Accelerated Weathering of Red Oak

Treated With Various Preservatives Used to Treat Crossties[1]

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This report contains results of an experiment made at the U. S. Forest Products Laboratory to determine if a laboratory method of accelerated weathering would indicate differences in surface checking of treated red oak specimens after the wood had been treated with various oil-type preservatives.

IT IS GENERALLY BELIEVED that creosote and oil borne preservative solutions are effective in retarding surface checks and end splits in weathering railway crossties. The bleeding of the preservative is presumed to create a film having vapor barrier characteristics, and this film limits moisture content changes. Studies to determine significant performance differences among creosote, creosote solutions, and pentachlorophenol solutions in terms of railway crosstie replacement would be costly and lengthy.

The present experiment consisted of specimens of northern red oak treated with various creosote and pentachlorophenol solutions and exposed to varying conditions that created moisture regain and drying gradients. Untreated specimens were used as controls.

Design of the Experiment

Treating Preservatives: Specimens of northern red oak were treated with the following preservative solutions:

Treatment No.	Preservative solution
1	Controls—untreated
2	Creosote-petroleum (50-50 percent)
3	Creosote-coal tar (70-30 percent)
4	Creosote (100 percent)
5	Penta[3] (2.5 Percent)—Medium gas oil
6	Penta (2.5 percent)—Residual fuel oil
7	Penta (2.5 percent) Heavy slurry oil
8	Penta (2.5 percent)—Heavy cycle oil

Species, Specimen Size, and Specimen Preparation: The species selected for this study was commercial northern red oak. The specimens were nominally 2 by 8 inches in cross section and 24 inches long. The 2- by 8-inch stock from which the specimens were cut was flat sawn and all heartwood. To provide specimens free of surface checks for treatment and exposure, green rough-sawn boards were purchased and kiln dried green from the saw. To provide the needed number of specimens free of surface checks at a moisture content of about 20 percent for treatment with the preservatives, it was necessary to procure three lots of 8-foot boards. These boards were kiln dried from the green condi-

[1] The work here reported was done in cooperation with the Dow Chemical Co., Midland, Mich. Presented at the 1961 Annual Meeting of the Forest Products Research Society, Louisville, Ky., Session 2 (Division 7, Treatments and Coatings), June 19, 1961.

[2] Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

[3] The four pentachlorophenol solutions were furnished by the Chapman Chemical Company, Memphis, Tenn. The firm reported that each solution contained 2.5 percent of pentachlorophenol. The suppliers and the properties of the petroleum oils they furnished are tabulated in Table 1. The coal-tar creosote and creosote solutions were furnished by the Forest Products Laboratory, and an analysis of their properties is given in Table 2. The 70-30 creosote-coal-tar solution was purchased in August 1956 from another commercial firm under AWPA Standard P2.

[4] Torgeson, O. W. 1957. Schedules for the kiln drying of wood. U.S. Forest Products Laboratory Report No. 1791. (Revised).

[5] 1954. Use of kiln samples in operating a lumber dry kiln. U. S. Forest Products Laboratory Report No. 1607. (Revised).

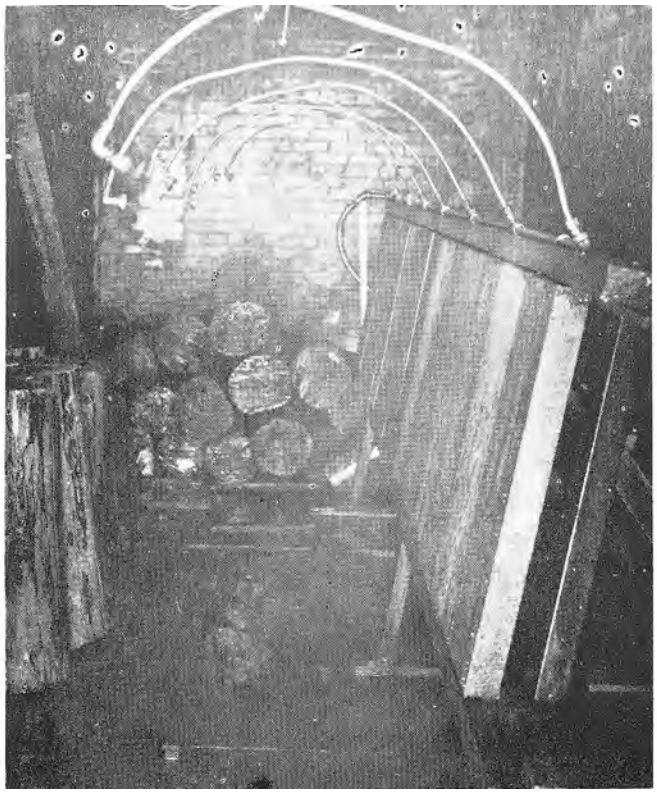

Fig. 1.—Spray chamber showing specimen rack and spray head arrangement.

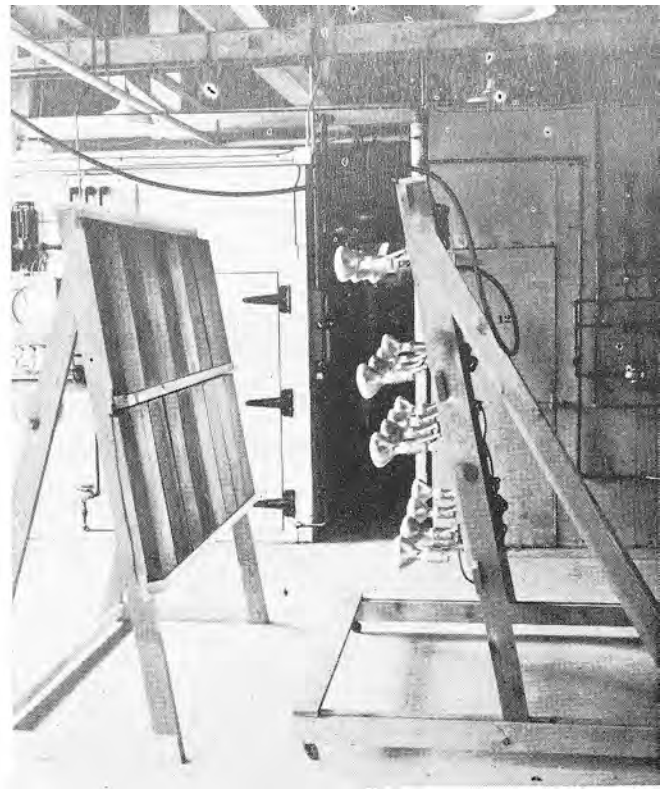

Fig. 2.—Infrared lamp bank for heating surfaces of specimens.

tion according to schedule T3-D1 for red oak.[4] The kiln-sample techniques was used to determine the average moisture content of the lot during the drying process. The boards were inspected for surface checking at an average moisture content of about 40 percent. Surface-check-free areas were marked on the boards for later inspection and acceptance as specimens. The first two kiln charges did not produce enough clear specimens free of surface checks for the experiment. A third lot was kiln dried by the same schedule, but the green rough-sawn boards were jointed on both sides to produce surfaced faces. Little surface checking occurred during kiln drying of these surfaced boards. Half the specimens needed in the experiment were obtained from the rough-sawn boards, and half were obtained from the "blanked" or surfaced boards.

When kiln dried to about 20 percent, the boards were removed from the kiln, and the 2- by 8- by 24-inch specimens were cut. A 1-inch moisture content section was cut from the adjacent ends of each specimen. These data provided a means of computing the calculated oven-dry weight of each specimen. The specimens were all stored in a room maintained at 80° F. and 90 percent relative humidity until needed for the preservative treatments. The control or untreated specimens were end coated with roofing cement when taken out of the humidity room. The others were end coated with the same material after the preservative treatments were made.

A few of the dried boards produced three specimens for the experiment. Fifty-four rough boards and 55 dressed boards were used. No attempt was made at the mill to identify the boards as to the tree from which they were sawn. As the boards became mixed during handling at the sawmill and at the Laboratory, the influence of tree effects is believed to be generally scattered throughout the experimental material. The boards were numbered and then cut into specimens. The specimens were also numbered, and they were randomly assigned to the eight treatments, one of which was the untreated controls, using a table of random numbers.

Experimental Design: Two hundred specimens were prepared, and 25 were randomly assigned to each of the 8 treatments. Five specimens of each of the 8 treatments were randomly assigned to an outdoor-exposure test, and the remaining 20 specimens of each treatment group were randomly assigned to cycling groups. Because of limitations of equipment, all of the 160 specimens could not be handled at one time through the exposure cycle. Ten cycle groups were therefore made up of 16 specimens each. Each preservative treatment and the controls were represented in each cycle group by 2 specimens. Ten replications of the cycle-exposure test were thus available to average out any differences that might exist in the operation of the equipment used for the accelerated weathering exposure conditions. The assignment of specimens to treatments, to cycle-exposure groups, and to outdoor- expo sure groups was done through use of random numbers.

The experiment was designed so that the analysis of variance could be used to test the significance of surface-check-rating means of the treatment groups. Each treatment was represented by 20 specimens in the cycle-exposure tests, and the specimens were allocated irrespective of whether they were rough or dressed. As a result of this random allocation of specimens to treatments, a disproportionality was created in the number of rough and dressed specimens in the various treatment groups. This lack of proportionality between rough and dressed specimens in the treatment groups made the analysis between the treatment groups for either the rough or dressed classification less reliable than

the analysis among treatment groups with the rough and dressed classifications pooled. The analysis will show, however, that the treatment effects in both the rough and dressed specimens are substantially the same as for the overall analysis.

Cycle Exposure Conditions: To accelerate the influence of changing-outdoor-climatic conditions on the development of surface checking, it was necessary to alternate the moisture content gradient between sorption and desorption phases. Any number of variations in temperature, relative humidity, water spray, and duration of exposure to create a moisture-content-regain gradient and a drying gradient could have been established as a cyclic exposure test procedure. The following exposure conditions were used in this test:

Step	Exposure	Time	Cumulated time
1	Water spray	1 day	1 day
2	Low relative humidit1Suppliedmperature	1 week	8 days
3	High relative humidity—low temperature	2 weeks	22 days
4	Infrared heating	6 hours	22¼ days
5	Low relative humidity—high temperature	18 hours	23 days

One of the larger Laboratory dry kilns was operated as a "wet room" for the storage of pole stubs. The pole sections were kept wet by means of a water spray. A rack was built and installed in this kiln to hold the 16 specimens, consisting of a single-cycle group. A special water line with a series of water spray heads was installed to provide the water-spray-exposure step of the cycle. The rack designed to hold these specimens provided a slight pitch to the specimens, which were resting on one end. The spray heads were adjusted so that the surfaces of all 16 specimens were wetted. The flat-sawn specimens were placed on the rack so that the face toward the bark was exposed to direct wetting from the spray heads. Figure 1 shows the arrangement of the spray rack, the water spray lines, and atomizing nozzles or spray heads inside the dry kiln. When the cycles were repeated, the placement of the specimens on the spray rack was random, so it was not likely that any specimen was placed in the same position in respect to the spray heads. A programmed order of placement on the spray rack was not deemed necessary.

Step 2 of the cycle-exposure test condition was conducted in a small drying chamber. The dry-bulb temperature was thermostatically controlled at 180° F. and, the wet-bulb temperature thermostatically maintained at 123° F. to produce a relative humidity of about 20 percent. The specimens when taken out of the spray chamber were allowed to stand for a few minutes so as to "drip dry."After weighing and inspection, the 'specimens then were placed in the drying chamber on stickers. Forced-air circulation in the drying chamber provided good air movement of the high-temperature, low-relative-humidity air through. the layers of specimens.

After the specimens were exposed 1 week to these rather drastic drying conditions, step 3 began. They were weighed, inspected, and then placed in another drying chamber operating at 140° F. dry-bulb temperature and 136° F. wet-bulb temperature, which produced a relative humidity of about 90 percent. As in the other drying chamber, the wet- and dry-bulb temperatures were thermostatically controlled. The wet-bulb wicks had to be changed quite often in both drying chambers, because the vapors from the treated specimens caused fouling of the wicks and errors in the wet-bulb temperature control. The specimens were placed on stickers in the drying chamber used for this step of the cycle exposure test.

Step 4 of the cycle exposure test consisted of 6 hours of exposure to infrared radiation to produce a drastic surface drying condition. The specimens were again weighed, inspected, and then placed on a rack, as shown in Figure 2. The bank of infrared lamps was positioned so that the distance between the lamps and the specimens was 36 inches. The specimens were placed on the rack with the side toward the bark exposed to infrared radiation. For step 5 of the exposure cycle, the specimens were again weighed, inspected, and then placed in the drying chamber operating at 180° F. and 20 percent relative humidity. After an additional 18 hours of drying, the cycle was completed, and the final weights and inspection data were obtained.

Each of the 10 cycle groups was subjected to this cyclic exposure test, which was repeated 6 times.

Measuring Technique for Surface Checking: A number of different methods may be used to determine the influence of the cycle-exposure condi-

Table 1.—SUPPLIERS AND PROPERTIES OF PETROLEUM OILS IN PENTACHLOROPHENOL SOLUTIONS

Property	Aromatic HB oil [1]	24 plus burner oil [2]	Decant oil C [3]	101E oil [4]
API gravity at 60° F.	16.1	14.7	4.5	7.2
Weight per gallon at 60° F. pounds	7.98	8.061	8.67	8.5
Specific gravity 60/60	0.9587	0.9679	1.0404	1.0202
Flash point [5] °F.	225	200	260	240
Viscosity at 100° F. [6] seconds	39	177.6	177.8	72.4
Viscosity at 210° F. [6] seconds	30.4	47.5	42	35.5
Pour point °F.	Below 0	Below 5	+70	+50
Color	Brown	Blackish brown	Brown	Greenish brown
Penta solvency at 75° F. percent	17	------	21	------
B. S. & W. [7] percent	.2	------	1	------
ASTM distillation				
Initial pulping point °F.	490	434	480	530
10 percent °F.	510	499	580	586
20 percent °F.	516	525	630	606
30 percent °F.	518	553	670	622
40 percent °F.	522	590	686	642
50 percent °F.	524	652	696	658
60 percent °F.	528	706	700	672
70 percent °F.	532	746	702 [8]	686
80 percent °F.	542	760	------	702
90 percent °F.	558	Cracked	------	716 [9]
End point °F.	590	------	------	716
Recovery percent	97	------	------	88

[1]Supplied by Enjay Co.
[2]Supplied by Standard Oil Company of Texas.
[3]Supplied by Cities Service Refining Co.
[4]Supplied by American Oil Co.
[5]Pensky-Martens closed tester, ASTM Standard D-93.
[6]Saybolt Universal, ASTM Standard D-88.
[7]Basic sludge and water.
[8]At 64 percent.
[9]At 88 percent.

tions on surface checking. The total lineal inches of surface checks for each of the 24-inch specimens could have been used, but the method fails to assess the severity of wide and deep surface checks. For example, a specimen could have a very few inches of checks, but they might be quite wide and deep. From the standpoint of this experiment, this might be more serious than if the specimen had a much greater total inches of surface checks that are narrow and shallow. A descriptive surface-check grading system could have been used, but conversion of such a system into a numerical rating that would have been suitable for statistical analysis was not considered feasible.

It was therefore decided to use a numerical rating system that provided data that could be statistically analyzed. After each step of the cyclic exposure test, the total length of surface checks on the face toward the bark was measured and recorded to the nearest half inch. The average width of the checks and the average depth of the checks were estimated. Surface check depths were estimated by using a thin feeler gage. A severity rating factor was applied to the total length of checks measured in accordance with the following classification:

Total length of surface checks Inches	Severity rating factor
0	0
0 to 2.0	1
2.25 to 6.0	2
6.25 to 18.0	3
18.25 to 48.0	4
48.25 or more	5

A numerical rating factor based on the estimated average width and depth of the surface checks was applied, using the following system:

Average width of checks Inches	Numerical rating factor: Checks less than 0.05 inch deep	Checks from 0.05 to 0.25 inch deep	Checks more than 0.25 inch deep
0 to 0.01	1	2	3
0.01 to 0.10	2	3	4
0.1 or more	3	4	4

The severity rating factor was multiplied by the numerical rating factor to provide a surface-check rating of the specimen. For example, if the total length of surface checks
, thPERCENT)ty rating woul
tmoistureage width was more tfian 0.01 inch but less than 0.10 inch and the average depth was 0.05 to 0.25 inch, the numerical rating was 3. The surface-check rating was then 2 X 3 = 6. The maximum surface-check rating that could be assessed against any specimen would be 5 X 4 = 20.

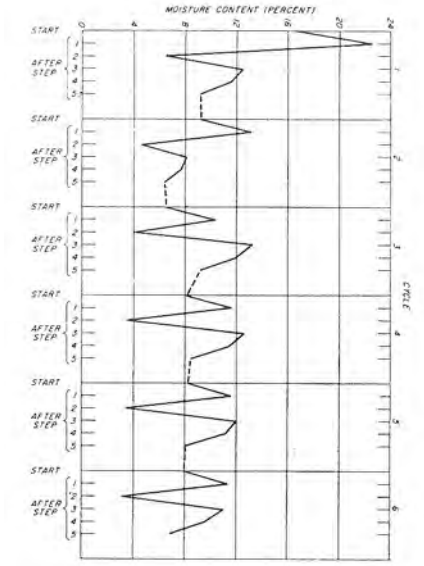

Fig. 3,--Average momture content of the 20 specimens of the control group after various steps and for six cycles.

In using this system of rating for surface checks, the values assigned a specimen were cumulative. That is, the values were carried forward or increased as indicated with the steps of the cycle or the additional cycles. After the first and third steps of the cycle exposure test, the surface checks were closed. The surface checks often were then difficult to detect, so that the previous surface-check rating would still be assigned to the specimen. The maximum surface checking for any particular cycle was usually found after step 4, infrared heating, although the additional drying of step 5 of the cycle occasionally caused more surface checks to develop.

Collection of Data

Green Moisture Content: In order to kiln dry the blanks from which the specimens were eventually cut, it was necessary to prepare kiln samples. The moisture content sections cut from the freshly sawn plank provided green moisture-content data. In kiln runs 1 and 2, six kiln samples were used, and in kiln run 3, eight were used. In all three kiln runs, kiln samples that were representative of the stock were selected. The average-green-moisture content of the two moisture sections cut for each kiln sample is given in Table 3. The average for the kiln samples of kiln run 1 was 86.7 percent, for kiln run 2 it was 83.0 percent, and for kiln run 3 it was 88.4 percent. The grand average-green-moisture content was 86.3 percent.

Moisture Content When Specimens Were Prepared: As previously mentioned, all of the planks in the kiln charge were examined for surface checking when their moisture content was about 40 percent. Surface-check-free areas were marked for later specimen preparation. The stock was kiln dried to about 20 percent, and the specimens then were cut, numbered, and assigned to treatments. Specimens were cut to exactly 24 inches in length, and a 1-inch moisture section was cut adjacent to each end of the specimen. Calculated oven-dry weights of the specimens were computed from the moisture values obtained.

The moisture content values after each step were calculated for the control group of specimens, based upon the known calculated oven-dry weight of the specimens and weight data after all steps of the six cycle exposures. The average moisture content of each of the 20 control specimens is given in Table 4. The changes in moisture content from step to step in a cycle, and from cycle to cycle, are indicated. The moisture regain in cycle 2 after step 2 was not so great as in cycle 1 and subsequent cycles, because the wet-bulb temperature in the drying chamber was not maintained at the desired level. After cycle 2 was completed, the wet-bulb control was readjusted to maintain the desired 90 percent relative humidity.

No attempt has been made to show similar moisture content changes for the treated specimens. With a changing tare weight of preservative, the moisture content estimates at any time during the cycle exposure tests would be subject to errors. Moisture content changes of the untreated controls indicate the maximum and minimum values that the treated specimens might have attained. It is recognized, however, that the preservatives may have retarded moisture changes in both the sorption and desorption phases of the cyclic exposure test.

Preservative Treatment: The cut specimens were stored in a humidity room maintained at 80° F. and 90 percent relative humidity until they were needed for the preservative treatments. After the preservative treatments, the specimens were stored in the Laboratory where they were allowed to drain.

After exploratory treatments of representative red oak specimens to determine proper initial air pressures, the test specimens were treated by the empty cell process, with the preservative temperature varying from 185° to 210° F., a treating pressure of 175 pounds per square inch for 3 hours, and a final vacuum equivalent to 25 to 27 inches of mercury for 30 minutes. There was no initial air pressure

used in the empty cell treatment of pentachlorophenol solution with 101E oil and the treatment 5 with aromatic HB oil. The initial air pressure for the other preservatives was applied for 15 minutes, as follows:

Preservative	Air Pressure P.s.i.
Coal tar creosote (treatment 4)	35
Creosote-coal tar solution (treatment 3)	20
Creosote-petroleum solution (treatment 2)	28
Pentachlorophenol in 24 plus burner oil (treatment 6)	25
Pentachlorophenol in decant oil C (treatment 7)	10

Each specimen was weighed before and after treatment, and the preservative retentions obtained for the individual specimens. Both the creosote and the two creosote solutions were later found to contain considerable moisture. It was necessary therefore to correct the retention values of these specimens to a dry oil basis. Such a correction was unnecessary for the four pentachlorophenol solutions, which were checked and found to contain only from 0.1 to 0.2 percent of moisture.

Cycle Exposure Tests: The cycle exposure tests were started on September 1, 1957, and the six cycles were completed on. April 12, 1958. After each step of the cycle exposure test, the specimens were weighed, and the surface checks were measured and recorded.

Analysis of Results

Moisture Content Changes During Cyclic Exposure Tests: The mean moisture content values of the untreated controls, as given in Table 4, are plotted in Figure 3. The mean values for the various cycles of exposure and the steps of the cycle are as shown in Table 5.

The moisture content increase during step 2 of cycle 2 is not as great as in the other cycles because of the lower equilibrium moisture content condition that prevailed in the drying chamber. The moisture changes that occurred during the last four cycles, however, averaged as follows:

Step 1-water spray-increase 3.72 percent

Step 2—low relative humidity-decrease 7.70 percent

Step 3-high relative humidity-increase 8.67 percent

Step 4-infrared heating-decrease 1.20 percent

Step 5-low relative humidity-decrease 2.87 percent

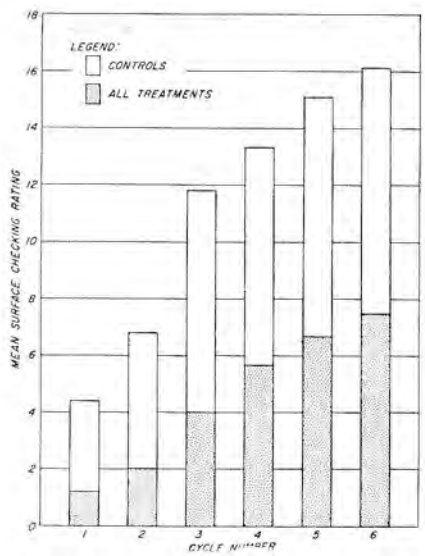

Fig. 4.-Surface checking rating after various cycles.

The low relative humidity exposure condition at a high temperature was effective in creating a moisture loss, and the 2-weeks' exposure to a high relative humidity at a moderate temperature resulted in appreciable moisture regain. Although infrared heating did not result in much overall moisture loss, the surface heating apparently created a very steep moisture gradient. After 6 hours of such exposure, the surface checks were open, and the additional drying at low relative humidity occasionally increased the severity of surface checking over that observed after infrared heating. The moisture changes of the controls during the cycle exposure conditions were sufficiently great to cause checking to develop after one cycle. The mean-moisture-content values show that the final values were decreasing as the cycles were repeated, suggesting that a change in hygroscopicity due to repeated heating was occurring.

Surface-Check Rating After Cycle No. 1: The mean-surface-check ratings for the various treatments after one complete cycle of accelerated weathering were found to be as follows:

Treatment No.	Mean-surface-check rating
1	4.40
2	1.05
3	.10
4	1.10
5	1.95
6	1.20
7	1.35
8	1.75

To determine if significant differences in these means exist, an analysis of variance was computed. The differences between treatment means are significant at the 1 percent level. The least significant mean difference at the 1 percent level is 2.43. The mean for treatment No. 1, the controls, is significantly larger than all the other treatment means. The least significant mean difference at the 5 percent level is 1.83. The treatment mean for treatment No. 3, creosote and coal tar (70-30), is smaller than the mean for treatment No. 5, penta in medium gas oil, and treatment No. 1. No other significant differences between treatment means are indicated.

The difference between the surface-check-rating means of the rough and dressed specimens is not significant. The mean values are 1.64 for the rough specimens and 1.59 for the dressed specimens.

Surface-Check Rating After Cycle No. 2: The mean-surface-check ratings for the various treatments after two complete cycles of accelerated weathering were as follows:

Treatment No.	Mean-surface-check rating
1	6.80
2	1.95
3	.95
4	1.80
5	2.95
6	1.75
7	2.25
8	2.45

The differences between treatment means are significant at the 1 percent level, and the least significant mean difference between treatments at the 1 percent level is 3.20. The mean for treatment No. 1, the controls, is significantly greater than all of the other treatment means. No significant differences between the other treatment means are indicated at the 1 percent level. The least significant difference between means at the 5 percent level is 2.40. None of the treatment means, other than treatment No. 1, is significantly different. After cycle No. 1, the mean for treatment No. 3 is smaller than the mean for treatment No. 5 at the 5 percent level, but after two cycles of accelerated weathering, this difference is no longer indicated.

The difference between the surface-check-rating means of the rough and dressed specimens is not significant. The mean values are 2.64 for the rough specimens and 2.59 for the dressed specimens. It is interesting to note that the increases over the results after cycle No. 1 are exactly the same.

Surface-Check **Rating After Cycle No. 3:** The mean-surface-check ratings for the various treatments after three complete cycles of the acceler-

ated weather exposure conditions were as follows:

Treatment No.	Mean-surface-check rating
1	11.80
2	3.90
3	3.10
4	4.05
5	4.35
6	4.00
7	4.75
8	3.85

The analysis of variance of the data collected after the third cycle exposure test indicated significant differences at the 1 percent level. The least significant difference between any two treatment means at the 1 percent level is 3.98. The mean for treatment No. 1, the controls, remains highly significantly greater than the means for the other treatments. No significant differences between the other treatment means are indicated, as was true after cycle No. 2. The least significant difference between treatment means at the 5 percent level is 2.99. None of the treatment means, except No. 1, are significantly different at the 5 percent level, as also was true after cycle No. 2.

The difference between the surface-check-rating means of the rough and dressed specimens is not significant. The mean values are 5.39 for the rough specimens and 4.56 for the dressed specimens. It is interesting to note that the mean for the dressed specimens through all of the first three cycles of exposure was consistently less than the mean for the rough specimens, although the difference is not great enough to be of statistical significance. The three sets of means are as follows:

Cycle exposure	Mean-surface-check rating: Rough specimens	Mean-surface-check rating: Dressed specimens	Difference
1	1.64	1.59	0.05
2	2.64	2.59	.05
3	5.39	4.56	.83

The difference between the means increases considerably after cycle No. 3 as compared with the results after cycles Nos. 1 and 2.

Surface-Check Rating After Cycle No. 4: The mean-surface-check ratings for the various treatments after four complete cycles of the cycle exposure conditions are as follows:

Treatment No.	Mean-surface-check rating
1	13.15
2	5.65
3	4.90
.4	5.90
5	6.50
6	5.30
7	6.00
8	5.30

The analysis of variance of the data after the fourth cycle indicates significant differences at the 1 percent level. The least significant mean difference between treatments is 4.81. The mean for treatment No. 1, the controls, remains highly significantly greater than the other treatment means. No significant differences between any two of the other treatment means are indicated, as was true after cycles Nos. 2 and 3. The least significant difference between treatment means at the 5 percent level is 3.62. None of the treatment means, except No. 1 are significantly different at this 5 percent level of testing, as was true after cycles Nos. 2 and 3.

The difference between the surface-check-rating means of the rough and dressed specimens is now significant at the 1 percent level. The mean values are 7.58 for the rough specimens and 5.64 for the dressed specimens. The means and differences between the means for the rough and dressed specimens for the four cycles are as follows:

Cycle exposure	Mean-surface-check rating: Rough specimens	Mean-surface-check rating: Dressed specimens	Difference
1	1.64	1.59	0.05
2	2.64	2.59	.05
3	5.39	4.56	.83
4	7.58	5.64	1.94

With repeated cycle exposure testing, the rough specimens after- four cycles surface checked more than did the specimens that were cut out of boards that were surfaced before being kiln dried.

Surface-Check Rating After Cycle No. 5: The mean-surface-check ratings for the various treatments after five complete cycles of accelerated weathering exposure conditions are as follows:

Treatment No.	Mean-surface-check rating
1	15.05
2	7.50
3	5.50
4	6.60
5	7.15
6	6.15
7	6.75
8	6.75

The analysis of variance indicates that the difference between means is significant at the 1 percent level. The least significant mean difference be-

Table 2.-PROPERTIES OF COAL-TAR AND CREOSOTE SOLUTIONS

Property		Coal-tar creosote	Creosote petroleum 50-50 solutions
Specific gravity at 38° C./15.5° C.		1.082	1.0315
Benzol imsol	percent	1.03	0.44
Moisture	percent	6.1	4.9
Coke residue	percent	2.64	-----
Distillation up to:			
210° C.	percent	0	0
235° C.	percent	4.4	1.0
270° C.	percent	30.2	13.4
315° C.	percent	52.5	37.0
355° C.	percent	74.7	56.8
Residue	percent	24.8	43.2
Volatiles	percent	0.5	0
Total		100.0	100.0
Specific gravity fractions at 38° C./15.5° C.			
235° C. to 315° C.		1.0366	0.9995
315° C. to 355° C.		1.1035	1.0275

Table 3.-GREEN MOISTURE CONTENT OF 2- BY 8-INCH PLANK

Kiln run	Moisture content Percent	Average moisture content Percent
1	80.0	
	79.3	
	94.7	
	93.7	
	85.6	
	86.9	
Total	520.2	86.7
2	75.1	
	68.5	
	92.5	
	93.0	
	83.9	
	85.3	
Total	498.3	83.0
3	83.2	
	83.1	
	89.2	
	86.0	
	90.7	
	87.9	
	92.4	
	94.3	
Total	706.8	88.4
Grand total	1,725.3	86.3

tween treatments at the 1 percent level is 4.87. The mean for treatment No. 1 the controls, remains highly significantly greater than the other treatment means. No significant differences between the means of other treatments are indicated. The least significant difference between treatment means at the 5 percent level is 3.67. The treatment mean for No. 1 is greater than all the others, and no difference between the other treatment means is indicated at this 5 percent level of testing.

The difference between the surface-check-rating means of the rough ressed specimens is significant at the 1 percent level. The mean values are 8.61 for the rough specimens and 6.75 for the dressed specimens. The means and differences between the means for the five cycles are as follows:

Surface-Check Rating After Cycle No. 6: The mean-surface-check ratings for the various treatments after six complete cycles of accelerated weathering exposure conditions are as follows:

Cycle exposure	Mean-surface-check rating: Rough specimens	Dressed specimens	Difference
1	1.64	1.59	0.05
2	2.64	2.59	.05
3	5.39	4.56	.83
4	7.58	5.64	1.94
5	8.61	6.75	1.86

The difference between the means after the fifth cycle is somewhat less than was found after the fourth cycle.

The analysis of variance of the surface-checking data obtained after the

Treatment No.	Mean-surface-check rating
1	16.10
2	7.95
3	5.75
4	7.40
5	8.00
6	7.10
7	8.05
8	7.60

sixth cycle of exposure was completed indicates that differences between treatment means are significant at the 1 percent level, as was true after all of the previous cycles. The least significant mean difference at the 1 percent level is 5.05. The mean for treatment No. 1, the control group, is highly significantly greater than the other treatment means, and no other differences are indicated. The least significant mean difference at the 5 percent level is 3.80. The mean for treatment No. 1 is significantly greater than all the other means, and no other significant differences exist at this level of testing. The preservative treatments were all equally effective in reducing the extent of surface checking as compared with the untreated controls. None of the preservative treatments appears to be superior to the others in this respect.

The means for the various preservative treatments have been pooled to provide a comparison with the means for the controls or untreated specimens. The data are plotted in Figure 4. The difference between the mean-surface-check rating for the controls of treatment No. 1 and the pooled mean of the preservative treatments Nos. 2 to 8, inclusive, increases as the number of cycle exposures increases. The exception to increasing differences with additional cycle exposures is found after cycle No. 4. The differences between means for the controls and for the pooled treatments for the various cycles are as follows:

Cycle No.	Mean-surface-check rating: For controls	For all pressure treatments	Difference
1	4.40	1.21	3.19
2	6.80	2.01	4.79
3	11.80	4.00	7.80
4	13.30	5.65	7.65
5	15.05	6.63	8.42
6	16.10	7.41	8.69

The treatment-mean-surface-check ratings for the various preservative treatments are plotted as a bar chart in Figure 5. The means are in order of the array, and the outstanding indication is that treatment No. 3 (creosote-coal tar (70–30)) consistently had the lowest ranking for all cycles. The difference between the surface-check-rating mean for treatment No. 3 and the means for treatment No. 7, the maximum, after the sixth cycle is 2.30. The difference is significant at about the 25 percent level, indicating that in three out of four trials in a similar experiment, treatment No. 3 would have a mean difference as great as 2.30 when compared with the maximum surface-check-rating mean. Although the 25 percent level is not considered as being high enough to justify drawing conclusions of significance, the low value for treatment No. 3 and its consistency for all cycles may be of some practical importance.

To further test the significance of the difference between the mean-surface-check-ratings, an analysis of variance was made involving the data

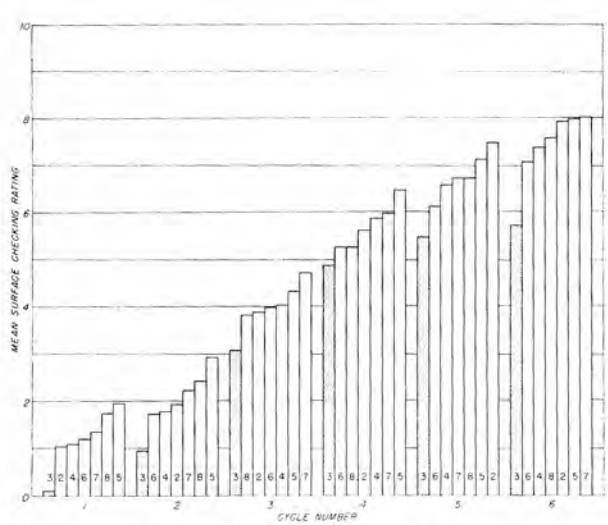

Fig. 5.-Mean surface checking rating for various preservative treatments.

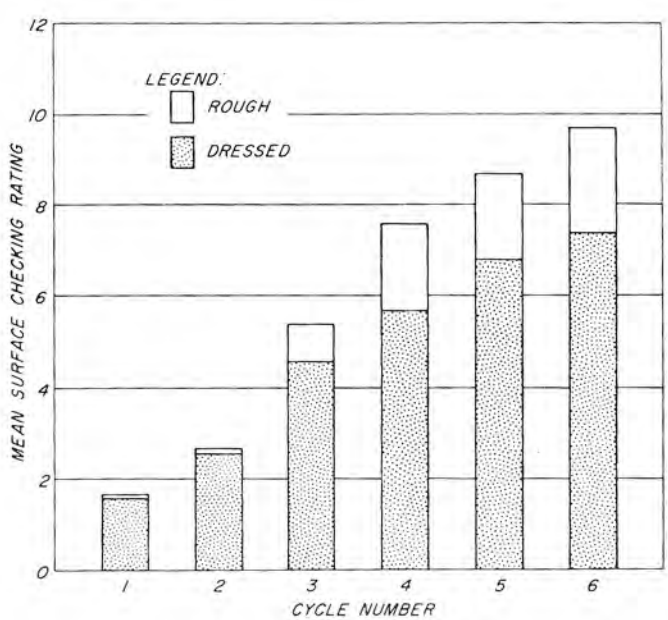

Fig. 6.-Mean surface checking rating after various cycles for rough and dressed specimens.

Table 4.-AVERAGE MOISTURE CONTENT OF "CONTROL" SPECIMENS AFTER VARIOUS STEPS IN SIX CYCLES OF EXPOSURE TEST

At start	After step No. 1	2	3	4	5	At start	After step Noanalyses of 2	3	4	5
CYCLE 1						CYCLE 2				
16.7	22.5	6.5	12.5	11.6	9.2	9.2	13.1	4.6	8.1	7.7	6.4
CYCLE 3						CYCLE 4				
6.5	10.4	4.0	13.2	11.9	9.2	8.1	11.6	3.6	12.6	11.4	8.4
CYCLE 5						CYCLE 6				
8.2	11.6	3.4	12.0	11.1	8.0	7.9	11.3	3.1	11.0	9.6	6.9

of all six cycle exposure tests. Two analyses`of variance were computed. In one, the controls (treatment No. 1) were included, and in the other, they were excluded. Here again, the mean for the controls is highly significantly different than the other treatment means, while the means for the various preservative treatments are not significantly different.

It is concluded that the seven different preservative treatments did not effectively develop different responses, as measured by surface checking, in the accelerated weather exposure conditions of this experiment. In other words, the specimens containing preservatives with pentachlorophenol did not surface check more or less than those containing the creosote or creosote solutions.

The surface-check-rating means for the cycle groups after the sixth cycle are as follows:

Cycle group No.	Mean-surf ace-check rating
1	8.31
2	9.75
3	9.19
4	9.94
5	7.94
6	5.50
7	9.31
8	6.50
9	7.50
10	11.00

An analysis of variance indicates that significant differences are to be found only at the 5 percent level. The least significant difference between these cycle-group means at the 5 percent level is 3.22. The mean value for cycle group No. 10 is the maximum value, and it is significantly greater than the means for cycle groups Nos. 6, 8, and 9.

After six complete cycles of exposure conditions, cycle groups Nos. 6 and 10 have established their positions in the array as consistently being in the first and last positions. Cycle groups Nos. 2 and 4 appear to have established the eighth and ninth positions in the array. It is likely that these four cycle groups were not greatly affected by variations in the cycle exposure conditions; the inherent characteristics of the specimens to surface check are more pronounced. The differences between the means of these groups are because of chance causes of specimen assignment. The changes in ranking of the other cycle-group means from cycle to cycle presumably are because of variations in cycle exposure test conditions which were associated with experimental error.

The combined analysis of variance shows that the differences between the means of cycle groups are significant at the 1 percent level, but that the interaction between cycle groups and cycles is not significant. This indicates that the cycle exposure conditions between cycles did not significantly affect the cycle-group means. In other words, the variations in cycle exposure conditions as between cycles were within experimental error as measured by surface checking effects. The interactions between cycle groups and treatments, however, are significant. This indicates that some treatments influenced the mean-surface-check rating more so than others for some cycle groups. Because of the few specimens representing each treatment in each cycle group, it was previously concluded that chance causes of specimen assignment to cycle groups were probably more 'influential than any other factor. Those treatments causing differences between the means of cycle groups were not determined. The main conclusion that can be drawn is that the necessity to split up the total number of specimens into cycle groups for processing through the accelerated cycle exposure test conditions did not introduce important effects into the experiment.

The analysis of variance after the sixth cycle indicates that the means for surface-check ratings between the rough and dressed specimens are highly significant. The mean values are 9.66 for the rough specimens and 7.32 for the dressed specimens. The means and differences between the means for all six cycles are as follows:

Cycle exposure	Mean-surface-check rating: Rough sped-mens	Dressed sped-mens	Differ-ence
1	1.64	1.59	0.05
2	2.64	2.59	.05
3	5.39	4.56	.83
4	7.58	5.64	1.94
5	8.61	6.75	1.86
6	9.66	7.32	2.34

The differences are significant after the fourth, fifth, and sixth cycles. The data are shown as bar charts in Figure 6. The combined analysis shows that the difference in the two surface conditions is highly significant. The surface-check ratings of the rough' and dressed specimens for the various treatments after the sixth cycle show that the means for the controls are the same, so the differences in surface checking between the treatments are due to the effect of the preservatives. The creosote-containing specimens all show a marked reduction in surface checking for the dressed specimens as compared with the rough specimens. The residual fuel oil with pentachlorophenol resulted in a reverse effect; the rough specimens surface checked slightly less than the dressed specimens. The other pentachlorophenol solutions resulted in a reduction in surface checking for the dressed specimens. Treatment No. 8, heavy cycle oil with pentachlorophenol, compared favorably with the creosote preservatives. The general indication is that treated wood will surface check less under conditions of exposure similar to those of this experiment when it is surfaced before the seasoning and the preservative treatments.

Surface-Check Rating Based on Rough or Dressed Specimens Only: Analysis of surface-check-rating data after each cycle and the combined analysis of the data show that the means differ significantly at the 1 percent level. The controls surface checked more than the treated specimens, while no significant differences were indicated among the means for the treated specimens regardless of the preservative used. Because of the disproportionate distribution of rough and dressed specimens to treatment groups, surface condition may have influenced the general indication that the treatment means, other than the controls, did not significantly vary between themselves. Do the treatment means in each of the two classifications (rough and dressed) have differences of statistical significance? To answer this question an independent analysis of variance was made for the two classifications. The analysis in both cases shows that the controls surface checked more than the treated

specimens and, further, that no significance in mean-surface-check rating exists between the preservative-treated groups.

Interpretation

The purpose of this study was to determine if creosote- and pentachlorophenol-containing preservative solutions reacted differently in their tendency to retard surface checking of oak in an accelerated weathering test. The data plotted in Figure 3, indicate that the cyclic exposure test conditions created desorption and sorption moisture gradients which are believed essential to create surface checking conditions. The treated and untreated specimens were exposed to six cycles of accelerated weathering conditions. The analysis of surface-check-rating data indicates that significant differences in surface checking tendencies between treatment groups are not present. The pentachlorophenol-containing solutions were just as effective as the creosote solutions.

All preservatives effectively reduce surface checking as compared with untreated controls. It is not likely that the preservatives have antishrink properties. Thus the differences in surface checking between the untreated controls and the treated specimens must be accounted for by a retardation of moisture changes. The plot of the surface-check data in Figure 5 suggests that treatment No. 3, creosote-coal tar (70:30 percent), probably is more effective than the other preservative solutions in this respect. The mean-surface-check rating for this treatment group is consistently less than the others after each of the six cycle exposure tests.

To extend the results of this surface-check study to the performance of preservative-treated railroad crossties is not within the scope of this investigation. The inference might be made that railroad crossties treated with preservatives containing pentachlorophenol are not expected to surface check and split any differently than crossties treated with creosote solutions. As crossties are dried before treatment, surface checking has developed, and whether the various preservative treatments influence the extension and penetration of old checks and splits and the development of new checks differently when some are already present cannot be interpreted from the data obtained in this experiment.

An interesting result of this investigation was the establishment that there was less surface checking in the accelerated weathering test among specimens cut from planks which were surfaced before drying than there was among specimens cut from normal sawmill rough-cut plank. If crossties could be seasoned without surface checking before treatment with a preservative, the interpretation is that surfaced ties would surface check and split less in service than rough-sawn ties. The shrinkage and checking characteristics of boxed-heart crossties are much different than flat-sawn side-cut plank, and the application of the results of this research to crosstie seasoning, preservation, and use is questionable. The finding, however, does have applicability in the seasoning of surface-check-prone species and in the seasoning, preservative treatment, and exposure of treated wood in lumber and plank dimensions. Surfacing before seasoning and preservative treatment is believed to be effective in minimizing surface checking in subsequent use exposure conditions. The reduction, although significant in this experiment, might not be of practical importance.

Table 5.-MEAN MOISTURE CONTENT OF CONTROLS (TREATMENT NO. 1)

Cycle No.	Moisture content					
		After steps				
	Start	1	2	3	4	5
	Percent	Percent	Percent	Percent	Percent	Percent
1 - - - - - - - - - - -	16.7	22.5	6.5	12.5	11.6	9.2
2 - - - - - - - - - - -	9.2	13.1	4.6	8.1	7.7	6.4
3 - - - - - - - - - - -	6.5	10.4	4.0	13.2	11.9	9.2
4 - - - - - - - - - - -	8.1	11.6	3.6	12.6	11.4	8.4
5 - - - - - - - - - - -	8.2	11.6	3.4	12.0	11.1	8.0
6 - - - - - - - - - - -	7.9	11.3	3.1	11.0	9.6	6.9

Conclusions

Three major conclusions are drawn from this experiment in accelerated weathering of treated and untreated red oak specimens to determine the effectiveness of preservative solutions in reducing surface checking.

All preservatives included in the experiment effectively reduced the amount of surface checking that occurred in accelerated weathering as compared with untreated controls.

No significant differences were found in the effectiveness of the different preservative solutions used in the experiment to minimize surface checking in the accelerated weathering tests.

Surface-check-free specimens obtained from plank that were planed before drying and preservative treatment, surface checked less in subsequent accelerated weathering than did specimens cut from rough-sawn plank.

Two minor conclusions can also be gained from the experiment.

In a species like red oak, surface checking can be accelerated by an artificial weather exposure condition creating moisture regain and drying gradients.

The surface-check-rating technique used in this study is satisfactory.

Recommendations

The experimental results of this experiment indicate that oils containing pentachlorophenol might be as effective as creosote preservatives in retarding the development of surface checks in a wood like oak when exposed to weathering conditions. The experimental results need to be verified by long-term field tests under use conditions. Because of the costs involved in making such tests with railroad crossties, it is recommended that the accelerated weathering experiment be replicated with fewer preservative solutions and many more specimens. Consideration also needs to be given to the use of a specimen that is boxed heart rather than side cut, and the complication of differences in surface roughness should be avoided. Should the replicated experiment confirm the indications of this experiment, a crosstie placement study should be considered. In the meantime, observations of surface checking and splitting in crossties treated with preservatives containing pentachlorophenol should be intensified to obtain a confirmation of the results of this experiment.

Although the effectiveness of machine surfacing or "blanking" of green wood members on reducing surface checking may be of more importance in seasoning than in preservation, the finding of this experiment needs verification, particularly if checking of treated lumber of dimension sizes is a real problem.

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