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Section 3 **Wood Protecting Chemicals**

Laboratory investigation of fire protection coatings for creosote-treated timber railroad bridges

Carol A. Clausen, Robert H. White, James P. Wacker, Stan T. Lebow, Mark A. Dietenberger, Samuel L. Zelinka and Nicole M. Stark

U.S. Forest Service
Forest Products Laboratory
One Gifford Pinchot Drive
Madison, Wisconsin 53726 U.S.A.

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IRG SECRETARIAT
Box 5609
SE-114 86 Stockholm
Sweden
www.irg-wp.com

Protective measures from fire for timber railroad bridges

Carol A. Clausen[1], Robert H. White[1], James P. Wacker[1], Stan T. Lebow[1], Mark A. Dietenberger[1], Samuel L. Zelinka[1] and Nicole M. Stark[1]

[1]U.S. Forest Products Laboratory, One Gifford Pinchot Drive, Madison, Wisconsin 53726 USA
cclausen@fs.fed.us; rhwhite@fs.fed.us; jwacker@fs.fed.us; slebow@fs.fed.us; mdietenberger@fs.fed.us; szelinka@fs.fed.us; nstark@fs.fed.us

ABSTRACT

As the incidence of timber railroad bridge fires increases, so has the need to develop protective measures to reduce the risk from accidental ignitions primarily caused by hot metal objects. Of the six barrier treatments evaluated in the laboratory for their ability to protect timbers from fires sourced with ignition from hot metal objects only one intumescent coating provided adequate fire protection. The intumescent barrier treatment also met environmental, performance (e.g. bond durability) and application criteria set forth in this study. These criteria also dictated the development of a flammability test, called the hot metal test that is compatible with the fire scenario specific to this study. The hot metal test evaluates protective materials on creosote-treated timber against ignition of gases generated by an 1100^{O}C heat source.

Keywords: barrier treatment, fire retardant, intumescent, railroad, crossties, protection, creosote

1. INTRODUCTION

An increase in frequency of fires in timber railroad bridges has renewed the need to address fire performance of creosote-treated wood bridge members and investigate options for adding protective materials to reduce the fire risk from ignitions. The focus of this study was fire incidents attributed to ignition sources from sparks, hot metal objects (e.g. metal brake shoes), and maintenance work that is routinely performed on steel rails. Other potential ignition sources not within the scope of this study include debris accumulation, decay, proximity of roadside vegetation, wildland fires and arson.

Despite operational improvements to reduce the incidence of sparks and residual hot metal objects along with efforts to reduce debris and other secondary ignition sources, the incidence of fire to timber rail bridges is increasing particularly in the hot, dry climates in the west and southwest United States. In 2011, the 341,181 km of railroad track in use by U.S. railroads was comprised of approximately 689,974,000 crossties (RTA 2014) with 76,000 railroad bridges (GAO 2007). There are critical sections of timber bridges, such as the bridge deck crib, which appear to be prone to fire resulting in hazardous situations for approaching trains, major disruption of rail traffic, and possible catastrophic losses of life and property.

There was an active research program in the United States devoted to fire performance of creosote-treated wood in the mid to late 1950's when the cost of fires on railroads exceeded $6 million USD (Collister 1963). As early as 1952, Hubert (1952) described the addition of triaryl phosphate to creosote–petroleum to provide fire protection for fence posts. Coburn and Morris (1956, 1958) reported on the behavior of proprietary compositions for treated southern yellow pine when subjected to fire and weathering tests, and developed basic information regarding the burn characteristics of treated timber. They investigated efforts to mitigate fires in timber railroad bridges treated with oil-type preservatives resulting from fuses, brake shoe slivers, brush and tumbleweeds. Gooch et al. (1959) reported on the addition of triaryl phosphate to creosote-petroleum to address concerns of U.S. railroads on the potential fire hazard present in trestles made of timbers treated with oil-type preservatives. They also examined phosphorus-halogen combinations as an option to address the flaming combustion of the hydrocarbon distillation products in tiers of cribs using a gasoline ignition source. One conclusion from that study was that large retentions of oil-type preservatives caused increased fire hazard. Coburn and Morris (1959) investigated the potential of adding fire-retardant chemicals (i.e. an aromatic ester of phosphoric acid) to the creosote-petroleum preservative treatment. They noted that creosote and mixed creosote treatments behaved differently and that the fire performance of the treated wood depended on the age of the treatment, the retention, and the wood species. They tested the performance of full-scale replica trestles using dry tumbleweeds as the ignition source. For the creosote/triphenol phosphate-treated trestles, two years of weathering did not significantly affect the results. It was noted that the most persistent flaming always occurred in protected locations where entrapped heat could cause volatile materials to burn above the wood surface and away from the influence of the phosphate additive.

The fire hazard of wood newly treated with creosote is generally acknowledged in the literature, but there are conflicting claims on the fire performance of the creosote-treated wood after some aging or weathering. Indeed, while sparks and hot metal objects are sufficiently hot enough to quickly ignite creosote-treated wood, without continued external heat exposure such fires normally self-extinguish with only localized damage after a period of flaming, smoking and smoldering. Conditions that might allow such a fire to progress to a more damaging fire include members of smaller dimensions, construction details that allow re-radiation between burning surfaces, upward flame spread that increases surface areas exposed to the flames, and sufficient air flow to advance glowing wood to flaming wood. Dowling (1994) studied the ignition and burning of timber bridges in bushfires. Embers from wood cribs were used as ignition sources. He concluded that most timber bridges damaged or destroyed in bushfires are probably ignited by small poles of glowing embers lodging in gaps or crevices. Ignitions occur in the gaps between deck planks usually at a point above a crossbeam. He also concluded that in experiments where timber members have been protected by intumescent paint or fire-retardant solution, the incidence of ignition was reduced but not eliminated.

Patented technologies (1962, 1975) disclosed fire-retardant creosote comprised of creosote, tricresylphosphate, chlorinated rubber, antimony tri-chloride and a phosphorus compound. The last known fire-retardant coating specifically for rail bridges constructed with creosote-treated wood was developed by the British Columbia Research Council and patented in Canada. It was first used about 1970, but its use was discontinued around 1993. Recent efforts pertaining to the fire protective coatings for treated wood in the United States are limited to utility poles treated with inorganic water-borne salts or pentachlorophenol. Recent literature on fire protection of creosote-treated wood is non-existent.

There is an existing American Railway Engineering and Maintenance-of-Way Association (AREMA 2013) Standard that addresses several of the performance characteristics of such a coating for these applications. It states "The dry film is expected to exhibit adhesion, durability, foot traffic, and fire retardancy. The fire retardancy is evaluated in a fire-test cabinet and also in a fusee test using a 10-minute fusee. Acceptance criteria for the fire cabinet test required self-extinguishment within the 30-minute free-burning period and limitations on total weight loss, char depth, char density, glowing combustion, and integrity of the coating." There was also an accelerated weathering component of the Specification. In 2013, there was a motion to have the Specification removed for lack of use. Ironically, the motion occurred at the same time the rail industry is experiencing an annual increase in catastrophic economic losses from rail fires in stringers, crossties, cribs, trestles and associated creosote-treated rail bridge substructures.

Criteria for barrier treatments have changed since the 1950's to emphasize environmental safety for use over water. Protective barrier treatments must be suitable for spray application, durable without the need for frequent re-application, flexible over a wide temperature range, able to bond to new or weathered creosote-treated wood without the need for surface cleaning, low cost, and dyed to enable identification of coated crossties and visual inspection of coated crossties for signs of physical and biological deterioration. There were two objectives for this study: 1) to develop a flammability test method to simulate ignition circumstances that lead to large and sustained fires on creosote-treated timbers and 2) to evaluate barrier coatings on new and weathered creosote-treated timbers for their ability to primarily reduce flame spread and secondarily, prevent ignition due to various chemical mechanisms such as volatile blocking, heat insulation, charring, or heat dissipation.

2. EXPERIMENTAL METHODS

2.1 Test Specimens

Creosote treated crossties (i.e. sleepers) were obtained from a railroad company. Crossties were designated as "new" or "weathered", cut to varying specimen sizes depending on the requirement of a specific test method, brush-coated with individual barrier treatments, and cured for 4 weeks at 70ºC and 50% relative humidity (RH) before initial fire performance screening in the Schlyter and mass loss calorimeter tests, leach testing and weathering. Uncoated new and weathered specimens served as controls. For mechanical testing of bond durability, specimens were brush-coated with two individual barrier treatments, and cured for 2 weeks at approximately 21ºC indoor prior to cyclic loading tests.

2.2 Barrier Treatments

Six barrier treatments were selected for evaluation based on test criteria and product claims:

- Concrete-like mixture of sand, ash, magnesium oxide and potassium phosphate designated GCR
- Latex paint augmented with potassium aluminum sulfate, designated ALM
- Latex-based intumescent fire retardant (FR) coating designated NT1
- Latex-based intumescent FR coating designated NT2
- Water based, thin film intumescent FR designated NT3

- Clear penetrating intumescent FR designated CLR

2.3 Leach Resistance

Leach resistance was evaluated using an adaption of American Wood Protection Association Standard Method E11 (AWPA 2013). Coated and cured specimens (102 by 102 by 38 mm) were immersed in 7.6 liters of deionized (DI) water for a total of 16 days. The leach water was replaced after 0.25, 1, 2, 4, 7, 9, 11 and 14 days during the course of the test. Following leaching, the specimens were reconditioned in preparation for mass loss calorimeter testing. The effect of leaching was also evaluated by rating the quality of coating adhesion and estimating the percent of coating area remaining following leaching. Coating adhesion was evaluated by gently prying at the coating with a putty knife. Quality of adhesion was assigned ratings ranging from 5 (good) to 1 (poor). Due to the subjective nature of the rating test, the same person evaluated all specimens for coating adhesion.

2.4 Weathering

Coated specimens (100 mm x 127 mm) were weathered in an Atlas Ci5000 according to ASTM G155, Cycle 1 for wood materials (ASTM 2010). Cycle 1 stipulates daylight filters, and a cycle of 102 minutes of light exposure at 63°C and 50% RH followed by 18 minutes of light exposure and water spray. The total exposure time was 2000 hours. After weathering, specimens were cut to 100 x 100 mm for the mass loss calorimeter test, air-dried and reconditioned.

2.5 Fire performance tests

2.5.1 Mass Loss calorimeter

The ASTM E2102 standard method for mass loss and ignitability was used to initially screen treatments and then evaluate leached and weathered specimens (ASTM 2013). The test is commonly referred to as the mass loss calorimeter test. For this method, a conical electric heater provided a constant heat flux onto 100 mm by 100 mm test specimens as the mass loss and heat release rate were recorded for a fixed amount of time (500 seconds). A spark igniter was placed above the specimen to ignite the combustible gases.

2.5.2 FPL Schlyter test

A burner was placed between two parallel vertical specimens for three minutes, then the burner was extinguished and the flame height was observed for an additional 3 min (Eickner 1977). Heat release rate calculated from oxygen consumption measurements (Dietenberger and Boardman 2013) was recorded for the duration of the test. The selected results reported included the peak heat release rate, the average heat release rate for the first three minutes, for the one minute after extinguishment of the burner and for the three minutes after extinguishment of the burner.

2.5.3 Flammability of large timbers

Communications from a railroad company suggested conditions during a fire incident included ambient temperatures ranging from 27 to 38°C, constant 16 km/h wind flowing horizontally to represent ambient wind flow across a rail bridge deck and an overhead wind speed of 40-48 km/h to represent “fanning” from 25-30 trains passing daily while travelling at 97 km/h, resulting in 1 minute of fanning at intervals of 20 minutes. Exploratory non-standard tests evaluated conditions of flammability specific to a railroad fire scenario from hot metal objects. A steel wafer (25 x 13 x 13 mm) heated to temperatures ranging from 427 to 649°C was placed in a groove, corner or crevice of individual pieces of creosoted-treated wood. At these lower temperatures, there was mostly smoke with small flaming. Placing a pilot flame in the smoke resulted in a flame developing across the whole specimen. The creosote vapors contributed to the overall flaming combustion. Steel wafers at 1100°C resulted in almost immediate ignition upon surface contact with creosote wood. Visual observations of the flame patterns supported the observation that the creosote was a significant factor in both continued flaming and spread of flames beyond that of untreated wood.

The exploratory tests included hot steel wafers at 1100°C being placed in different locations within a 0.91 x 0.91 m crib (Fig. 1 and 2). The timbers were creosote treated. The intent was to simulate hot metal becoming lodged in the joint of a crosstie and stringer. With application of the hot wafer in a crevice within the corner of two timbers (Fig. 1), the flames propagated to full involvement of the wood crib in about 8 minutes (Fig. 2). In a subsequent test with another wood crib, several attempts resulted in self-extinguishment with limited flaming. The second crib had timbers with a more "weathered" appearance.

Figure 1: Flames in wood crib of creosote-treated treated
timbers ~30 s after application of hot metal wafer wafer

Figure 2: Flames in wood crib of creosote-
timbers ~8 min after application of hot metal

2.5.4 Hot metal test

Results from the flammability scenario led to the development of a new fire test protocol for evaluating the propensity of wood to flame when exposed to hot metal as the ignition source. The new method is called the "hot metal test". Specimens were 38 thick x 127 wide x 787 mm long with two spacers 38 x 38 x 787 mm attached to each specimen with a 50 mm separation. The specimen was cut from the creosote-treated crossties such that the original exposed surfaces of the crosstie were the interior U surfaces formed by the 38 mm square pieces and the 38 x 127 mm board. The barrier treatment being evaluated was applied to the top surface and U surfaces of the specimen. Two nails were placed in the U-groove 25 mm from bottom end when placed in the holder. The ignition source was a 09.5 x 12.7 x 50 mm piece of steel heated in a furnace/oven to 1093°C.

Figure 3: Hot metal test apparatus (left) and ignition source (right)

A thermocouple was placed on the top surface of the bottom board in the test specimen. A second thermocouple was placed 330 mm from the bottom end of the specimen. The third thermocouple was placed at the top end of the U-groove.
The specimen was placed on a supporting metal frame at a 60° angle. To perform the test, the hot metal was placed at the bottom end of the U-groove so it fit between the two 38 mm square pieces and was supported by the two nails. The 12.7 mm width of the hot metal was in contact with the wood surface (Fig. 3). A data acquisition system was used to record the temperature data and visual observations were made.

2.6 Bond Durability Under Mechanical Testing

A set of sawn lumber railroad crossties and glulam bridge stringers were used to assemble a simulated railroad bridge specimen, apply brushed-on barrier treatments, and subject them to a million load cycles. Three one-meter long, weathered, creosote-treated glulam stringers were interconnected with thru-bolts at 41 cm intervals along the member neutral axis. The test span length measured 2.7 m (center-to-center) of bearing supports and included a closely "packed" chord, each measuring 51 cm wide and consisting of three glulam stringers (Fig. 4). Sawn timber crossties (measuring 250 x 250 x 910 mm) were lag screwed into the top of stringers with 127 mm clear spacing. A short 990 mm long section of steel rail (seated on steel ties plates) served as the loading head. The end supports consisted of built up steel beams measuring 300 mm wide, providing for a 2.4 m clear span length.

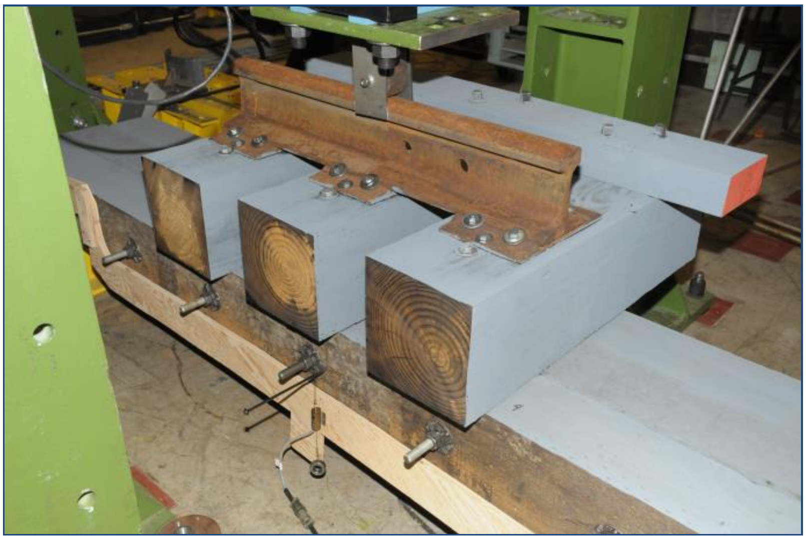

Figure 4: Coated bridge specimen and test set-up for the million load cycle testing.

Each bridge specimen was loaded to an equivalent level based upon in-service bridge span/deflection criteria provided by a railroad company. However, since the length of the glulam stringers were less than the typical in-service bridge spans, target deflection levels were computed in order to generate an equivalent degree of curvature at the compression topside of the stringer members. The actual stringer chord height was reduced by half for each bridge specimen in order to significantly reduce the required applied load to a more manageable level of approximately 20 Kips. A 110-Kip MTS actuator was utilized to apply repetitive loads at a rate of 1 Hz. Midspan deflections were recorded by a calibrated LVDT mounted on a plywood yoke which rested on screw spikes inserted at the neutral axis of the bridge stringer end supports.

Railroad bridge test specimens were fully assembled prior to application of the barrier treatments. Barrier treatments were applied to the horizontal top surface of the glulam stringer chord and the horizontal and vertical surfaces of the cross ties. Both barrier treatments (NT1 and ALM) had some degree of bleed-through by the creosote preservatives, with the NT1noted as providing the most effective coverage. The ALM seemed to achieve no visible protective coating on those members with heavy creosote residue. After application, a period of 2 weeks elapsed before cyclic testing commenced. Visual inspection of the protective coatings was performed daily throughout the million load cycles loadings. Photographic documentation was used to track any signs of protective coating degradation or wear.

3. RESULTS AND DISCUSSION

3.1 Application Characteristics

Application characteristics were noted for each barrier treatment. GCR had a very short application time before the product hardened and was nearly impossible to apply with a brush. ALM demonstrated creosote bleed-through and obvious poor adherence. NT1 was a paintable coating that resulted in a smooth grey film without bleed-through. NT2 was a thick paste that resulted in a smooth blue finish without bleed-through. NT3 provided a paintable white film with notable creosote bleed-through after drying. CLR was a thin, clear finish that was not visible upon drying.

3.2 Initial screening for fire performance

Results from the initial screening for fire resistance are shown in Tables 1 and 2. The Schlyter test indicated that GCR, NT1 and to a lesser extent ALM provided a degree of protection relative to the control specimen. Favorable results are in bold red (Table 1).

Table 1. Average heat release rate results from the Schlyter tests

Treatment[a]	New Sleepers				Weathered Sleepers			
	Peak HRR[b]	Average HRR			Peak HRR	Average HRR		
		0 to 3 min	3 to 4 min	3 to 6 min		0 to 3 min	3 to 4 min	3 to 6 min
	[kW]	[kW]			[kW]	[kW]		
Control	81 (15)[c]	53 (16)	60 (13)	58 (10)	66 (6)	30 (9)	51 (4)	51 (3)
GCR	**15 (4)**	**9 (1)**	**4 (1)**	**1.4 (0)**	**35 (19)**	**11 (1)**	**19 (9)**	**21 (18)**
ALM	100 (19)	62 (16)	**51 (11)**	**32 (6)**	63 (15)	35 (12)	**32 (12)**	**22 (9)**
NT1	**40 (27)**	**26 (19)**	**24 (24)**	**18 (24)**	**17 (7)**	**12 (4)**	**4 (3)**	**1.3 (1)**
NT2	96 (34)	55 (28)	63 (19)	56 (23)	71 (0)	36 (3)	57 (6)	54 (7)
NT3	97 (7)	60 (4)	67 (6)	57 (10)	54 (12)	22 (10)	41 (8)	42 (6)
CLR	105 (22)	72 (23)	71 (18)	54 (17)	66 (8)	36 (6)	51 (10)	45 (14)

[a] N=3, [b] HRR - Heat Release Rate, [c] (Standard Deviation)

To evaluate the relative performance in the mass loss calorimeter tests, the differences between the means for the coated samples and mean of the uncoated control samples were determined (Table 2). The bold red values are statistically significant at 0.05 probability via Tukey test using SAS software. Not all cells have the same number of replicates. Data for weathered and new railroad crossties were combined. The mean results for the 180 s heat release rate (HRR) averages of the barrier treatments, before leaching or weathering, were all less than that for the uncoated samples (Table 3). All of the coatings increased the times for sustained ignition, reduced the heat release rates, and reduced the mass loss rate. The improvements were only statistically significant from the controls for the NT1 and to lesser extent GCR and NT3. For samples without weathering or leaching, NT1 was better than GCR and NT3 by a wide margin with an average HRR of -93 for NT1 compared to an average HRR of -42 for NT3 and -40 for GCR.

Table 2: Differences in ignition times, mass loss, and heat release rate between mean results for coated samples and uncoated control

Treatment	Time for sustained ignition [s]	Final ML[a] [%]	Peak MLR[b] [g/m^2-s]	Peak HRR[c] [kW/m^2]	Average HRR (180 s) [kW/m^2]
Control	-	-	-	-	-
GCR	21.5	-2.4	-2	-29	**-40**
ALM	9.8	0.9	-2.6	-33	-32
NT1	3	-9.4	**-8.4**	**-88**	**-93**
NT2	7.5	-0.9	-1.2	-20	-19
NT3	2.8	-1.1	-2.7	**-43**	**-42**
CLR	0.5	0.5	-0.8	-17	-11

[a] Mass loss, [b] MLR - Mass Loss Rate, [c] HRR - Heat Release Rate

Table 3: Average heat release rate (HRR) for 180 s after observation of sustained ignition[a]

Treatment	Mean HRR [kW/m^2]	Significantly different than control[b]
Control	149	-
GCR	109	Yes
ALM	117	No
NT1	56	Yes
NT2	130	No
NT3	107	Yes
CLR	138	No

[a] Data for weathered and new crossties were combined
[b] 0.05 probability via Tukey test using SAS software

Based on results from the initial screening for fire performance, only specimens coated with NT1, NT3, GCR and ALM were further tested for fire performance after leaching and weathering.

3.3 Leaching

The barrier treatment with the best adhesion after leaching was NT2, with NT1 and NT3 (Fig. 5) maintaining lesser but substantial adhesion. The coatings with poorest adhesion were the GCR and ALM, which also exhibited somewhat poor adhesion prior to leaching. We were not able to judge the extent of adhesion of CLR after leaching because the coating was not visible. While the lack of visibility of CLR may have advantages for inspecting the condition of crossties and other wood members, it would be more difficult to inspect the condition of the barrier treatment in the field.

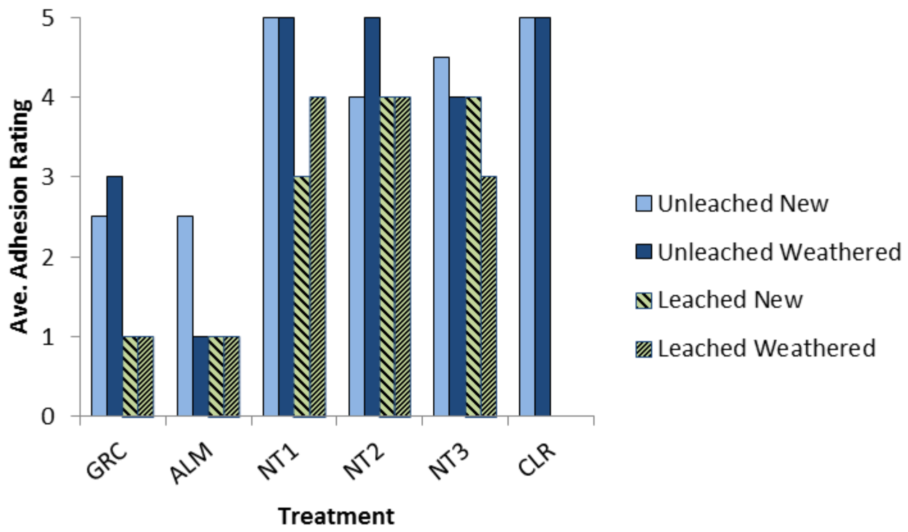

Figure 5: Average ratings of adhesion quality for leached and unleached specimens. The rating scale ranges from 5 (good) to 1 (poor)

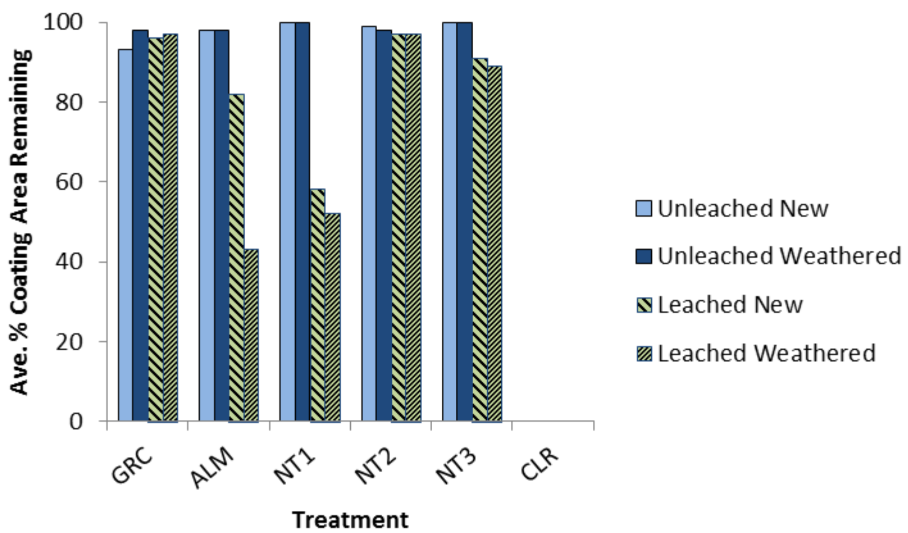

Figure 6: Average percent barrier treatment remaining after leaching based on visual inspection

The percent specimen surface with remaining coating (Fig. 6) can be somewhat misleading because it does not consider quality of adhesion. There appeared to be little consistent difference in barrier treatment performance for specimens cut from the new versus weathered crossties, with the exception of ALM which appeared to lose a larger percentage of barrier treatment during leaching when it was applied to weathered crossties.

Post-leaching specimens were tested in the mass loss calorimeter (Table 4). The loss of performance as the result of the leaching was only significant for the NT1 and, to a lesser extent, the GCR barrier treatment. ALM leached results for mass loss was an improvement from the ALM unleached results. While reduced from the value for no leaching, the average heat release rate for 180 second results for the NT1 barrier treatment were still significantly different than the uncoated control specimens.

Table 4. Differences between mean results for barrier treatments with and without leaching exposure

Treatment	Time for sustained ignition [s]	Final ML[a] [%]	Peak MLR[b] [g/m^2-s]	Peak HRR[c] [kW/m^2]	Average HRR (180 s) [kW/m^2]
GCR	**-29.3**	3.98	0.9	18.3	10.1
ALM	3.2	2.76	1.15	26.5	17.6
NT1	-1.6	-7.3	**-6.92**	-49.8	**-55.7**
NT3	-0.8	-0.45	-2.27	-10.0	-11.5

[a] ML - Mass Loss, [b] MLR - Mass Loss Rate, [c] HRR - Heat Release Rate

Bold red *values are 0.05 probability via Tukey test using SAS software; data for weathered and new sleepers were combined*

3.3 Weathering

Observations during the first two weeks of weathering noted that a significant amount of flaked coating could be seen in the bottom of the weathering chamber. Upon completion of the 2000 hr weathering cycle, specimens were air dried, and reconditioned at 70ºC and 50% RH before fire performance testing.

In the mass loss calorimeter tests (Table 5), the means for NT1 after weathering were higher (i.e. worse) and the difference was statistically significant than the original NT1 and also higher, but not statistically different than the control. The means for the other coatings were lower than the control but not statistically different. While not statistically significant, the means also increased (compared with non-weathered samples) for the NT3, NT2, and GCR samples. Of the coated samples, GCR and ALM had the lowest means.

No barrier treatment after weathering had means that could be considered better than the control based on statistical analysis (Table 6). The means for fire performance for NT1 after weathering were worse than the coated samples that were not weathered. The means for the weathered NT1 coated samples were also higher, but not statistically different, than uncoated control samples. The means for the other coatings after weathering were not statistically different than the respective unweathered samples.

Table 5. Average heat release rate (HRR) for 180 s after observation of ignition for weathered samples

Treatment	Mean HRR [kW/m^2]	Significantly different than control[a]
Control[b]	149	-
GCR	118	No
ALM	123	No
NT1	153	No
NT3	142	No

[a] 0.05 probability via Tukey test using SAS software; data for weathered and new sleepers were combined

[b] Control samples were not weathered

Table 6. Difference between mean results for coatings with and without weathering exposure

Treatment	Time for sustained ignition [s]	Final Mass Loss [%]	Peak MLR[a] [g/m^2-s]	Peak HRR[b] [kW/m^2]	Average HRR (180 s) [kW/m^2]
GCR	15.5	4.2	1.4	9.8	-9.5
ALM	5.2	7.5	-0.7	-21.2	-24.6
NT1	-1.6	-5.9	**-7.5**	**-78.6**	**-97.2**
NT3	1.3	4.6	-1.5	-33.1	-40.5

[a] *MLR - Mass Loss Rate,* [b] *HRR - Heat Release Rate*

Bold red *values are 0.05 probability via Tukey test using SAS software; data for weathered and new sleepers were combined*

3.4 Bond Durability Under Mechanical Testing

A typical plot of the cyclic load protocol is provided in Fig. 7.

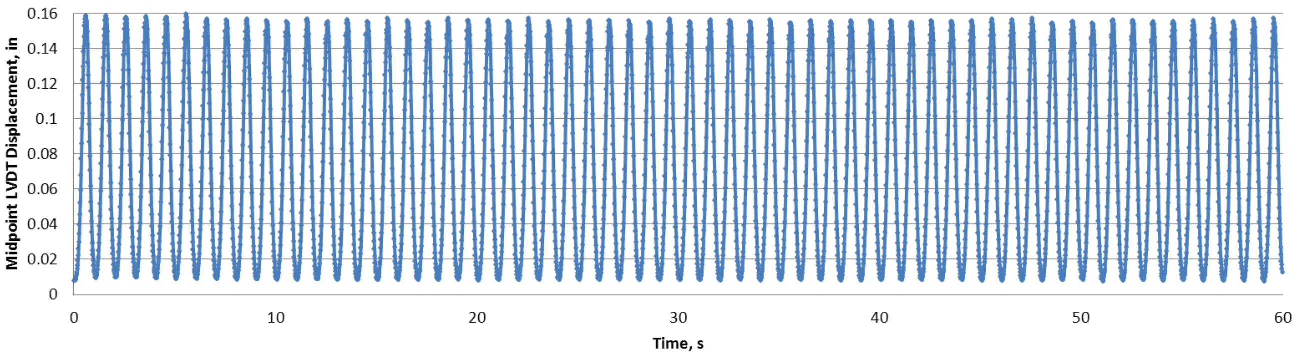

Figure 7: Displacement data for the initial minute of cyclic lading applied to NT1 coated specimen

Both barrier treatments evaluated for bond durability performed satisfactorily under load testing to 1 million load cycles. Minor wear of NT1 was noted, with the magnitude increasing over the million cycle test period. Minor flaking of ALM was noted after a half million load cycles. Both coatings exhibited some degree of creosote preservative bleed-through. In the case of ALM some entire crosstie surfaces appeared to be uncoated shortly after application because of severe bleed-through, particularly on newly treated timbers. The barrier treatment bleed-through made it more difficult to evaluate the barrier treatment performance under mechanical cyclic load testing.

4. CONCLUSIONS

The flammability scenario of large timbers by small pieces of hot metal resulting in a fully developed fire in creosote-treated wood is plausible and does not require external vegetation or debris. A hot metal fire test was developed that is compatible with the flammability scenario. Initial screening for fire performance revealed that under the conditions of this study, not all products were fire resistant. Bond durability was the dominant performance criteria when assessing fire retardant barrier treatments for coating creosote-treated wood in controlled laboratory settings. The leaching and weathering tests were severe tests of resistance to wetting and UV, and poor bond durability suggested these methods may be more severe than actual conditions in the field. The treatments NT1 and ALM performed satisfactorily under mechanical load testing for 1 million cycles. Field performance of the barrier treatment with the best overall fire performance and adhesion, i.e. NT1, is warranted and the durability of the intumescent performance should be verified after some period of field exposure, e.g. 1 year. Additional research is needed to develop pressure treatments for crossties and bridge components that will provide reliable protection against decay and fire.

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