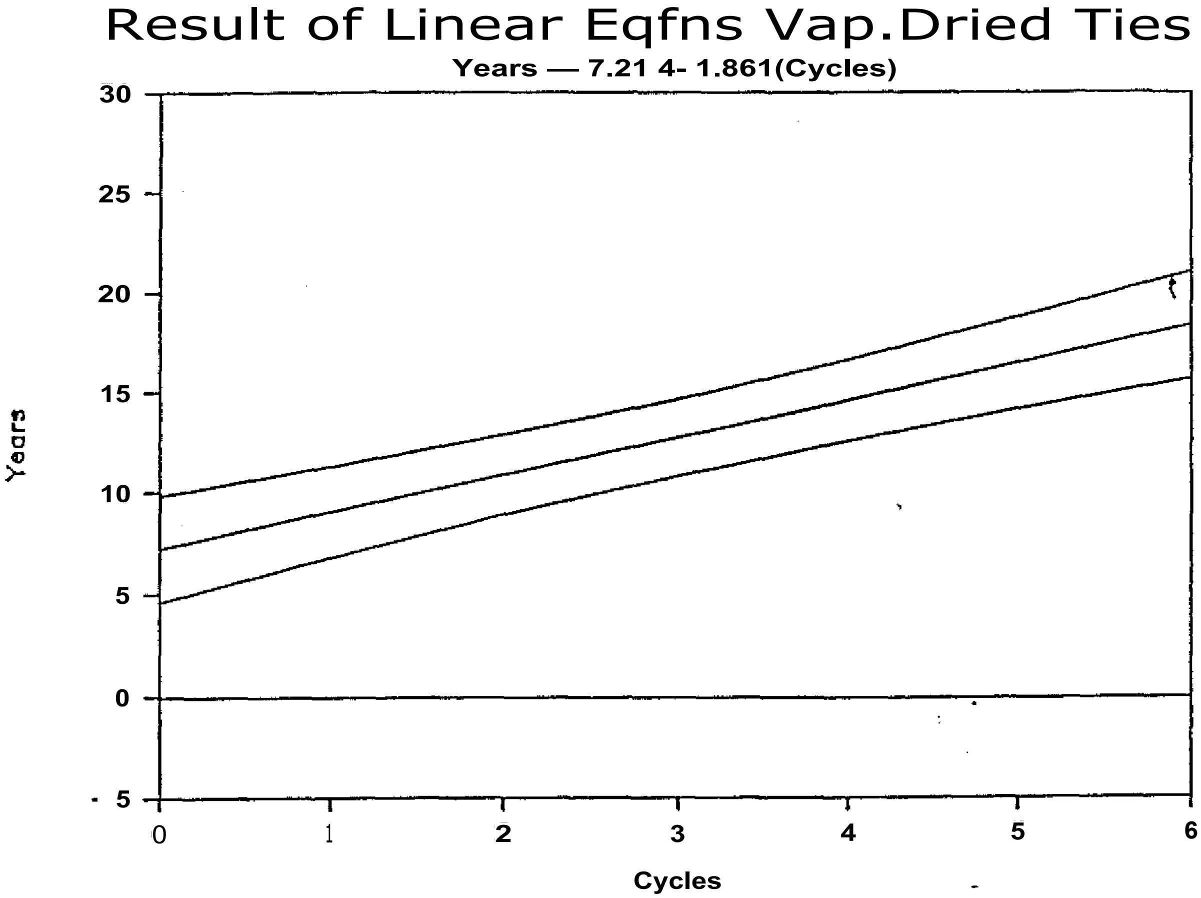

Figure 8—Prediction of tie age by using the number of cycle of accelerated aging test in term of MOE (psi) in compression (based on test data of vacuum-dried red oak crosstie specimens), 1 kPa = 0.145 X psi.

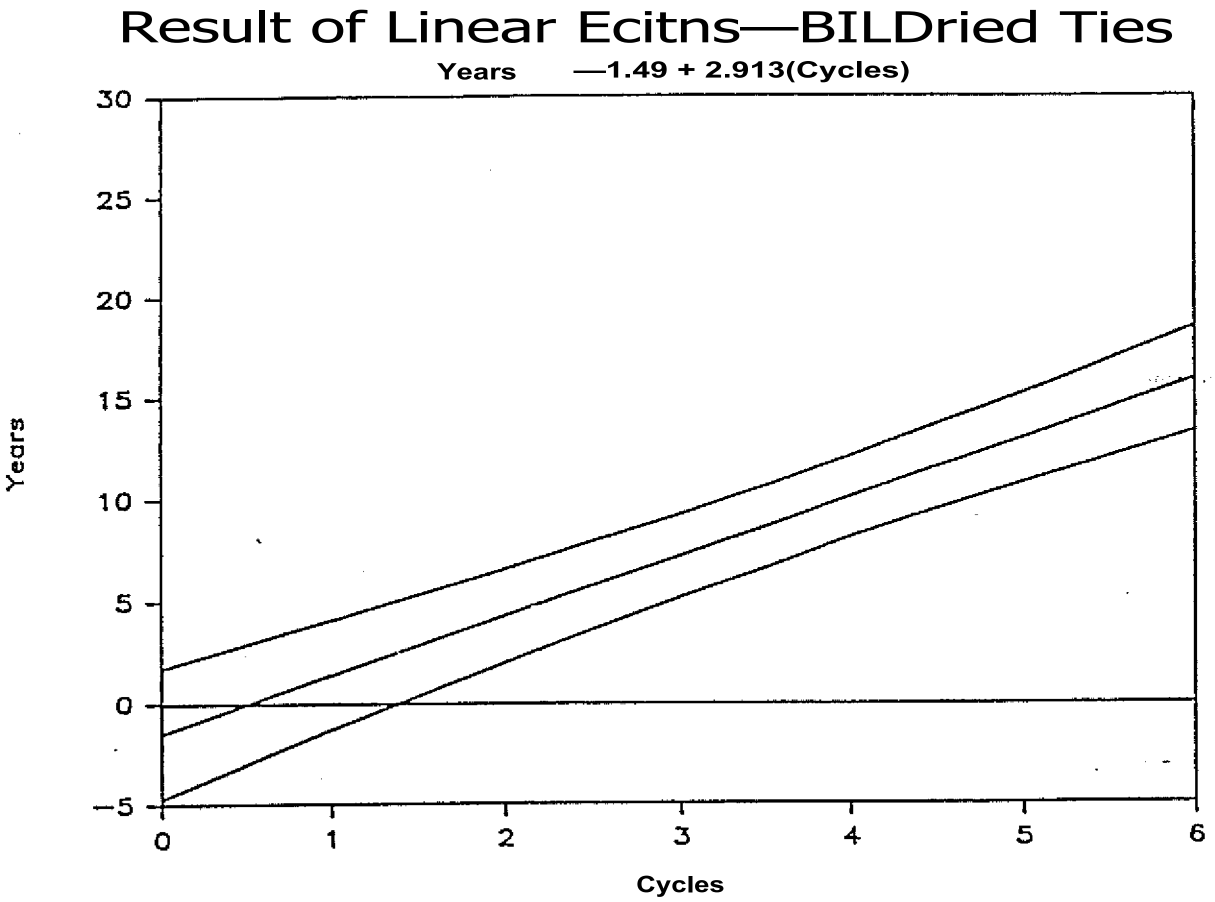

Figure 9—Prediction of tie age by using the number of cycle of accelerated aging test in term of MOE (psi) in compression (based on test data of Boulton-dried red oak crosstie specimens). I kPA = 0.145 psi.

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 inservice 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

This study was supported by funds administered through the Association of American Railroads; and the Affiliated Laboratory Core Program, College of Engineering, and the Department of Forestry, Illinois Agricultural Experiment Station, University of Illinois, Urbana, Illinois 61801.

We are grateful to Mr. W. S. Lovelace, Ms. J. J. O'Dea, and Mr. J. E. Hinson, Norfolk Southern Railway Company, Alexandria, Virginia, also Kerr-McGee Chemical Co. for the red oak crossties used in this study; and to Mr. R. L. Lantz, Mr. M. A. Franck, and Mr. N. L. Hawker, Koppers Company, Illinois, for the oak crossties used in the preliminary investigation of this experiment. Mr. M. D. Roney, CP Rail, Quebec, Canada, and Mr. J. B. Miller, Sante Fe Railroad, Chicago, and Mr. R. H. Bescher, Ohio, provided valuable counsel for the experiment.

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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. R000loK: 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 Roo: Thank you very much, Dr. Chow: Our next paper is entitled "Recent Research on .Alkylarnmonitn 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.