STUDIES ON RAILWAY CROSSTIE DETERIORATION

by

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Abstract

The results of several studies on wood tie deterioration, supported by CP Rail (CPR) are presented. Investigation of ties in track marked for removal showed that splitting is the most common cause of removal in both mainline tracks and secondary tracks. In main line ties, plate cut and associated spike loosening is the next most important reason for tie removal. On secondary lines, where ties survive longer because of the reduced plate loading, decay is a more important reason for replacement. Detailed microscopic examination of ties of all ages in track show that mechanical failure is the most common cause of tie plate deterioration in jackpine ties. We conclude that there is little advantage to treating this species in situ with borate rods or other remedial treatments. Denser and stronger Douglas-fir, hard maple and oak ties, on the other hand, resist mechanical failure and have a high incidence of decay infection, suggesting that in situ treatments are warranted. Checking and high moisture contents have an overwhelming influence on the rate of decay and mechanical deterioration in the respective tie groups.

Introduction

There are an estimated 60,000,000 treated wood railway ties in service in Canada at this time (Cooper and Ung 1989). This represents a large wood resource and a substantial capital and maintenance expense to the owners of the lines. With an average in-service life of 20 - 40 years, 2 - 3,000,000 ties are removed annually. Many are recycled as landscaping timbers or fenceposts, but with increasing restrictions on burning or landfill disposal of the remainder, their disposal is developing into a major challenge for railway companies. Identification of practices and procedures that can extend the service life of ties will reduce these capital and maintenance costs and also help with the disposal problem by reducing the quantities of ties removed annually.

For the past 3 years, CP Rail (CPR) has been supporting a wide-ranging and comprehensive evaluation of wood tie performance by Morrison Hershfield Ltd. and the Faculty of Forestry, U. of T. The experimental approach and some of the more significant results are summarized in this paper.

Experimental Approach

An initial study of ties marked for removal was made on three lines, representing a range of geographic locations and track loadings. Every tenth tie, marked for removal over a track distance of several miles was inspected in track and all performance limiting defects, such as plate cut, loose spikes, end splits, full splits, drying checks, visible advanced decay and weathering were recorded. Where decipherable, dates stamped on the tie ends were recorded. Ties were also tested before removal by sounding, boring near checks or splits with an increment borer and by electrical resistance moisture reading at the centre and near the plates.

A sample of 50 ties, including some ties that were not marked for removal, were evaluated with a sonic testing device (Pandrol's "PANLOGGER"). A track testing device designed by Canadian National Railways to evaluate the lateral spreading resistance of the rails (gauge holding ability) was also evaluated. After the marked ties and the PANLOGGER tested ties were removed from track, they were dissected with a chainsaw and evaluated for species, internal condition and overall integrity.

In follow-up studies, ties of the main species used - jackpine (Pinus banksiana), red oak (Quercus rubra), white oak (Quercus alba), Douglas-fir (Pseudotsuga menziesii) and hard maple (Acer saccharum) were investigated to try to clarify the mode of degradation in the tie plate area. Ties of all ages and conditions were selected in track from a number of lines (Table 1). Ties for study were confirmed for species microscopically and for age from date stamps on the ends of ties. The ties were characterized for condition in track, then removed by CPR personnel and sent to the lab for analysis.

Ties were characterized for condition before cutting - plate cut, externally visible decay, pilodyn hardness at the plates and centres, and severity of checking and splitting. The ties were then cross-cut through the centres and the plate areas and the cross-sectional discs examined and characterized for visible deterioration and other characteristics, including quality of preservative treatment, presence of advanced decay, mechanical damage, staining, depth of checks and splits, pith location and orientation of annual rings. Cross sectional slices from the plate and centre regions of each tie were marked at five standardized locations (diagonally in from each corner and at the tie centre) and moisture contents determined by oven-drying.

These sections were then examined by incident light microscopy for characterization of mechanical failure. Samples were taken from zones most likely to contain decay and cross and radial sections cut with a microtome and stained with safranin/fast green to provide contrast between the wood and fungal hyphae. The sections were mounted and scanned in a transmitted light microscope for the presence, distribution and extent of decay activity.

Table 1: Description of railway lines in tie studies

Study (subdivision)	Species	Location	Traffic Level (gross tons/yr) x 10^6	Precipitation (mm/yr)
Initial evaluation	all	Owen Sound	1	820
	Douglas fir	Mountain	68	1050
	Maple/oak/ birch	Winchester	16	900
Deterioration study	Jackpine	Belleville	20	820
"	Maple	Vaudreuil	15	970
"	Douglas-fir	Thompson (Kamloops)	63	230
"	Douglas-fir	Cascade	63	1200
	Red oak	(Hell's Gate)	63	1200
	White oak		63	1200
"	Red Oak	Galt	23	860
	White oak	(Milton)	23	860

Results and Discussion

Evaluation of tie condition in track

Of the ties marked for removal, the majority were rejected primarily due to end splits or full length splits (about 45%). By comparison, about 12% had plate cut damage above CPR's failure criteria, 5% had advanced decay and about 20% failed from a combination of failure modes - primarily splitting in combination with plate cut. About 20% of these marked ties were judged to have retained adequate strength to perform satisfactorily at least until the next scheduled inspection (5 years). This demonstrates the need for an instrument that can predict the internal condition of the tie better than can be inferred from externally visible signs of deterioration. By the nature of this study, one cannot predict the number of ties left in track that appear sound but have lost their load carrying capacity. However this type of error is probably not as common.

Most in situ inspection procedures did not provide a significantly better estimate of the tie condition than the visual inspection. Pilodyn readings helped differentiate between hardwood and softwood ties, without the need for species identification, because of the higher density and hardness of the hardwoods. Otherwise, it gave no consistent indication of weathering damage or decay. The electrical resistance moisture meter showed that most ties were at a sufficiently high moisture content to support decay near checks and near the plate area. As shown by the detailed moisture content measurements discussed below, the highest moisture contents were at or below the middle of the ties, deeper than the moisture meter needle length.

The "PANLOGGER" was able to detect internal decay pockets better than sounding, or external examination. In combination with visual observations it could assist the inspector in deciding if a tie should be removed. Despite its ease of use, it is slower than visual inspection. However, it need not be used on new ties, or obviously split or otherwise ruined ties; ultimately, sonic inspection may prove economical by saving suspicious looking ties that are in fact still sound.

Relationship of wood moisture content to tie condition

The moisture contents are consistently higher in the plate areas compared to the centres in all species (Table 2). The moisture contents are also related to the geographic area, with low MC values in ties in the dry Kamloops area of the Thompson subdivision. Correlation analyses show the moisture content is significantly higher in the presence of decay, deeper checks, increased plate cut and increased ring shear beneath the plate.

The moisture content is usually highest at the tie centre. In ties cut from smaller trees, this represents the location of the pith and the terminus of checks in boxed heart ties. Moisture contents are generally higher in the bottom portions of ties due to gravitational distribution of moisture that gains access through checks and perhaps to moisture ingress from the ballast. Diffusing salts applied as in situ treatments will tend to move preferentially into these areas as well and may not be lost readily through the top surfaces through rainfall extraction.

Quality of preservative treatment

All ties studied had been pressure treated with creosote/ petroleum oil (50/50). There is a significant species effect on treatment Table 3), depending on the amounts of sapwood on the ties and the inherent permeability properties of the heartwood.

Jackpine ties have the deepest average minimum penetration, followed by maple. Ties of both oak species and Douglas-fir evaluated in this study had minimal creosote penetration. In all cases, drying checks extended well below the depth of preservative.

Table 2: Comparison of tie moisture contents

Species	Subdivision	Age (yrs)	# ties	Moisture Content (%) Plate top	Plate mid	Plate bot	Plate ave	Centre top	Centre mid	Centre bot	Centre ave
Jack-pine	Belleville	0-10	3				33				23
		11-20	14				96				45
		21-30	7				94				64
		31+	7				87				63
Maple	Vaudreuil	0-10	4				48				40
	+	11-20	9				52				46
	Belleville	21-30	12				62				51
		31+	13				69				63
Red oak	Galt	11-20	4	74	92	84	77	68	86	80	82
		21-30	2	74	96	86	83	84	104	82	87
		30+	6	67	94	74	75	40	81	69	60
	Thompson	0-10	1	33	45	36	36	30	40	38	36
		11-20	2	37	50	32	38	28	46	33	34
Cascade		0-10	2	56	78	85	72	54	77	57	60
		11-20	5	80	83	72	77	55	88	61	64
White oak	Cascade	11-20	6	61	69	49	59	50	68	46	52
		21-30	1	85	76	81	82	94	92	66	82
Douglas fir	Thompson	11-20	3	29	107	44	51	20	22	22	21
		21-30	8	31	68	37	58	18	22	22	21
		30+	6	45	64	45	49	18	20	22	21
	Cascade	11-20	13	68	113	68	77	37	73	47	48
		21-30	5	90	128	98	101	51	60	60	56
		30+	2	106	110	98	103	91	65	78	75

Staining of wood in railway ties

Iron staining was observed deep into the plate area. In hardwoods, the blue iron tannate stain increased in extent with age of the ties and was more extensive in wetter ties. The alkali solubility of wood from the plate areas was higher on the average than from the tie centres, but not statistically different. Higher values are expected if significant iron degradation of cellulose or decay are present.

Table 3: Comparison of the quality of preservative treatment of the ties studied and their checking characteristics.

Species	Subdivision	Age	# ties	Min. Pen.* (mm) P	Min. Pen.* (mm) C	Ave. Check Depth (mm) P	Ave. Check Depth (mm) C
Jack-pine	Belleville	0-10	3	15.3	8.0	7	17
		11-20	14	11.3	4.8	46	24
		21-30	7	7.6	7.9	77	70
		31+	7	5.4	13.2	69	18
Maple	Vaudreuil + Belleville	0-10	4	7.6	10.0	42	45
		11-20	10	4.2	5.1	55	49
		21-30	12	4.8	3.6	74	65
		31+	3	1.3	12.3	62	38
Red oak	Galt	11-20	4	1	1.5	72	84
		21-30	2	<1	<1	86	64
		31+	6	<1	<1	200	60
	Cascade	0-10	2	2.8	9	72	72
		11-20	5	1.2	<1	86	53
	Thompson	0-10	1	<1	<1	68	67
		11-20	2	<1	<1	68	70
White oak	Galt	11-20	6	1	<1	64	82
		21-30	1	<1	<1	85	57
	Cascade	11-20	5	<1	<1	115	69
Douglas-fir	Cascade	11-20	13	1.7	3.8	57	68
		21-30	5	<1	<1	130	78
		31+	2	2	1	130	98
	Thompson	11-20	4	<1	3	98	58
		21-30	8	<1	<1	92	61
		31+	6	<1	<1	78	51

* The minimum depth of penetration at the top surface of the tie.

Decay as a mode of deterioration

Relatively few ties had obviously identifiable decay visible in track (Table 4). Ties from the secondary line (Owen Sound) had more visible decay, probably because of the longer average age of ties in the line because of the light traffic volumes. Dissection of ties marked for replacement showed that advanced internal decay was not a significant factor in the most abundant softwood tie used in Ontario. This is attributed to the relatively thick treated sapwood band retained on the ties. Even though checks often extend below the treated sapwood, the large reservoir of creosote results in bleeding into the checks that inhibits decay. Some older jackpine ties on the secondary lines had evidence of soft rot in the plate areas.

Advanced decay was more common in the hardwood species than in the pine. Also, Douglas-fir, in spite of its reputation for moderate heartwood decay resistance, had more advanced decay than the less durable pine species. Again, this can be attributed to the very poor quality of creosote treatment in the Douglas-fir ties evaluated in this study (Table 3). Microscopic examination confirmed the presence of incipient decay in several ties without macroscopically visible decay

Where decay was present, it was usually found in both the plate and centre regions of the tie. Thus, detection of decay in the centre of the tie by sonic or other devices should give a good prediction of soundness of the tie as a whole. Decay was generally associated with poor creosote penetration and with cracks in the wood.

Deterioration under tie plates and plate cut as a mode of tie failure

Plate cut is partially attributable to abrasion caused by lateral movement of small stones and other grit under the plate. This mode was also identified by Miller and Houghton (1981) and Von Schrenk (1927). Plate deterioration is also characterized in the softwoods by crushing of low density earlywood, extensive ring shear damage and pith distortion under the plates.

Jackpine ties were significantly more plate cut than hardwood or Douglas-fir ties (Table 5) except in the oldest ties where decay contributed to excessive plate cut in all species. In jackpine, the average plate cut increased significantly after about the 10th year (as did moisture content). Douglas-fir from the drier location (Thompson) had somewhat less plate cut than that fir from the wetter Cascade location.

Table 4: Characterization of decay in ties removed from service.

Species	Subdivision	Total # ties	............Decayed ties............ visible in track P	C	visible in dissected ties P	C	observed microscopically * P	C
Jack pine	Belleville	31	1	0	3	2	8	6
Maple	Vaudreuil	21	4	3	16	16	19	19
Douglas fir	Thompson	17	0	0	1	1	17	17
	Cascade	20	0	0	5	5	19	19
Red oak	Thompson	3	0	0	1	1	1	1
	Galt	12	0	0	4	4	8	8
	Cascade	7	0	0	2	2	7	7
White oak	Galt	7	0	0	1	1	3	3
	Cascade	5	0	0	1	1	4	4

* ties with microscopically detected decay include those with visible advanced decay.

It was apparent that the various modes of failure interacted to a great extent. Checks led to high internal moisture contents, which promoted decay and appeared to contribute to deterioration under the tie plates. Mechanical damage of cells under the tie plate increased the water permeability of this area promoting decay, while decay development and the increased moisture content weakened wood and accelerated the rate of mechanical damage.

Despite the high incidence of advanced decay in hardwood ties, they generally resist plate cut damage because of their inherent high density and strength. This corresponds to relatively modest increases in plate moisture contents with age in hardwood ties compared to an abrupt increase in plate area moisture content in pine and Douglas-fir ties after 10 years in service. Only the oldest hardwood ties had significant collapse of the plate area. Jackpine, on the other hand, had significant plate area deterioration, characterized by delamination, crushed fibers and flattened pith regions. Microscopic examination of the plate regions shows that the delamination effect results from a rolling type shear (Gunzerodt et al, 1988) in the low density earlywood portions of the softwood ties and from tensile separation at the earlywood/latewood interface. Other common microscopic failure modes in the softwood plate areas include localized crushing and splitting between cells near the surface, crushing of the earlywood deeper below the surface, radial splits and random breaks across the cells.

Table 5: Average splitting rating and plate cut of ties evaluated.

Species	Subdivision	Age	# ties	Splitting * Rating End	Splitting * Rating Full	Average Plate Cut (mm)
Jack-pine	Belleville	0-10	3	3.3	3.7	2.0
		11-20	14	2.7	3.3	6.1
		21-30	7	1.0	2.6	9.9
		31+	7	1.6	3.7	7.1
Maple	Vaudreuil + Belleville	0-10	4	3.2	3.8	1.5
		11-20	10	2.2	2.3	3.1
		21-30	12	1.9	1.9	2.8
		31+	3	1.0	2.3	8.0
Red oak	Galt	11-20	4	1.2	3.2	3.1
		21-30	2	1.5	4.0	2.4
		31+	6	1.5	2.7	4.4
	Cascade	0-10	2	2.5	3.5	2.9
		11-20	5	1.2	2.2	4.2
	Thompson	0-10	1	1.0	3.0	3.2
		11-20	2	2.0	3.5	2.8
White oak	Galt	11-20	6	1.5	3.2	3.9
		21-30	1	1.0	2.0	5.1
	Cascade	11-20	5	1.2	2.2	5.2
Douglas -fir	Cascade	11-20	13	1.9	2.2	5.4
		21-30	5	1.6	3.0	6.4
		31+	2	0.5	4.0	8.8
	Thompson	11-20	4	2.0	4.0	4.3
		21-30	8	2.6	3.4	6.0
		31+	6	2.8	4.0	5.1

* End split rating:
- 0 = split both ends >25mm wide.
- 1 = split both ends 12-25 mm or one end >25 mm.
- 2 = 6-12mm both sides or >12mm one end.
- 3 = <6mm both ends or 6-12 mm one end.
- 4 = No end splits.

Full split rating:
- 0 = Continuous split >12mm wide.
- 1 = Continuous split 6-12 mm wide.
- 2 = Continuous split < 6mm wide.
- 3 = Discontinuous splits < 6mm wide.
- 4 = No full length splits.

In hardwoods, damage in the plate area is mainly confined to limited crushing of the vessels, close to the top surface of the tie, separation at the annual rings and tearing and abrasion directly under the plate.

Splitting and checking as modes of tie deterioration

Splitting and checking were significant contributors to tie deterioration. The depth of checking was significantly higher in ties with the pith located at greater distances from the surface. Ties cut from larger trees, with no enclosed pith, or the pith close to one of the surfaces did not check badly. Also, checking and splitting were worse in ties with lower creosote treatment quality. Badly checked ties also had significantly worse shear delamination, plate cut and flattening of the pith region. It appears that checks into the plate areas contribute to mechanical degradation.

Red oak ties appear more prone to end splitting than the other species (Table 5). Douglas-fir ties from the dry region were less split than those from the high rainfall region, suggesting that changes in moisture content contribute more to splitting than lower MC's only.

Ties are often checked when placed in service as a result of the moisture content gradient that develops during air drying and the differential between radial and tangential shrinkage of the wood. This latter effect is particularly important in ties with boxed heart. Checking worsens with age and after several years in service, most of the wood is too wet to be subject to shrinking and swelling stresses, except at the very surface. In spite of this, after several years in service, most ties are extensively checked and split. This appears to result from development of end splits from the "brooming" effect of high plate loads close to the ends of the ties and extension of these splits into the plate area, by the prying effect of stones that lodge in the splits. Similarly, modest checks that form on the tie top surface develop into splits as stones and dirt from the ballast collect in the checks and prevent the check from closing when the wood swells. This also creates a prying effect that can eventually split the tie.

Since splitting is the most common cause of tie removal and contributes to other tie deterioration modes, control of checks in service is an obvious approach to extending service lives of wood ties. Laminated ties avoid the boxed heart problem and have greatly reduced checking (Hosli et al 1989) and have performed satisfactorily for 50 years or more.

Predrilled holes

In all studies, it was observed that the spikes only rarely hit the predrilled holes. These holes promote parallel to grain creosote distribution in the plate area in jack pine ties and assist in sterilization, but the usefulness of this practice is questionable as it permits entry of moisture into the critical spike hole area.

Conclusions

- Jack pine does not have sufficient strength for mainline applications.
- Creosote is effective in reducing tie deterioration when sufficient penetration depths are obtained. Unless treatment depths can be improved in Douglas-fir, oaks and hard maple, they will be good candidates for in-track preservatives.
- Checking and splitting are the accompanying build up of moisture is central to deterioration of wood crossties.
- Anti-splitting devices should significantly extend the tie life, particularly in areas with severe changes in moisture content.

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