Association of American Railroads
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THE EFFECTS OF DRYING METHODOLOGY ON THE PROPERTIES OF OAK CROSSTIES

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13. ABSTRACT

A direct comparison of the effects of three common seasoning methods on wood crosstie strength was conducted. Three crossties were cut per log by a commercial saw mill. Each crosstie was subjected to a different drying method (air seasoning, vapor drying, or, Boulton drying). The crossties were then treated by commercial treatment plants with their processes and were subjected to a battery of mechanical tests. The crossties were then subjected to an artificial, accelerated ageing process. Results show differences in strength of both the new and aged specimens. The air dried crossties were superior to the artificially dried crossties in most respects.

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EXECUTIVE SUMMARY

Artificial seasoning of wooden crossties is a viable and extensively used alternative to the more common practice of air drying. The benefits of such a procedure lie in its reduced drying times which can be measured in hours compared to the many months which are required for air drying. These savings are realized through reduced inventory costs, more accurate and reliable scheduling and a greatly reduced lead time in meeting current demands.

However, the effect that such an accelerated procedure has on the strength properties of crossties, and ultimately, the performance of these crossties has not been sufficiently characterized.

The Association of American Railroads (AAR), initiated a research project to determine the effects of artificial seasoning techniques on the mechanical properties of crossties directly after treatment and also through a simulated accelerated ageing process. The artificial seasoning techniques include both Boulton and vapor drying methods. The mechanical testing criteria used include static bending, compression, surface hardness, and spike resistance tests. There was also a measurement of the amount of checking prevalent after each seasoning technique had been administered and throughout the simulated ageing process.

The results of this study showed that there were significant immediate as well as long term effects of artificial seasoning on the mechanical properties of crossties. Statistical analysis of the results showed that the air dried crossties were superior to the artificially seasoned crossties in most cases prior to accelerated ageing. Throughout the ageing process, the air dried and the Boulton dried crossties proved to be superior in most respects, to the vapor dried

crossties. Face hardness results showed no difference among the three treatment groups.

Although significant differences were shown to exist, no attempt has been made to quantify these effects in terms of economic life cycle costing. This is a necessary step in understanding the true suitability of artificial seasoning, and will be addressed in the near future.

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ACKNOWLEDGEMENTS

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Mr. Randy Wingard, Executive Director, Railway Tie Association

Mr. John Choros, Manager, Track Engineering, Association of American Railroads

1.0 INTRODUCTION

Artificial seasoning of wooden crossties is widely used in the railroad industry. These methods of wood drying offer many advantages to the railroads, including: reduced inventory costs, flexibility in maintenance planning and purchasing due to greatly reduced lead times, and more reliable plant production schedules due to elimination of uncertainty in air drying times.

While artificial seasoning is a valuable tool to the wood treaters and the railroads, its effects on the mechanical properties and, ultimately, the performance of the crosstie have not been characterized. However, two field performance tests have been reported by AAR member railroads. The Baltimore and Ohio Railroad tested air dried and vapor dried oak crossties at Green Spring, West Virginia from 1947 to 1966. The test involved observing (i.e. tracking) the replacement of 800 intermixed air and vapor dried crossties. Under heavy tonnage and poor support conditions, the air dried crossties had a projected average life of 25 years. The vapor dried crossties had a projected average life of 20 years. Thus, the air dried crossties exhibited a 25% longer service life in this situation.[1]*

The second test involved air dried and Boulton dried oak crossties. The test was performed by the Pennsylvania Railroad at Mc Veytown, Pennsylvania from 1945 to 1965. This test involved observing the replacement of 2660 crossties in four consecutive sections of mainline track. The crossties were evenly divided between air dried and Boulton dried. In addition, two types of anti-splitting devices were tested; approximately 70% of both the air and Boulton crossties had "Sharon" irons and 30% had dowels. The results of the test, after 20 years of observation, were: the air dried crossties have a longer average life.[2]

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[*] Numbers in brackets refer to References listed in Section 5.0.

Air Dried, Sharon Iron	19.2 yrs.
Boulton Dried, Sharon Iron	19.2 yrs.
Air Dried Dowelled	22.8 yrs.
Boulton Dried, Dowelled	19.8 yrs.

The Sharon Iron crossties were affected by derailment damage (especially the air dried test section). Because of this, the dowelled crossties offered the best comparison between drying methods. On that basis, the air dried crossties have a 15% longer life than the Boulton dried crossties.

It should be noted that neither of these tests had matched specimens for each treatment (i.e. specimens cut from the same tree). Both tests used local timber cut at the same time from one area for each seasoning method. Some of the difference in performance between the seasoning methods may be due to differences in the original wood or lack of quality control in the (at that time) new and unfamiliar seasoning methods. It is unlikely that these factors account for all of the differences seen between the seasoning methods. But, a scientific experiment encompassing all three methods is required.

In 1990, the Association of American Railroads initiated a research project to characterize the effects of seasoning methods on crosstie mechanical properties. The objectives of the project were:

1) Direct comparison of the mechanical properties of identical crossties seasoned by (one of) three methods: air drying, vapor drying and Boulton drying. The crossties will be tested after treatment (i.e. in new condition).

2) Direct comparison of the performance of the crossties seasoned by three methods under artificial ageing. Specimens will be tested at various (artificial) ages in order to generate strength-age relationships. In this way, the long term effects of seasoning method on crosstie performance may be assessed.

3) To demonstrate the utility of the artificial ageing method as a crosstie performance evaluation tool.

2.0 METHODOLOGY

To accurately determine the effects of seasoning method on crosstie mechanical strength and crosstie performance, one must eliminate (or minimize) the effects of other factors. This test was designed to minimize the other factors, such as: wood material variability, moisture content, creosote treatment, crosstie testing methods, etc.

A total of 30 crossties were used in the tests; 10 were selected for each seasoning method group (air, vapor, and Boulton drying). The 30 crossties were cut from 10 logs which had been selected for their uniformity. The logs were red oaks of the same age and size. They were harvested from the same location.

One of the three crossties cut from each log was placed in each of the three seasoning method groups. The location of the crosstie (i.e. its position) in the log was also considered to be a factor in crosstie strength and performance. All crossties were identified and tagged by log number and position number. Exhibit 1 shows these locations. The crossties were then distributed in the following manner: each group received one crosstie from each log and an equal distribution of crossties from each position in the log in the pattern of selection shown in Exhibit 2.

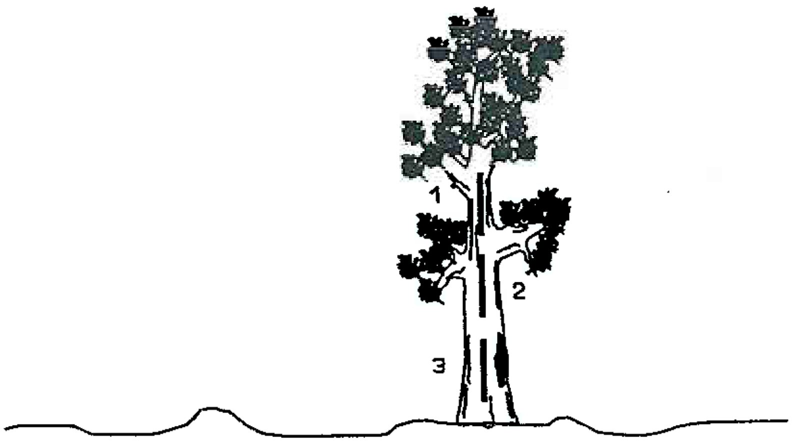

Exhibit 1. Crosstie Numbering Scheme as taken from Tree.

LOG NUMBER	POSITION NUMBER		
	1	2	3
1	AIR	BOULTON	VAPOR
2	VAPOR	AIR	BOULTON
3	BOULTON	VAPOR	AIR
4	AIR	BOULTON	VAPOR
5	VAPOR	AIR	BOULTON
6	BOULTON	VAPOR	AIR
7	AIR	BOULTON	VAPOR
8	VAPOR	AIR	BOULTON
9	BOULTON	VAPOR	AIR
10	AIR	BOULTON	VAPOR

Exhibit 2. Crosstie Distribution Among Test Groups.

All 30 crossties were cut and incised with the same equipment at the same time. The air dry crosstie group was stacked for air drying. The vapor dry crosstie group was shipped to the vapor drying plant and the Boulton dry group was Boulton dried and creosote treated at the crosstie plant adjacent to the sawmill. The vapor dry crossties were dried and creosote treated approximately two weeks after the Boulton dry crossties were treated. The air dry crossties were treated approximately 11 months after the Boulton dry crossties were treated.

For each of the drying processes, ten crossties were dried and creosote pressure treated according to AWPA C6-89.[3]. The air dried crossties were pressure treated with 60/40 oil-creosote solution to an average retention of 7.07 (113 kg/m^3) pounds per cubic foot. The treatment cycle consisted of 3 hr soaking at 200° F (93° C), a 6.5 hr. pressure treatment at 200 psi (1379 kPa), followed by a final vacuum of 26 inches Hg (660 mm) for 1.5 hr.

Vapor drying was carried out for 5 1/2 hr after which, a vacuum of 16-23 inches (406 - 584 mm) Hg was applied for 2 hours. The materials were then pressure treated with 70/30 oil-creosote solution to a retention of 7.48 pcf (120 kg/m^3) using a treatment cycle consisting of a 2.5 hr pressure period at 190 psi (1311 kPa) followed by a 1.5 hr vacuum period at 24 inches Hg (610 mm).

The Boulton drying process consisted of 12 hours of boiling-under-vacuum at 180-190° F (82 - 88° C). The crossties were then treated using the empty cell process with 60/40 oil-creosote solution for 5 hr to a retention of 6.8 pcf (109 kg/m^3) followed by 2 hr of final vacuum at 26 inches Hg (660 mm).

The vapor and Boulton drying processes and preservative impregnation in the study had cycle times of 11.5 hrs and 19 hours, respectively. On the other hand, the air drying process typically 8-12 months. All the crossties were dried and treated by two commercial wood preserving companies.

3.0 RESULTS AND DISCUSSION

After seasoning and treatment, each group of crossties was bundled and shipped to the University of Illinois Wood Science laboratory in Urbana for mechanical testing and artificial accelerated ageing. Initial tests were completed within two months of receipt of the crossties.

Upon receipt of the crossties, they were weighed, measured for length and the moisture contents determined. Exhibit 3 lists these properties as well as the crosstie wood densities calculated from them. The average density of the three groups was different even though the crossties are from the same trees. This was due to the different moisture contents in the crossties.

The low moisture contents of the air dried crossties (compared to the other two groups and the AWPA specification for maximum moisture content[3]) added complications to the test. Wood strength is inversely related to moisture content below the fibre saturation point (about 30 percent for Red Oak). The air dried crossties, with moisture contents ranging from 17 to 25 percent, are clearly in the range where strength properties are sensitive to moisture content. The vapor dried and Boulton dried crossties, with moisture contents ranging from 27 to 58, and 36 to 47 percent respectively, are almost entirely above the range of sensitivity. The wide difference in moisture content between the artificially dried crossties and the air dried crossties makes direct comparison of the effect of seasoning method difficult. The full span bending tests were conducted at the natural (as received) moisture contents. Logistical problems prevented conditioning full size crossties in a moisture chamber.

However, once the full length crossties were tested in bending, they were cut into 18" pieces for the remainder of the testing spectrum. These pieces were then conditioned at 20%

CODE	SIZE (IN.)	MOISTURE CONTENT (%)	WEIGHT (LBS.)	DENSITY (LB/FT^3
1-3-VPR*	7-1/8" X 9-1/16" X 101-7/8"	40	249	65.4
2-1-VPR	7-1/4" X 9-1/4" X 102"	36	270	68.2
3-2-VPR	7-1/4" X 9-1/4" X 102-1/8"	44	270	68.1
4-3-VPR	7-1/4" X 9-1/16" X 102"	37	260	67.0
5-1-VPR	7-1/4" X 9-1/16" X 102"	36	258	66.5
6-2-VPR	7-1/4" X 9-1/4" X 102"	27	262	66.2
7-3-VPR	7-1/4" X 9-1/8" X 102"	58	247	63.3
8-1-VPR	7-5/16" X 9-3/16" X 102-1/4"	40	308	77.5
9-2-VPR	7-1/8" X 9-1/16" X 102-3/16"	40	246	64.4
10-3-VPR	7-1/4" X 9-1/8" X 102-1/16"	45	257	65.8
AVERAGE		40	263	67.2
1-2-BLTN	7-1/16" X 9-1/8" X 102-1/4"	43	247	64.8
2-3-BLTN	7" X 9-1/8" X 101-7/8"	40	254	67.4
3-1-BLTN	7-1/16" X 9-1/4" X 102-3/16"	44	258	66.8
4-2-BLTN	7-1/16" X 9-5/16" X 102"	44	252	65.7
5-3-BLTN	7-1/8" X 9" X 102"	40	246	65.0
6-1-BLTN	7-1/4" X 9-1/8" X 102-1/8"	42	267	68.3
7-2-BLTN	7-1/16" X 9-1/8" X 102-1/16"	45	244	64.1
8-3-BLTN	7" X 9-1/8" X 102-3/8"	36	253	66.9
9-1-BLTN	7-1/8" X 9-3/8" X 102-1/4"	47	255	64.5
10-3-BLTN	7-1/8" X 9" X 102-3/16"	41	253	66.7
AVERAGE		42	253	66.0
1-1-AIR	6-7/8" X 9-1/8" X 102-1/8"	24	225	60.6
2-2-AIR	7-1/16" X 9" X 102-3/16"	18	230	61.1
3-3-AIR	7-1/16" X 9-3/16" X 102-1/16"	24	232	60.5
4-1-AIR	7-1/16" X 9-1/16" X 102-3/16"	25	227	60.0
5-2-AIR	7-1/16" X 9" X 102"	25	220	58.7
6-3-AIR	7-1/8" X 9-3/16" X 102-1/8"	25	226	58.3
7-1-AIR	7-1/16" X 9-1/16" X 102-1/8"	23	220	58.2
8-2-AIR	7" X 9-3/16" X 101-7/8"	17	230	60.6
9-3-AIR	7-1/8" X 8-15/16" X 101-13/16"	21	222	59.4
10-1-AIR	7-1/8" X 8-15/16" X 101-7/16"	21	227	60.0
AVERAGE		22	226	59.8

Exhibit 3. **Red Oak Crosstie Specimens from Seaman Timber Company (Boulton Dry and Air Dry) and Santa Fe Treating Plant (Vapor Dry).**

* 1-3 VPR = (Log Number, Position Number, Seasoning Method).

humidity for a minimum of one week. This conditioning created a similar state of moisture for all of the samples, at least in the top one inch of the specimens. The moisture contents of the specimens below the one inch depth were not determined, and thus, might have some influence on the measurements which followed. After the initial array of measurements, the specimens were subjected to the accelerated ageing process for the first time. Taking into consideration the severity and harshness of this procedure, it is assumed that any differences in moisture content, throughout the specimens, have been equalized by the end of this first cycle. Therefore, any influence of moisture content variation on the properties of the specimens would be considered negligible subsequent to the initialization of the accelerated ageing process.

3.1 NEW CROSSTIE STRENGTH

The crossties were subjected to a battery of tests prior to the inception of the Artificial Ageing Process. These tests formed a baseline indication of the effects of the three drying methods on the strength properties of the crossties immediately following seasoning. The testing included; Static Bending, Compression Modulus perpendicular to the grain, Surface Hardness, and Spike Resistance tests.

3.1.1 Static Bending

The whole crossties (prior to cutting into smaller sections) were subjected to a static bending test (ASTM D-143[4] and D-198[5]).

Two indices are derived from the static bending test; bending modulus of elasticity (M.O.E.) and bending modulus of rupture (M.O.R.). The bending MOE of a specimen is a measure of the specimen's performance in fatigue. The bending MOR is a measure of the specimen's strength capacity. The bending MOE measurements were plotted by position number (refer to Exhibit 1) in order to show that there were no gross variations in material properties within the source stock of the material (i.e. different levels of the tree). Exhibit 4 reveals that the position number of the crossties did not significantly influence the material properties of the crossties. An Analysis of Variance (ANOVA) test, between each pair of treatment groups reveals that there is no statistical difference between the groups (90% confidence). Therefore, one can conclude that the position of the crossties in the log (tree) has no significant effect on the strengths of the crossties or any differences detected between the various groups.

Exhibits 5-8 graphically illustrate the results of the bending MOE measurements. Exhibit 5 shows the bending MOE for each of the crosstie numbers corresponding to the same respective log. The air dried samples have consistently higher moduli than the Boulton and vapor dried crossties. Concurrently, the vapor dried crossties have moduli values which are consistently higher than the Boulton dried crossties. The ANOVA test suggests that all three groups are statistically different (99% confidence). Exhibit 6 plots the bending MOE versus the moisture content of each of the samples from the three drying groups. The higher moduli values of the air dried crossties coincide with their relatively lower moisture contents. In general, when a crosstie dries down within this moisture content range it experiences an increase in strength. This relationship makes strength comparisons difficult between the air dried crossties and the other two groups. However, the moisture contents of the Boulton and vapor dried crossties are similar (Avg. M.C. values of 42 and 40 respectively). The data suggests that the vapor dried crossties are stronger in fatigue than the Boulton dried crossties at this moisture content range.

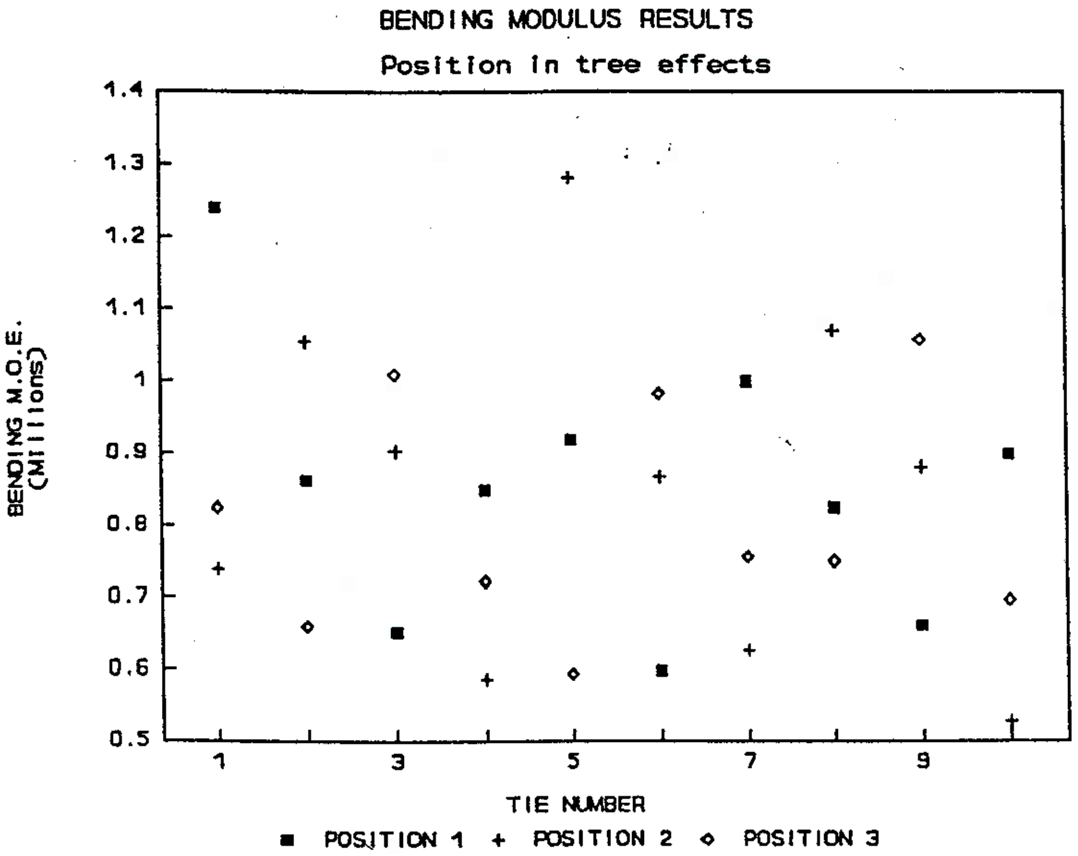

Exhibit 4. Bending M.O.E. vs. Crosstie Number and Crosstie Position in Tree.

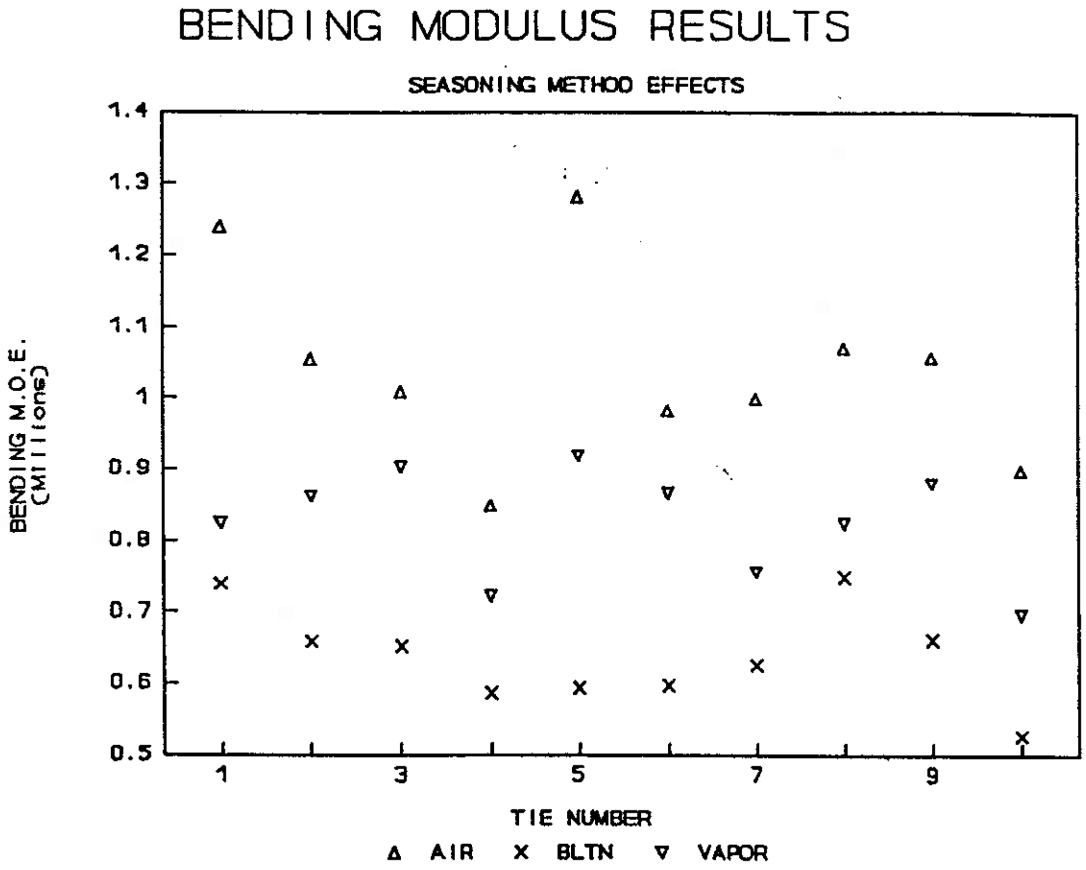

Exhibit 5. Bending M.O.E. by Crosstie Number for Air Dried, Boulton Dried, and Vapor Dried Samples.

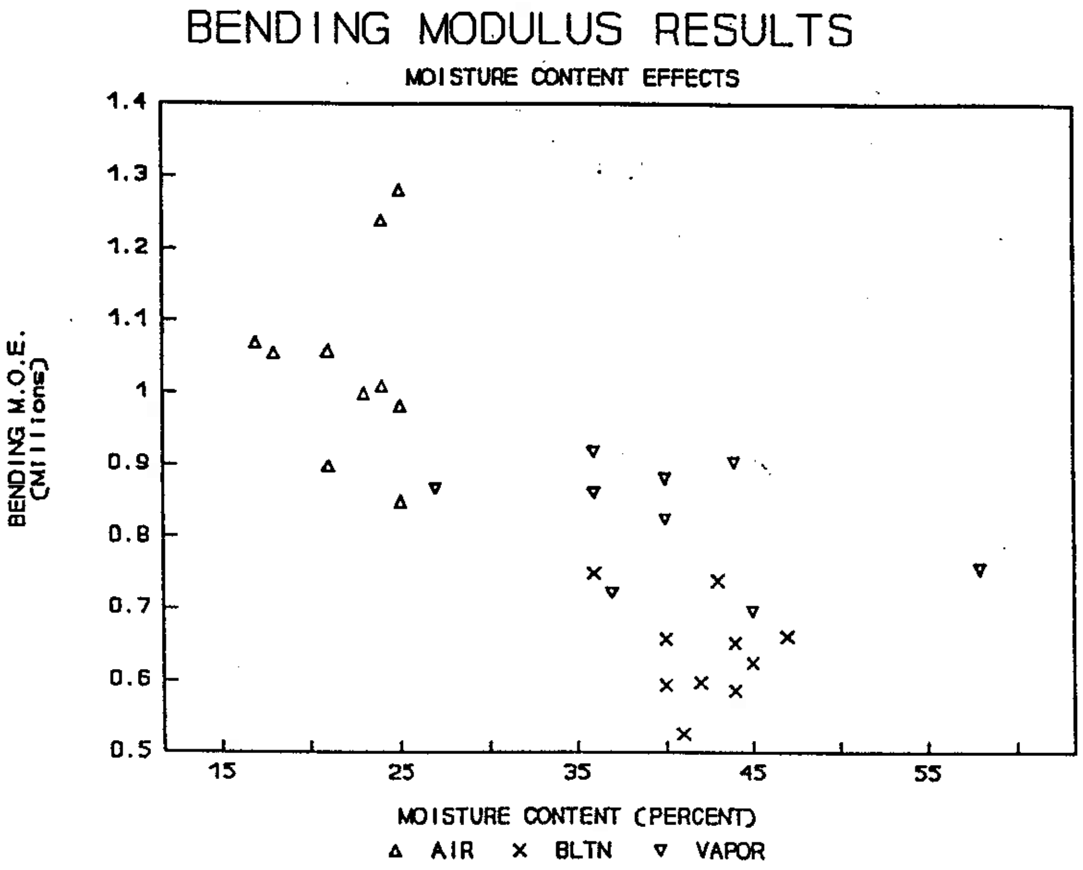

Exhibit 6. **Bending M.O.E. vs. Moisture Content for Air Dried, Boulton Dried, and Vapor Dried Samples.**

Exhibit 7, which plots bending M.O.E. versus specimen density, also supports this conclusion. Exhibit 8 shows the mean value of each of the three methods with their corresponding (±) standard deviations. The data shows that vapor dried crossties of approximately the same specimen density (and moisture content) are stronger in terms of bending modulus than the Boulton dried crossties. The air dried crossties are not directly comparable due to the moisture content difference.

Exhibits 9 & 10 present the bending M.O.R. for the same whole crosstie samples and static bending tests. Exhibit 9 compares the bending M.O.R. versus the moisture content of the samples and Exhibit 10 compares the M.O.R. versus the specimen density at the given moisture contents. The air dried samples again have a higher strength value than the Boulton and vapor dried crossties, but the difference is not as prominent as seen in the bending M.O.E. measurements. Comparisons of the Boulton and vapor dried crossties show virtually no distinct superiority in strength capacity between the two groups. Exhibit 11 shows that there is significant overlap, between the groups means ±1 standard deviation.

Overall, the results of the static bending test suggest that the various drying methodologies may have some effect on crosstie strength. The fatigue related strength of the crossties seems to be more affected than the ultimate strength capacity of the crossties. However, it is this fatigue strength which is more directly applicable to railroad crossties, their load environment, and their failure modes.

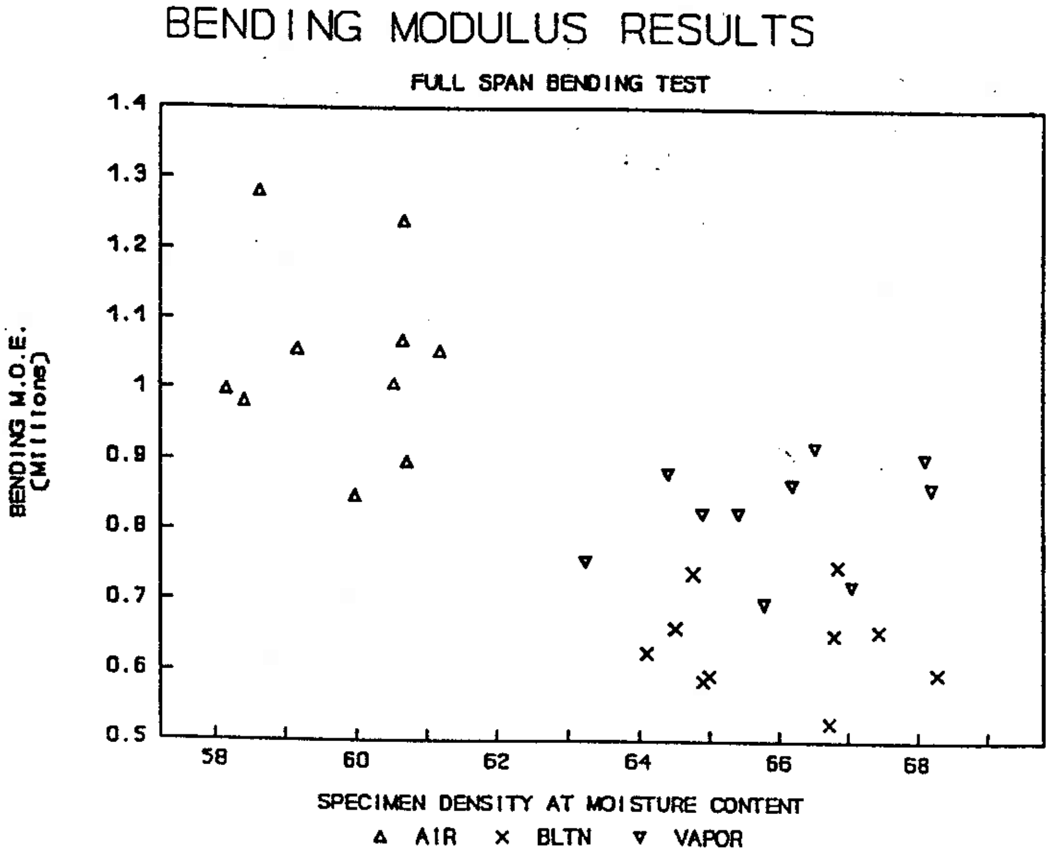

Exhibit 7. **Bending M.O.E. vs. Specimen Density.**

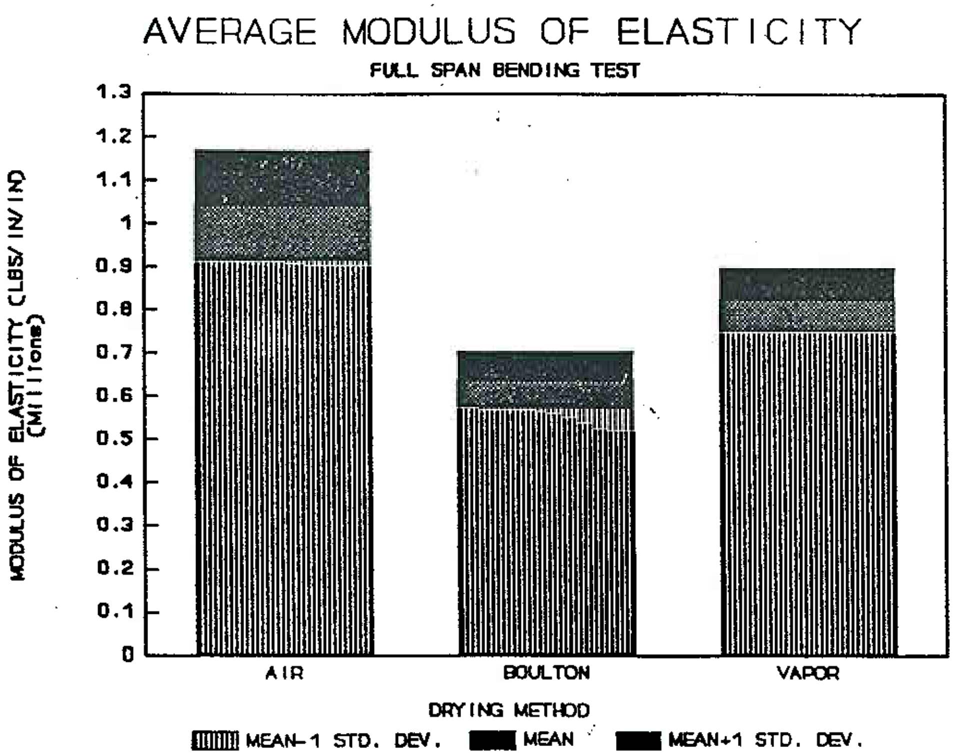

Exhibit 8. Bending M.O.E. Means for each Drying Method.

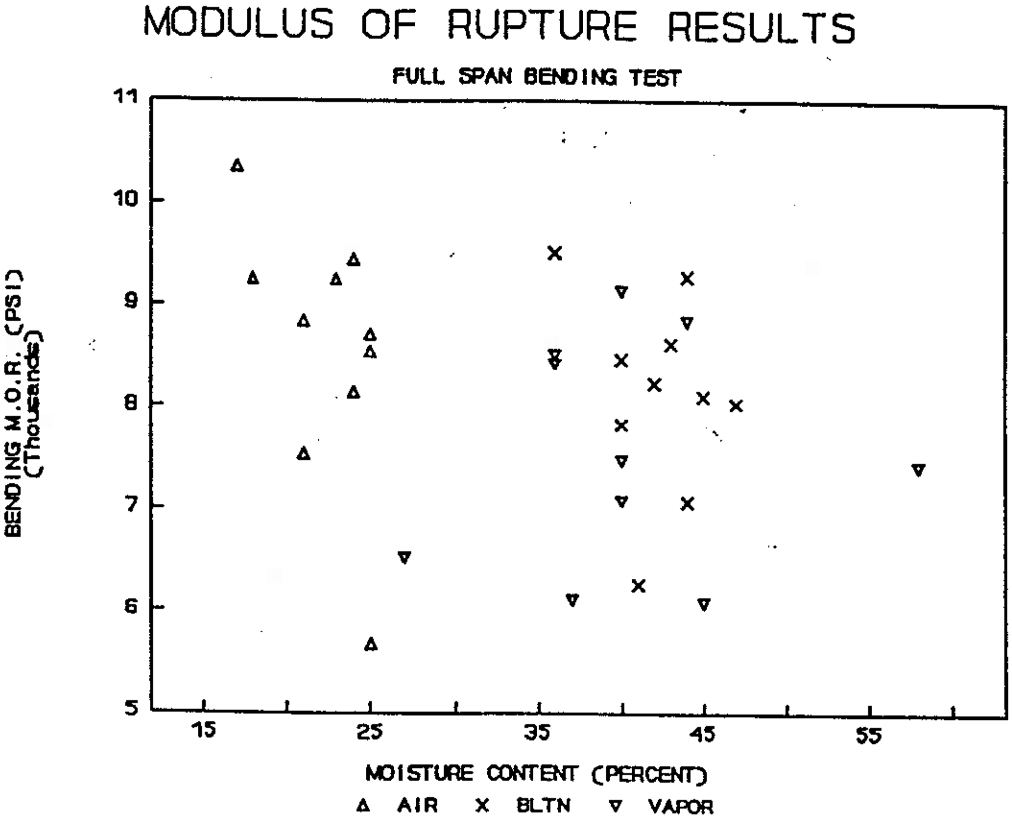

Exhibit 9. Bending M.O.R. vs. Moisture Content.

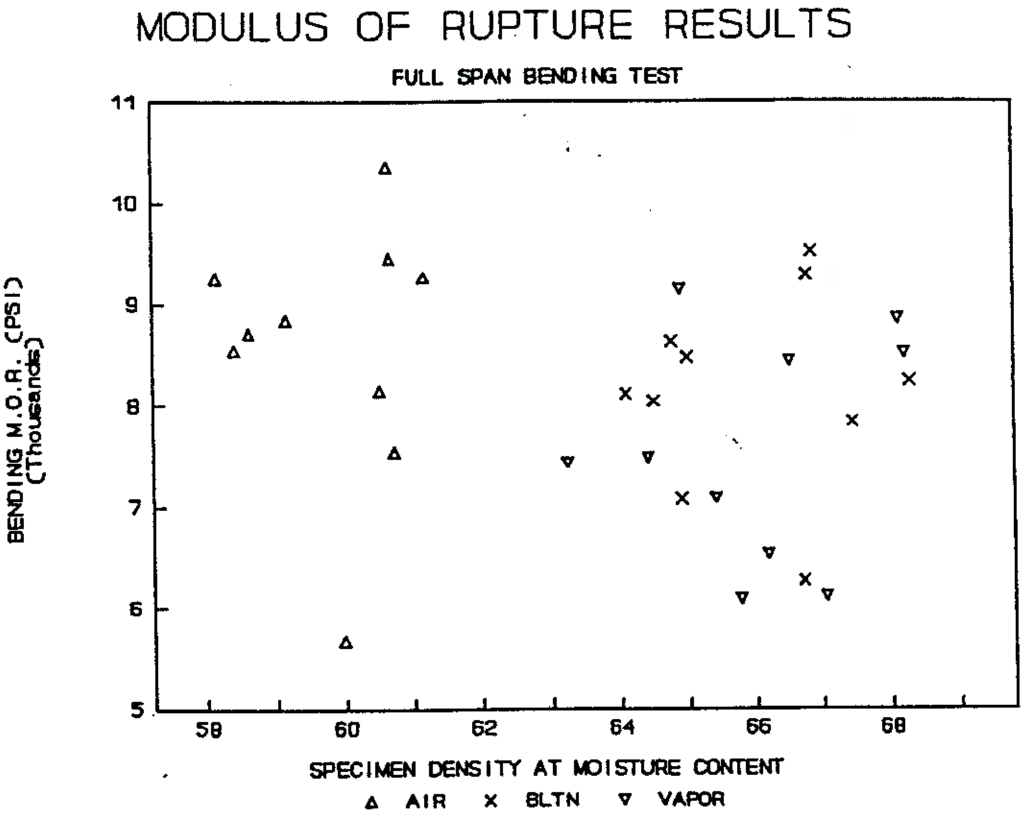

Exhibit 10. **Bending M.O.R. vs. Specimen Density.**

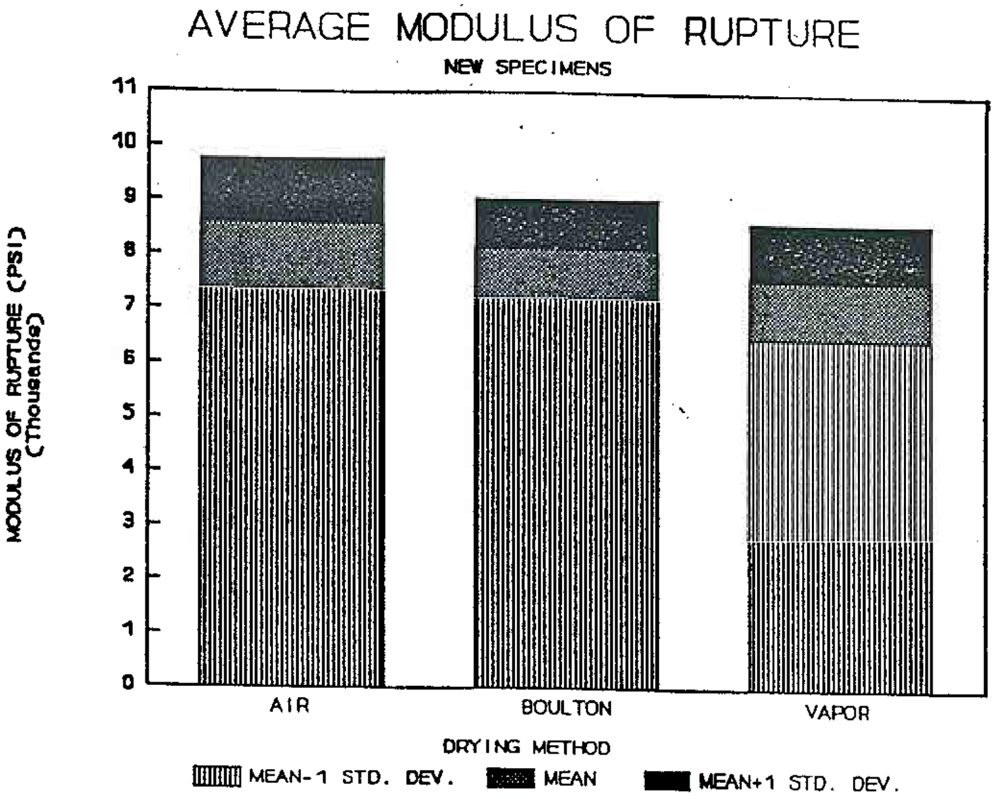

Exhibit 11. Bending M.O.R. Means for each Drying Method.

3.1.2 Compression Modulus

The compression modulus test is a measure of the crossties crushing capacity in the critical crosstie plate area. These tests were performed on the 7" x 9"x 18" specimens which were obtained from the original full length samples. The results are listed in Exhibit 12.

Due to the conditioning which takes place prior to testing, all three drying groups are at approximately the same moisture content (in the top inch) and thus are subject to direct comparisons between the groups.

Exhibit 13 plots the compression modulus values for the three drying groups by crosstie number. Note that there are two crosstie numbers per drying group which do not have modulus values. Only eight out of ten crossties were used, in order to eliminate any specimens which were damaged during the preparation process. Exhibit 14 plots the mean ± 1 standard deviation for each of the three groups. The bar chart shows significant overlap between the air dried and Boulton dried values and also between the Boulton dried and vapor dried values. An analysis of variance was run for the three groups of compression modulus values. The results confirmed that the air dried and vapor dried crossties were significantly different samples. This was based on a 90% confidence level. The analysis showed that no other group pairings were significantly different at this confidence level.

Therefore, it can be shown at a 90% confidence level that the air dried crossties, before any ageing occurs, are approximately 12% stronger in compression than vapor dried crossties at the same moisture content.

3.1.3 Surface Hardness

Surface hardness measurements were administered to the 7" x 9" x 18" specimens. This test defines the face hardness and likely plate cutting resistance of the crossties. Exhibit 15 lists the results of this measurement.

CROSSTIE NO.	AIR DRIED	BOULTON DRIED	VAPOR DRIED
1	38,410	29,325	
2	35,510	34,325	25,315
3	32,280	29,750	26,735
4	35,300	34,445	27,615
5	35,200	32,890	30,375
6	32,570		29,850
7	24,000	24,875	30,125
8		31,985	27,890
9			
10	29,850	23,780	30,110
AVG.	32,520	30,172	**28,500**
STD. DEV	**4041**	**3808**	**1767**

Exhibit 12. Compression Modulus Values (PSI) for new Crosstie Samples.

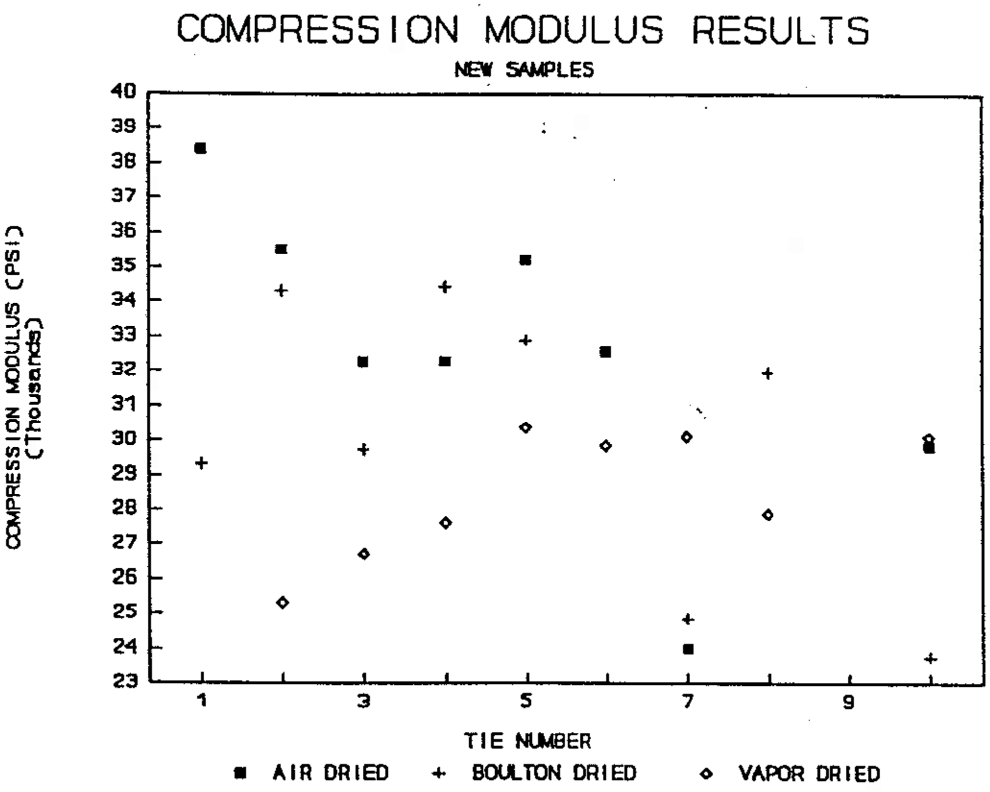

Exhibit 13. **Compression Modulus Values by Crosstie Number.**

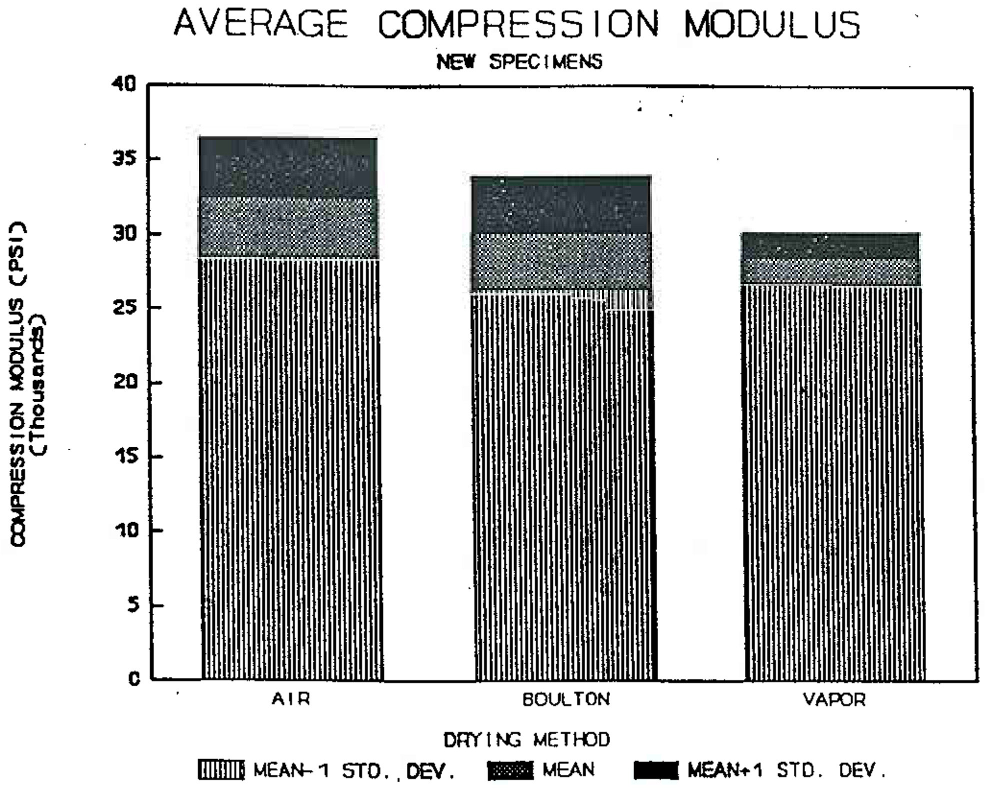

Exhibit 14. Compression **Modulus** Means **for each** Drying **Method.**

CROSSTIE NO.	AIR DRIED	BOULTON DRIED	VAPOR DRIED
1	3175	3680	3720
2	3205	5085	3430
3	3755	3935	3620
4	4285	3185	5500
5	3500	4705	4420
6	3985		4475
7	3300	4800	5360
8		5365	
9			
10	4045	5150	4555
AVG.	**3656**	**4488**	**4385**
STD. DEV.	**395**	**735**	**722**

Exhibit 15. Face Hardness Values (LBS) for new Crosstie Samples.

Exhibit 16 plots the face hardness values for the three drying groups by their respective crosstie numbers. Exhibit 17 plots the means ± 1 standard deviation for each of the drying groups. An analysis of variance between pairings of the treatment groups reveal that none of the groups are significantly different from any of the other groups at a 90% confidence level.

One interesting observation of the results is noted in the distribution of the surface hardness values within each of the treatment groups. Although the Boulton and vapor dried crossties have higher average hardness modulus, the values are widely scattered in comparison to the air dried crossties. This suggests that the air dried crossties are more uniformly treated not only from crosstie to crosstie but also throughout a particular crosstie itself. This uniformity may be an important factor when considering standards and specifications.

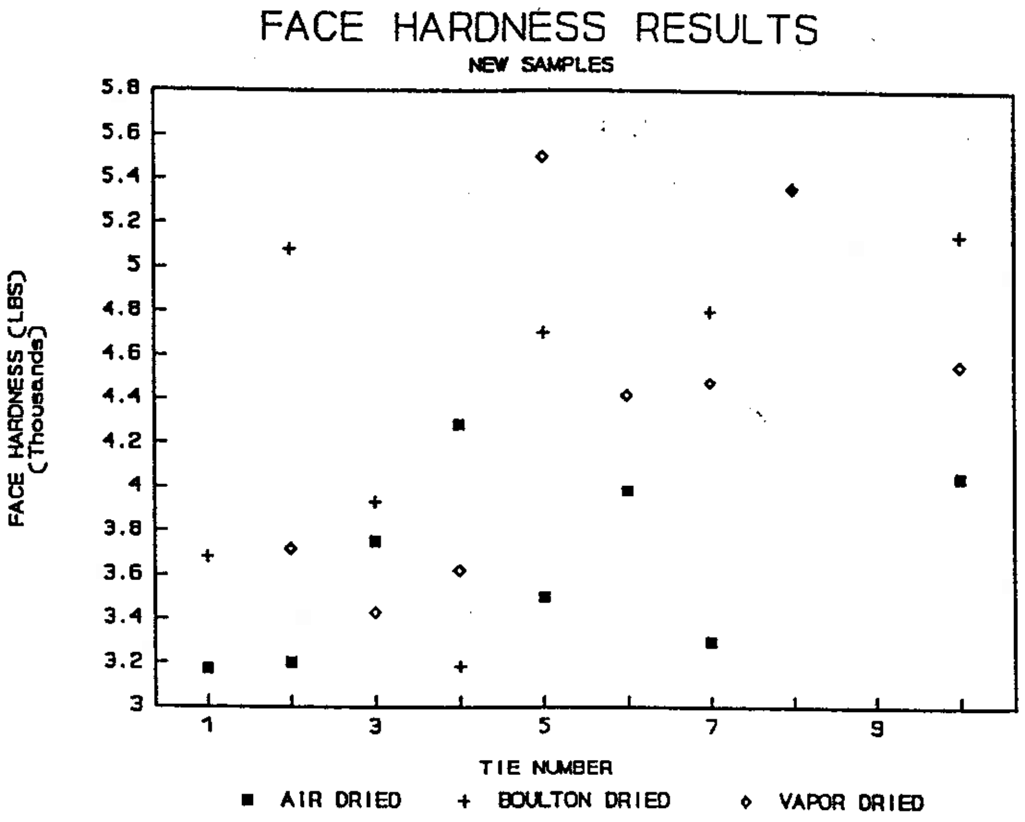

Exhibit 16. **Face Hardness Values by Crosstie Number.**

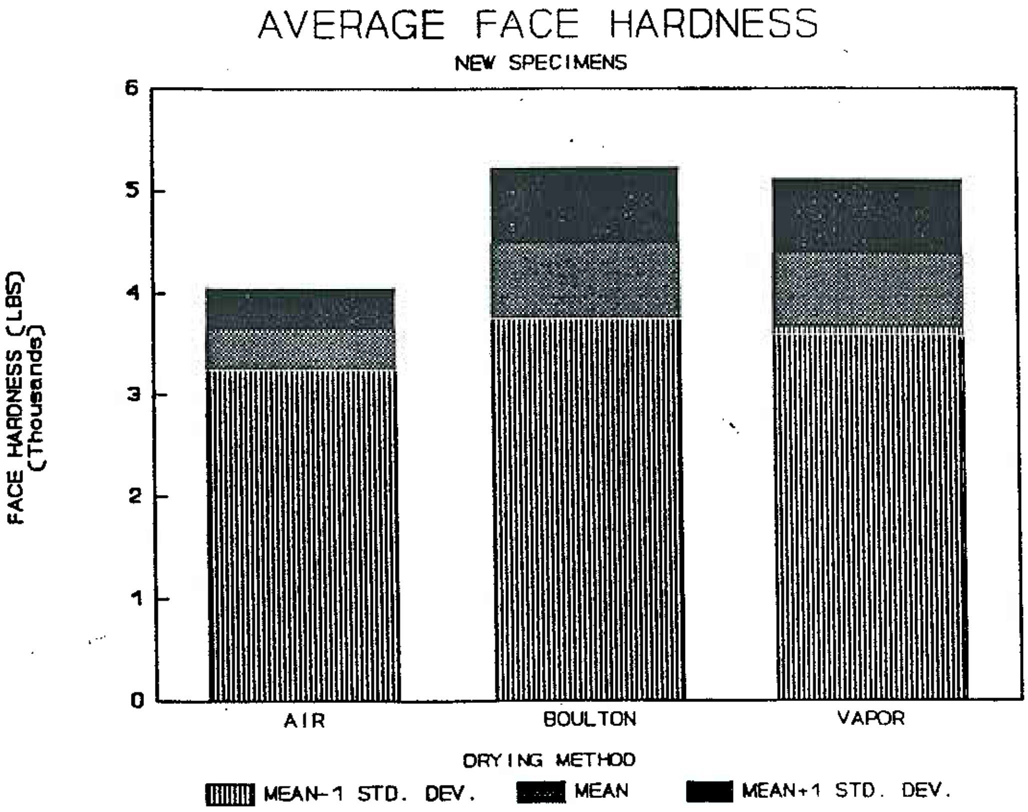

Exhibit 17. Face Hardness Means for each Drying Method.

3.1.4 Spike Resistance Tests

These tests are used to indicate the rail gage and rollover restraint capacity of the crosstie. The spike resistance tests include; spike drive-in and withdrawal, and a lateral resistance test. Exhibit 18 lists the results of these tests.

3.1.4.1 Spike Drive-In

This test measures the force required to drive a spike into the crosstie. The results of this measurement are plotted by crosstie number in Exhibit 19. The average drive-in values for each of the drying groups are plotted along with their respective standard deviations in Exhibit 20. These results reveal that the air dried crossties require a larger drive-in force than the Boulton and vapor dried crossties. An analysis of variance shows that the air dried sample is significantly different (higher) than the Boulton and vapor dried samples which are not significantly different than each other at a 90% confidence level. The average differences between the air dried crossties and the Boulton and vapor dried crossties are 12% and 18% respectively.

DRYING METHOD		SPIKE DRIVE-IN FORCE (LBS.) NEW	DIRECT WITHDRAWAL FORCE (LBS.) NEW	LATERAL RESISTANCE @ (0.2" DISPLACEMENT) FORCE (LBS.) NEW
VAPOR	2-1	7,950	6,280	3,020
	3-2	9,030	9,570	2,275
	4-3	8,970	6,460	2,290
	5-1	10,050	8,380	2,090
	6-2	9,910	7,740	2,485
	7-3	7,290	6,400	2,585
	8-1	6,900	6,230	3,357
	10-3	9,760	8,180	3,170
AVERAGE		**8,735**	**7,405**	**2,660**
BOULTON	1-2	9,020	8,130	2,650
	2-3	9,260	8,430	3,315
	3-1	10,445	7,470	2,690
	4-2	9,630	8,040	2,520
	5-3	9,750	7,890	3,480
	7-2	9,040	8,740	2,820
	8-3	8,700	6,720	2,350
	10-2	8,840	7,480	3,940
AVERAGE		**9,335**	**7,865**	**2,970**
AIR	1-1	9,890	8,690	3,400
	2-2	12,400	8,030	3,250
	3-3	10,305	9,290	4,075
	4-1	11,490	9,430	3,305
	5-2	11,150	8,260	3,225
	6-3	10,310	8,240	3,660
	7-1	9,450	7,890	3,200
	10-1	10,270	8,470	3,580
AVERAGE		**10,660**	**8,538**	**3,460**

Exhibit 18. Effect of Drying Method and Accelerated Ageing on Spike Resistance of Treated Red Oak.

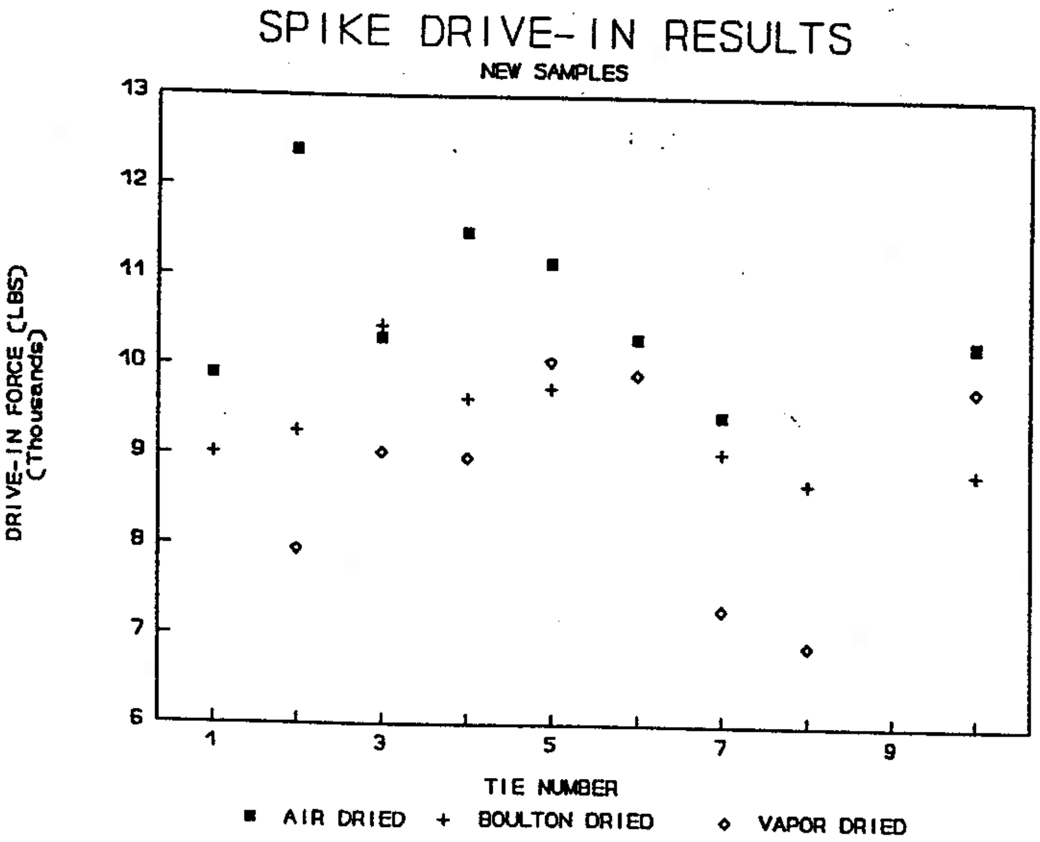

Exhibit 19. Spike Drive-In Force Values by Crosstie Number.

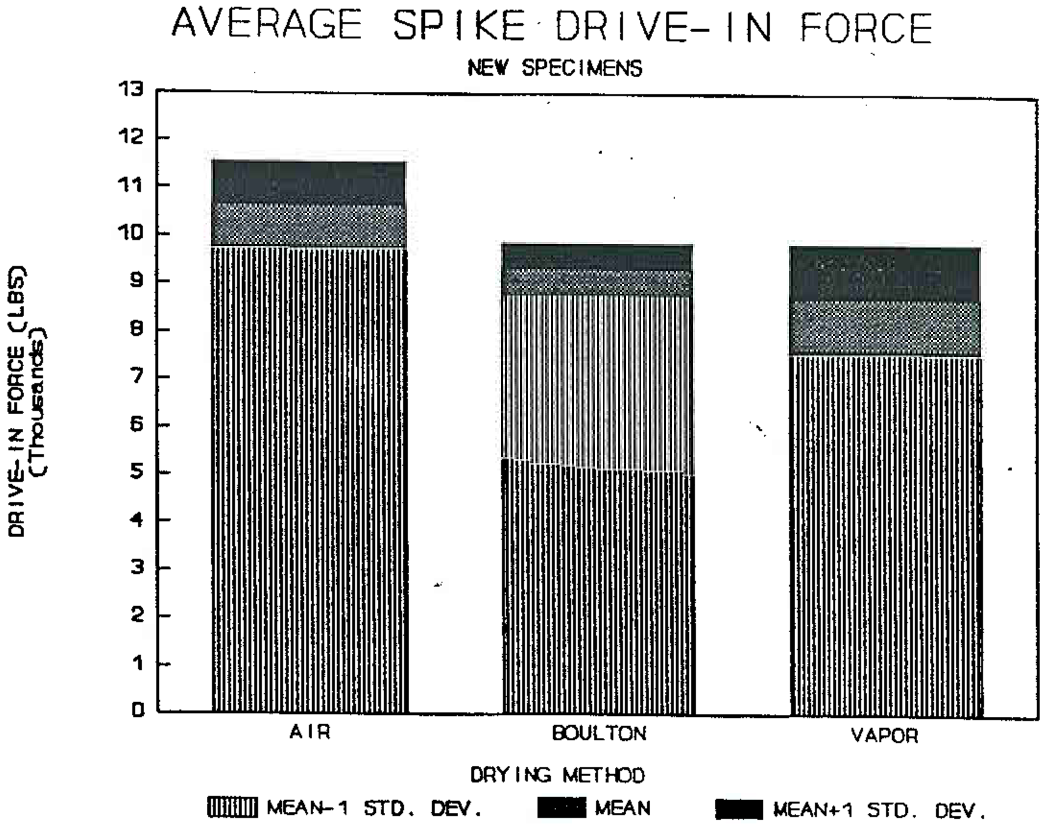

Exhibit 20. Spike Drive-In Force Means for each Drying Method.

3.1.4.2 Spike Withdrawal

The spike withdrawal test is a measure of the crosstie's ability to hold down rail. The withdrawal force is the maximum force required to extract a cut spike from a crosstie in the crosstie plate area.

Exhibit 21 plots the withdrawal force required for each of the three drying groups by their respective crosstie numbers. Exhibit 22 plots the mean value of each of the drying groups along with the standard deviations. Similar to the spike drive-in analysis, the air dried crossties have higher resistance to spike withdrawal than the Boulton and vapor dried crossties. Analysis of variance tests show that this difference is significant at a 90% confidence level. The air dried crossties, on average, require 8% and a 13% higher withdrawal forces than the Boulton and vapor dried crossties respectively.

3.1.4.3 Spike Lateral Resistance

The third spike resistance test is a lateral resistance test which defines the crosstie's gauge holding ability. The "lateral resistance" is defined as the force required to displace the inserted spike 0.2 inches laterally.

Exhibit 23 shows the withdrawal forces for the three drying methods plotted by crosstie number. Again, the air dried crossties perform at higher and more consistent force levels than the Boulton and vapor dried crossties as illustrated in Exhibit 24. An analysis of variance proves this difference to be significant (90% confidence). A 14% and a 23% higher lateral force is required to displace the spike 0.2 inches for the air dried crossties compared to the Boulton and vapor dried crossties respectively.

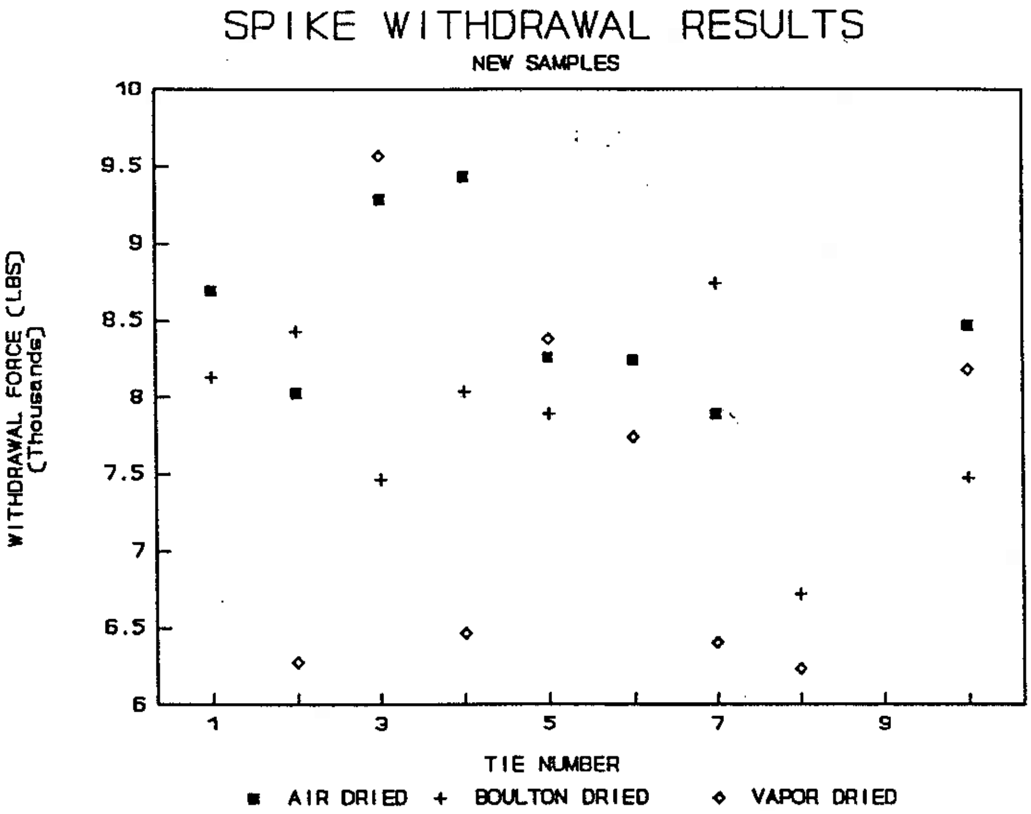

Exhibit 21. **Spike Withdrawal Force Values by Crosstie Number.**

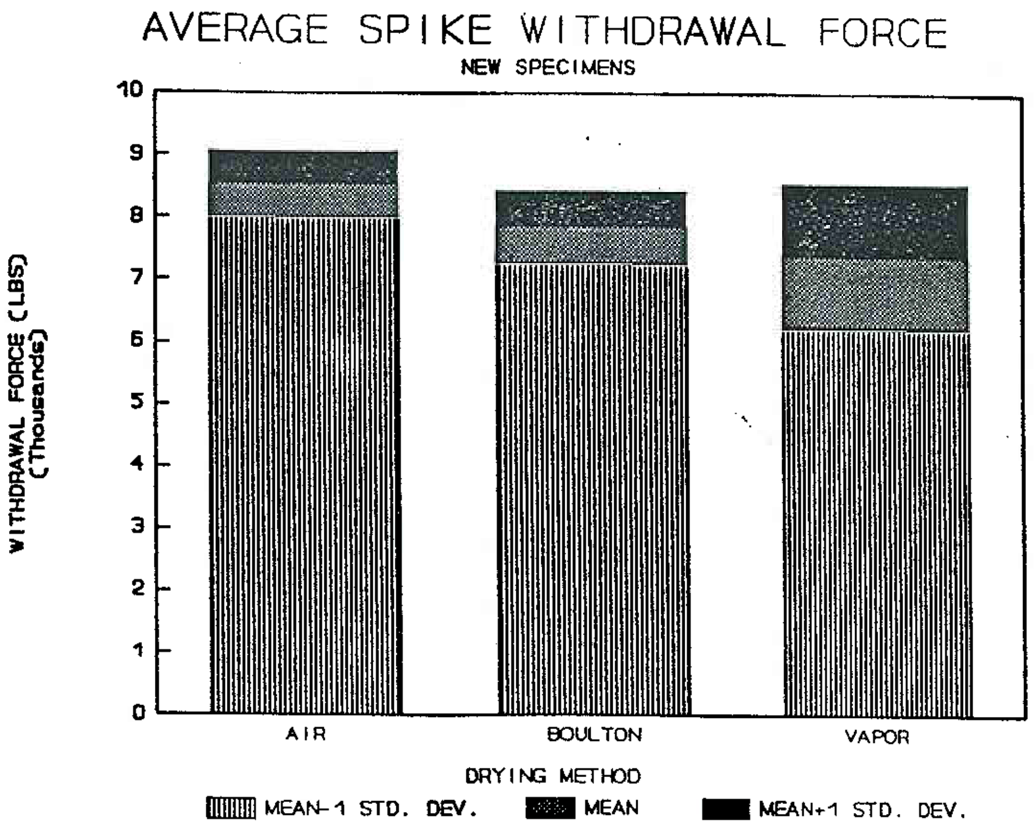

Exhibit 22. Spike Withdrawal Force Means for each Drying Method.

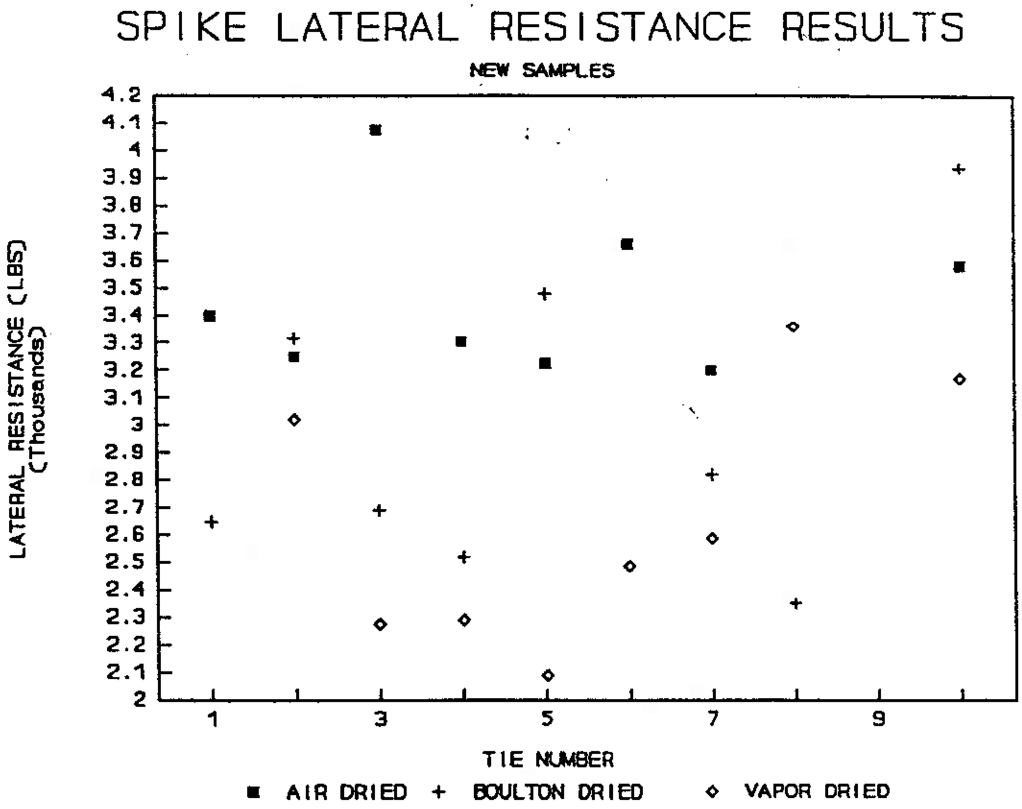

Exhibit 23. **Spike Lateral Resistance Forces by Crosstie Number.**

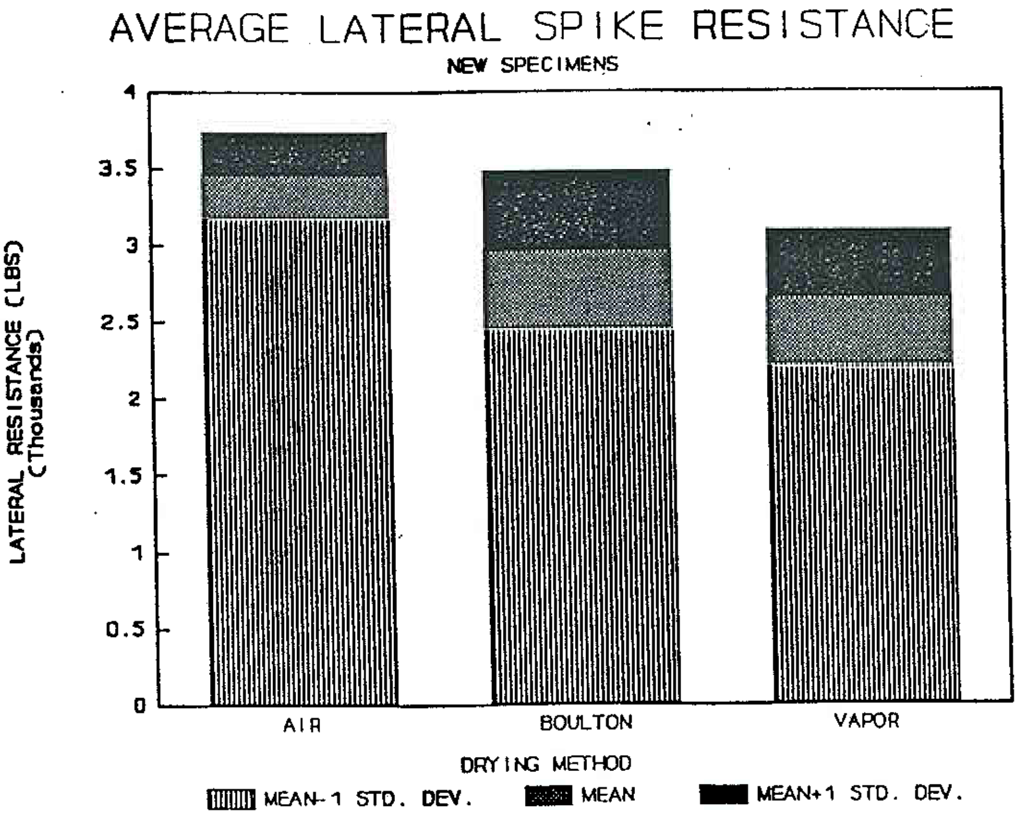

Exhibit 24. Spike Lateral Resistance Means for each Drying Method.

3.2 ARTIFICIALLY AGED CROSSTIE STRENGTH

In addition to the immediate effects of the three drying methods, it was also desired to examine the long term effects of these procedures on the specimens. They were subjected to an accelerated ageing process which artificially, through a series of environmentally controlled operations, simulates the degradation or ageing of the crossties. The artificial ageing process is broken down into cycles, each of which simulates a proportion of the crosstie's life. One artificial ageing cycle consisted of:

a. 30 minutes soaking in water at 25-inch (635 mm) vacuum
b. 30 minutes pressure soaking in water at 170 psi (1172 kPa) pressure
c. 3 hours freezing at 0° F (-18° C)
d. 10.5 hours of steaming at 250° F (121° C) and 15 psi (103 kPa) pressure
e. 9.5 hours of oven drying at 220° F (104° C)
f. 22 hours conditioning at 70° F (21° C) and 90% Relative Humidity

There are 6 cycles required to attain a specimen equal to 20+ years of equivalent service life. The effect of each cycle, in terms of equivalent life, varies with regard to specimen characteristics and also with regard to the index which is being used to characterize the degradation of the samples[6]. Compression Modulus and face hardness tests were performed on the specimens after each cycle of artificial ageing up to 6 cycles. A measure of the growth of checks and splits, defined as the area loss under the crosstie plate area, is also recorded following each of the ageing cycles. The spike resistance tests were also run, but only for the "new crosstie" state, and again after 6 cycles.

3.2.1 Compression Modulus vs. Artificial Ageing

Modulus of Elasticity in compression perpendicular to the grain tests were run prior to and then after each cycle of artificial ageing. The results of Analysis of Variance indicated that the number of cycles and the method of drying had significant effects on M.O.E. in compression perpendicular to the grain. Multiple mean comparisons showed that vapor dried samples had the lowest M.O.E. in compression values for each of the cycles. Between air and Boulton dried samples, there is a slight difference in M.O.E. in compression values following the second and third cycles, with the mean difference being less significant prior to the second and following the fourth cycle. The results of this analysis is summarized in Exhibit 25. This table is a summary of multiple mean comparisons of the three drying groups. Comparisons are made by rows. Means with the same letter in a row are not significantly different using Fisher's LSD (Least Squared Difference) procedure at a confidence level of 95%. Values in parenthesis are actual mean values in psi. Each value is an average of eight crosstie samples. Note from the table that, for new (0 cycle) samples, the average compressive value of the vapor dried crossties was 12.5 percent less than that of air dried crossties. However, ANOVA showed that the difference was not statistically significant at a 95 percent confidence level. Recall though, that this difference was shown to be statistically significant at a 90 percent confidence level earlier in this report (Section 3.1.2).

The apparent long-term superiority of the Boulton and air drying methods over vapor drying can be seen by regressing the logarithm of M.O.E. in compression values against the number of cycles (Exhibit 26). Thus, the resulting regression models have the form Log Y = K - bx where Y is the M.O.E. in compression perpendicular to the grain value, K is the regression intercept, and x is the number of cycles. Vapor drying has a lower M.O.E. in compression value at the start of weathering and exhibited the steepest decline with continued ageing compared to the other drying methods. At the end of the sixth cycle, M.O.E. in compression perpendicular to the grain of vapor dried crossties was reduced to about 30.6 percent of the

CYCLE	VAPOR	BOULTON	AIR
0	A (28502)	A (30172)[2]	A (32515)
1	B (19522)	A (23011)	A (24852)
2	B (14881)	A (18661)	AB (16931)
3	B (11507)	A (15056)	AB (14545)
4	B (9302)	A (13634)	A (12618)
5	B (8175)	A (12334)	A (11621)
6	B (6892)	A (10793)	A (9924)

[1] Means with the same letter in a row are not significantly different using Fisher's LSD procedure at alpha = 0.05. Example: at Cycle 4, Vapor is significantly different from Boulton and air. Boulton and air are statistically the same.

[2] Values in parentheses are actual mean values in psi. Each value is an average of ten crosstie samples.

Exhibit 25. Multiple Comparison of M.O.E. in Compression Perpendicular to the Grain Means of Artificially Aged Crossties from Three Drying Methods. Means Comparisons are by Rows.[1]

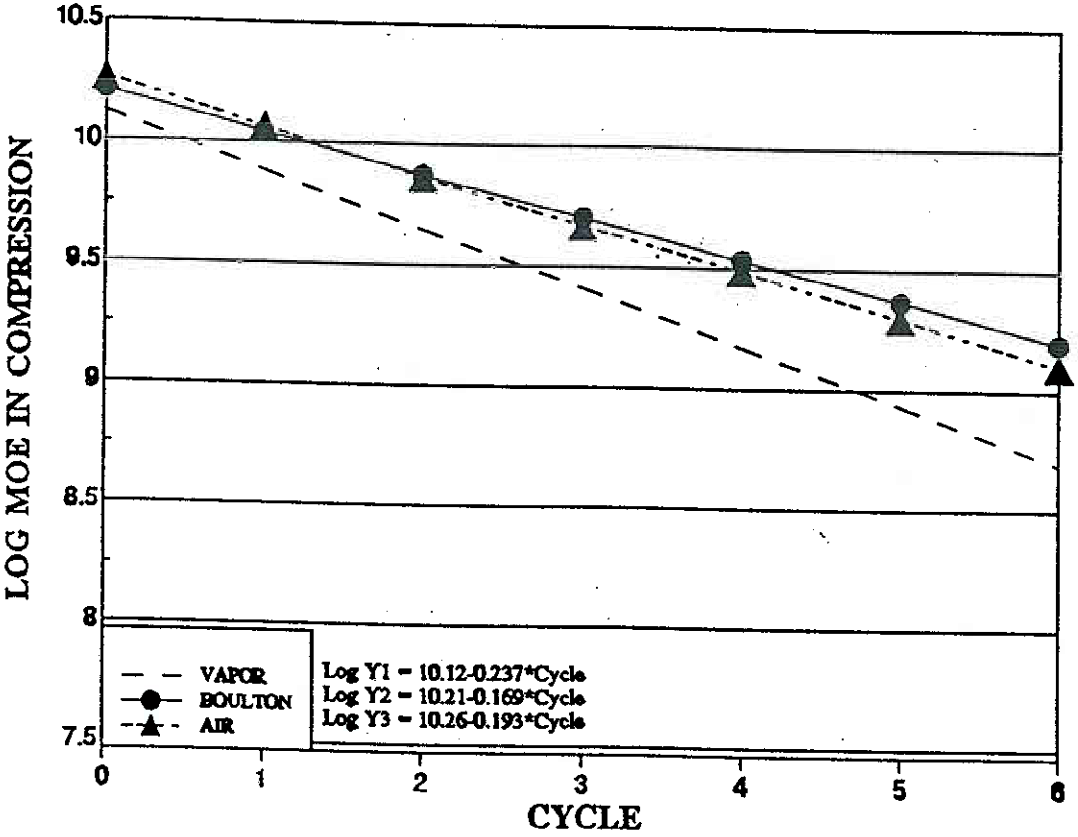

Exhibit 26. Loglinear M.O.E. in Compression Perpendicular to the Grain of Vapor, Air, and Boulton Dried Crossties.

average air dry MOE value after six cycles of accelerated ageing.

Exhibit 27 presents the effect of artificial ageing (number of cycles) for each individual drying method. Mean comparisons are made by columns. The same letters in a given column shows that the difference between the mean values is not statistically significant at a 95 percent confidence level. The table shows that there is rapid decrease in compression modulus through the first few cycles (depicted as different letters) and then a decrease in the rate of change throughout the latter cycles (depicted by a repetition of letters).

3.2.2 Face Hardness vs. Artificial Ageing

Results of ANOVA showed that surface hardness property was not significantly affected by the method of drying. Multiple mean comparisons showed that within each cycle, the surface hardness means of crossties resulting from the three drying methods were similar. No significant differences were found between the intercepts and slopes of the loglinear lines for face hardness values (Exhibit 28). However, hardness values for each drying method deteriorated as the number of cycles increased. Vapor drying had the highest initial hardness values but the lowest after six cycles. Once again, the rate of hardness decrease was more rapid during the first three cycles (Exhibit 29). The results showed that drying method does not affect face hardness of crossties within the six cycle test period although ageing does reduce hardness.

CYCLE	VAPOR	BOULTON	AIR
0	A	A	A
1	B	B	B
2	C	C	C
3	D	D	CD
4	DE	DE	DE
5	E	DE	E
6	E	E	E

[1] Means with the same letter in a column are not significantly different using Fisher's LSD procedure at alpha = 0.05.

Exhibit 27. Multiple Comparison of M.O.E. in Compression Perpendicular to the Grain Means of Crossties at Various Cycles and Drying Methods. Means Comparisons are by Columns.[1]

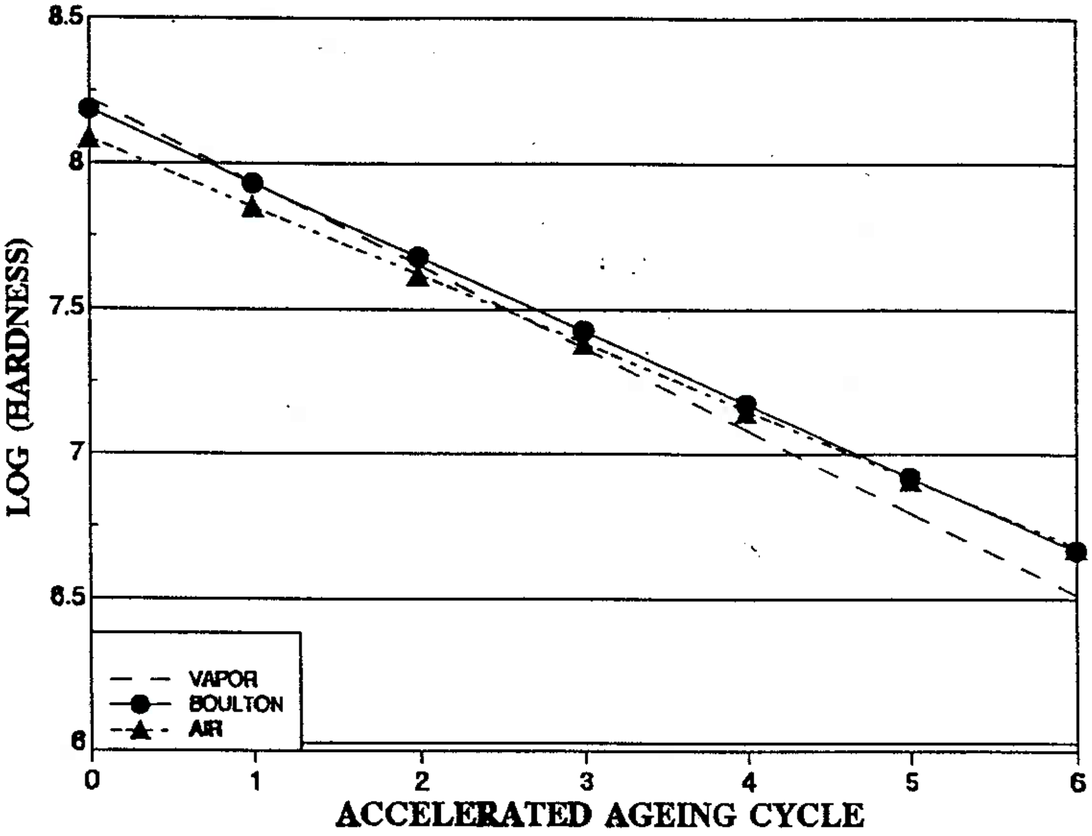

Exhibit 28. Loglinear Face Hardness Values of Crossties from Three Drying Methods.

CYCLE	VAPOR	BOULTON	AIR
0	A (4385)[2]	A (4488)	A (3656)
1	B (2714)	B (24861)	B (2726)
2	C (1991)	C (1991)	C (1817)
3	DC (1510)	DC (1546)	C (1632)
4	E (1993)	E (1433)	CD (1307)
5	E (960)	EF (1032)	D (992)
6	E (758)	F (878)	D (929)

[1] Means with the same letter in a column are not significantly different using Fisher's LSD procedure at alpha = 0.05.

[2] Values in parentheses are actual means values in pounds. Each value is an average of ten crosstie samples.

Exhibit 29. Multiple Comparison of Hardness Cycle Means for each of the Drying Methods. Means Comparisons are by Columns.[1]

3.2.3 Spike Resistance Tests vs. Artificial Ageing

The spike resistance tests include a drive-in test, a spike withdrawal test, and a spike lateral resistance test. Due to the destructive nature of these tests, they were administered only for the "new crosstie" condition and after 6 cycles of artificial ageing.

3.2.3.1 Spike Drive-In Force vs. Artificial Ageing

The spike drive-in force of crossties was sensitive to difference in drying methods. Before artificial ageing, air dried crossties had a higher drive-in force than those from the other drying methods, while there was no significant difference in drive-in force of crossties dried using Boulton and vapor drying. After 6 cycles, crossties dried with the Boulton process showed higher drive-in force compared to those dried with the other processes; however, the results were not statistically different. There were drastic reductions in drive-in force between the two "age" groups for all of the crossties dried in different drying methods. The average reductions in spike drive-in force after artificial ageing for 6 cycles relative to the new condition were: 60.4% for vapor dried crosstie, 54.2% for Boulton dried crossties, and 63.0% for air dried crossties (Exhibit 30).

3.2.3.2 Direct Withdrawal Force vs. Artificial Ageing

The spike withdrawal loads of crossties prior to accelerated ageing were found to be sensitive to drying methods at a 90% confidence level. The air dried crossties exhibited higher withdrawal forces than the Boulton and vapor dried crossties. There were significant reductions in direct withdrawal loads for all crossties by the sixth cycle. After six cycles, the air and Boulton dried crossties exhibited significantly higher withdrawal loads compared to vapor dried crossties. The average reductions on direct withdrawal loads after artificial ageing for 6 cycles relative to the new condition were as follows: 86.3% for vapor dried crossties, 80.9% for Boulton dried crossties, and 77.6% for air dried crossties (Exhibit 31).

3.2.3.3 Lateral Resistance vs. Artificial Ageing

The drying methods resulted in significant differences in spike lateral resistance of crossties even before they were subjected to the artificial ageing process. Air dried crossties exhibited higher lateral resistance than vapor and Boulton dried crossties and comparable trend was noted for crossties tested after six cycles of artificial ageing. There was significant reduction in lateral load resistance between the two age conditions. The average percent reduction were as follows: 67.7% for vapor dried crossties, 60.1% for Boulton dried crossties, and 51.4% for air dried crossties (Exhibit 32).

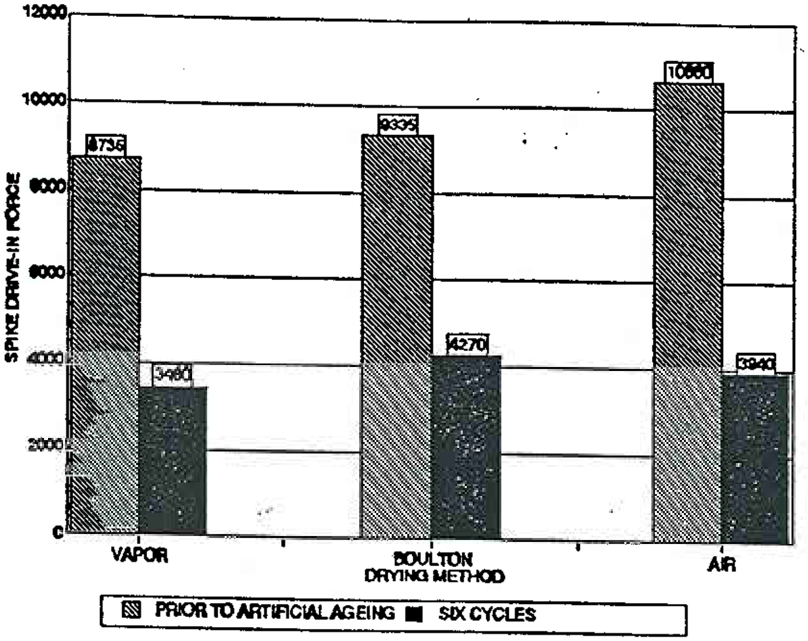

Exhibit 30. Spike Drive-In Force of Air, Vapor, or Boulton Dried Crossties.

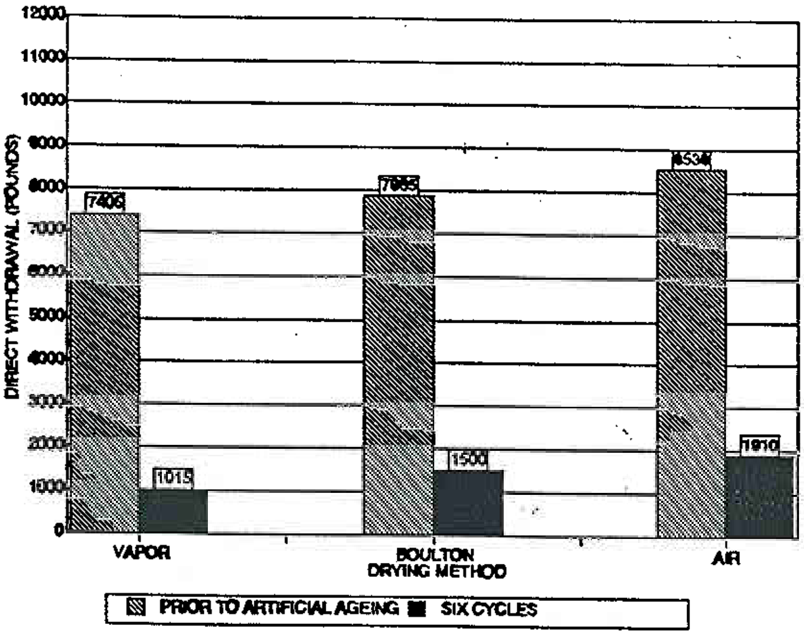

Exhibit 31. Direct Spike Withdrawal Loads of Air, Vapor, or Boulton Dried Crossties.

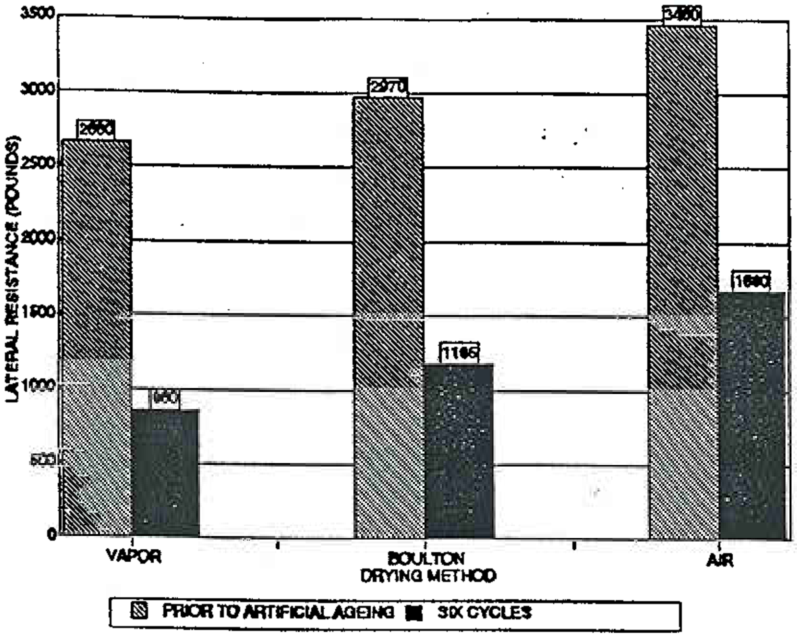

Exhibit 32. **Lateral Spike Resistance Loads of Air, Vapor, or Boulton Dried Crossties.**

3.2.4 Area Loss vs. Artificial Ageing

Surface area loss was calculated from the differences in measured (top) surface area from one ageing cycle to the next. Surface area was measured by subtracting the area of checks and splits from the total surface area (length x width).

There was no conclusive evidence (at 95% confidence level) that the drying methods affected the amount of surface area loss among artificially-aged crossties. Pairwise comparisons showed that the means of percent surface area loss were different only at the first and sixth cycle. From second to fifth cycle of artificial ageing, all the means were statistically similar. Initially, air drying caused the most number of checks and splits in crossties; however, vapor dried crossties developed significant amounts of checks and splits after the sixth cycle, compared to air dried crossties (Exhibits 33 -34).

Significant increase in surface area loss was noted as the number of cycles increased, regardless of the drying method. Results of analysis of variance showed that artificial ageing had a more significant effect on the amount of checks and splits in crossties, than the method of drying.

In contrast to the results of ANOVA and pairwise comparisons, the smoothed lines of the data seem to reflect differences among the drying methods. as shown in Exhibit 35. The lines were developed by regressing the percent surface area loss against number of cycles. Since measurements started at cycle 1 and with the premise that there is not initial fiber separation, we used a regression model with a constant equal to zero. The model therefore, has the form $Y = bX$ where Y is the percent surface area loss, X is the cycle number, and b is the slope of regression line or rate of loss in surface area. This methodology normalizes the data prior to ageing, therefore only taking into account the damage induced by the artificial ageing process. All the regression models were statistically significant. Vapor drying had the highest regression coefficient, denoting a more rapid rate of fiber separation.

CYCLE	VAPOR	BOULTON	AIR
1	AB (0.9)[2]	B (0.1)	A (1.4)
2	A (2.0)	A (1.2)	A (2.2)
3	A (2.7)	A (1.9)	A (2.6)
4	A (3.7)	A (2.6)	A (3.3)
5	A (5.1)	A (3.6)	A (3.9)
6	A (6.7)	AB (4.6)	B (4.4)

[1] Means with the same letter in a column are not significantly different using Fisher's LSD procedure at alpha = 0.05.

[2] Values in parentheses are actual means values in pounds. Each value is an average of ten crosstie samples.

Exhibit 33. Multiple Mean Comparisons of Percent Surface Area Loss due to Differences in Drying Methods. Means Comparisons are by Rows[1]

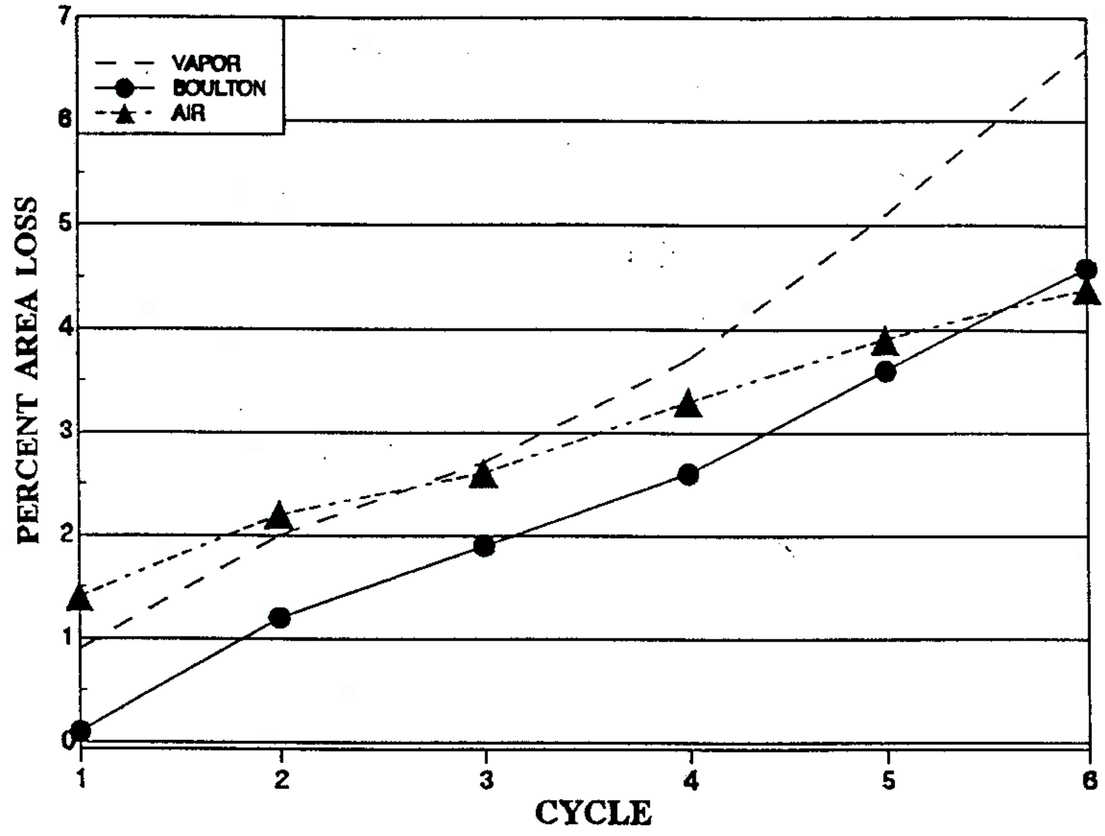

Exhibit 34. Average Percent Surface Area Loss of Artificially Aged Crossties from Three Drying Methods.

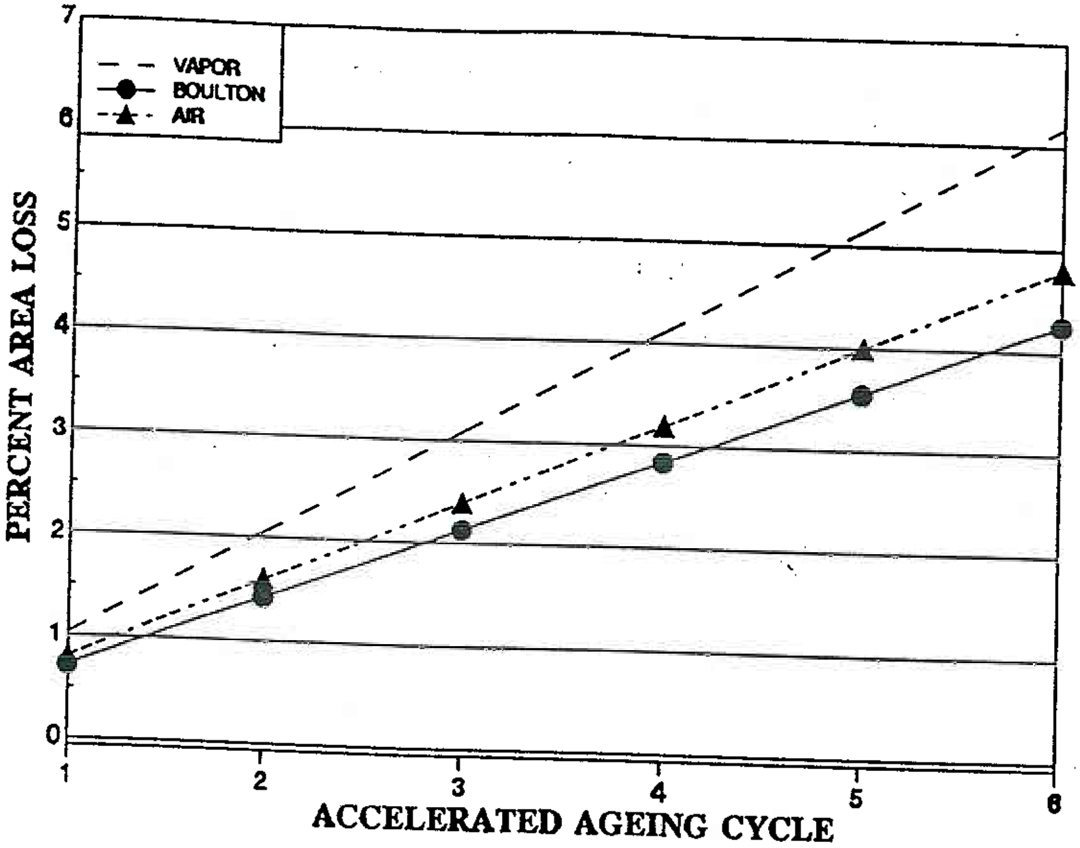

Exhibit 35. Linear Representation of Percent Surface Area Loss of Crossties from Three Drying Methods.

4.0 SUMMARY AND CONCLUSIONS

This study has centered entirely on the effects of three drying methods; air drying, Boulton drying, and vapor drying, on the properties of new and artificially aged crossties. Traditional justification on the choice of drying methods primarily emphasized the economics of drying and crosstie inventory costs. The results presented in this study suggest that the immediate as well as the long term effects of conditioning treatments must also be considered.

Conclusions which may be drawn from this study include:

- Statistical analysis showed that vapor dried crossties are stronger in bending than Boulton dried crossties prior to artificial ageing. The air dried crossties were the strongest, but the results were not directly comparable due to a difference in moisture content.

- Compression modulus tests revealed that air dried crossties were statistically superior to Boulton and vapor dried crossties prior to artificial ageing. Through the artificial ageing process, the air and Boulton dried crossties proved to be statistically stiffer than the vapor dried crossties at a 95% significance level.

- Face hardness test results were statistically similar for all three drying methodologies prior to and throughout artificial ageing.

- All three spike resistance tests (insertion, withdrawal, and lateral resistance) prior to artificial ageing showed the air dried crossties to be superior to the Boulton and vapor dried crossties. This was also true for the lateral resistance tests which were run throughout artificial ageing. Air and Boulton dried crossties both were statistically superior to the vapor dried crossties in spike withdrawal once artificial ageing was administered.

- The rate of deterioration of surface area (as measured by checking) was shown to be greatest for the vapor dried crossties throughout the artificial ageing process.

In summary, this study has shown that significant differences exist in the properties of crossties which have been air dried, Boulton dried, and vapor dried. These differences exist not only directly after treatment but also throughout a simulated ageing process which can be indicative of a crosstie's effective life. Further studies (economic) are necessary to quantify the significance of these differences with respect to life cycle analysis.

5.0 REFERENCES

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