Effect of a Polymer Additive on Properties of Creosote-Treated Wood

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Abstract

The potential for using a low molecular weight polyethylene (PE) polymer to improve the properties of creosote-treated wood was evaluated on samples of six different wood species. Samples were impregnated with creosote alone or amended with the PE additive and then tested to failure in third-point loading to determine modulus of elasticity and modulus of rupture. Samples were then subjected to three soak–dry cycles to assess the impact of moisture uptake on fastener performance or water repellency. The presence of the PE was associated with lower preservative retentions, but had no significant effect on modulus of elasticity, modulus of rupture, water repellency, or fastener withdrawal resistance. The results suggest that the additive limited preservative uptake, but did not improve any of the wood properties evaluated.

Creosote has a long history of successful use as a wood preservative (Hartford 1973). One of the primary uses for creosote is the treatment of wood for railroad applications. Creosote has excellent activity against fungi and insects and its oily nature is believed to provide lubrication to the tie spike. Although creosote has a long history of successful usage, there is always the potential for improving performance through various additives. Several insecticides and molluscicides have been explored for enhancing creosote performance in marine applications (Goldstein and Dreher 1962, Webb and Baldwin 1981, Webb and Johnson 1987, Woods and Cookson 1995), and some tie producers add boron into creosote in a dual-treatment process, but these systems are primarily concerned with enhancing biocidal performance. Decay is an important factor in tie service life, but physical degradation is also important. Ties often fail from splitting, plate cut, or spike failure (spike kill). Thus, it would be useful to explore additives that improve other performance attributes such as resistance to moisture uptake, reduced corrosivity, or improved mechanical properties. One possible group of additives for this purpose would be low molecular weight polyethylene polymers. These materials have the potential to improve stiffness and long term wear. For example, oxidized low molecular weight polyethylene (LMWPE) has been used as an antislipping agent, as a lubricant, and in adhesive formulations. The systems have low flash points, and would be soluble in creosote. Creosote would be an especially attractive solvent because it is used at elevated temperatures that would improve additive solubility and reduce viscosity. This should minimize any effects LMWPE might have on penetration into the wood.

The purpose of this study was to assess the potential for using an oxidized polyethylene (MW$\sim$ 4,000) additive to improve the properties of creosote-treated wood in comparison with wood treated with nonamended creosote or copper naphthenate.

Materials and Methods

Kiln dried lumber of red oak (*Quercus rubra* L), black gum (*Nyssa sylvatica L*), soft maple (*Acer rubrum L*), hard maple (*Acer saccharum* L), ponderosa pine (*Pinus ponderosa* L), and Douglas-fir (*Pseudotsuga menziesii* (Mirb) Franco) were obtained and cut into 25 by 25 by 400-mm-long beams that were free of knots, stains, or other defects. The maples, along with black gum, do not produce a clearly defined heartwood so the specimens were likely a mixture of heartwood and sapwood. The ponderosa pine was all sapwood, while the red oak and Douglas-fir were largely heartwood. The beams were conditioned to constant weight at 23°C and 65 percent relative humidity (RH) before being weighed.

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The beams were then immersed in the desired preservative solution (creosote or copper naphthenate) and subjected to a 650 mm Hg vacuum for 20 minutes. Creosote is the primary preservative used for treatment of railroad ties, whereas copper naphthenate was tested because it is increasingly used to treat ties in railway bridges. The pressure was raised to 1.03 MPa and held for 120 minutes. The pressure was then released, the samples were removed from the treatment solution, wiped clean of excess solution, and weighed. The differences between initial and treated weight were used to calculate net retention on a weight-per-unit-volume basis in kg/m^3. The treatments evaluated were an American Wood Protection Association (AWPA) P1/P13 creosote diluted 1:1 in toluene and heated to 60°C, the same solution composition with 3 percent of the polymer additive, or 2 percent (as Cu) copper naphthenate in diesel (CuNaph) used at ambient temperature (20°C to 23°C; AWPA 2016). Copper naphthenate was included to provide a comparator preservative system. Each treatment was replicated on 15 beams per wood species.

The beams were conditioned to constant weight at 23°C and 65 percent RH. The beams were then subjected to a three-point bending test to failure according to ASTM Standard D143, with loading at a rate of 6 mm/min with a span of 350 mm (US Department of Agriculture [USDA] 2010, ASTM International 2015a). Load and deflection were continuously recorded and the slope of the load deflection curve was used to calculate modulus of elasticity (MOE), while the ultimate load was used to calculate modulus of rupture (MOR).

The beams were then used to evaluate fastener withdrawal capacity and changes in water repellency over three wet–dry cycles. Briefly, five beams of each species and treatment were selected from the failed samples. The beams were again conditioned to constant weight at 23°C and 65 percent RH. Eight small-diameter pilot holes were then drilled into each beam, avoiding any areas compromised from bending tests. The holes were approximately 35.0 mm apart from one another and 7.20 mm from the edge of the beam. Eight 3.33-mm-diameter smooth shank common nails were driven into the pilot holes so that the heads were 6.35 mm above the wood surface and extended through the end of the beams (Fig. 1). The effective depth of fastener penetration was 25 mm. Withdrawal resistance was evaluated on one fastener from each beam after each moisture cycle by placing the beam in a specially constructed jig on an Instron Universal Testing Machine. The fastener was withdrawn in tension at a rate of 2.54 mm/min as described in ASTM Standard D1761 (ASTM International 2015b). Maximum force required to withdraw the fastener was recorded for each sample.

The effect of each treatment on water repellency was assessed visually by placing three 20-μL droplets of water on a beam and observing the shape of each droplet. Water droplets were assessed at 5-minute intervals over a 25-minute period (Beck et al. 2014). Droplet shape was categorized on a scale from 1 to 5 where 1 = contact angle >90°, 2 = contact angle 60° to 90°, 3 = contact angle 30° to 60°, 4 = contact angle 5° to 30°, and 5 = contact angle <5°. Although data were collected for all five time points, the 25-minute readings were used for treatment comparisons.

After the initial assessments for fastener withdrawal resistance and water droplet behavior, the beams were completely immersed in tap water in a pressure vessel and subjected to a 30-minute vacuum (625-mm Hg). The vacuum was released and the pressure was raised to 0.55 MPa and held for 30 minutes. The pressure was released and the samples were blotted dry and placed in plastic bags to retain moisture prior to being incubated for 20 days at 30°C and 90 percent RH. The hot, wet conditions were intended to foster metal corrosion. At the end of the posttreatment conditioning period, the beams were removed from the bags and oven-dried to constant weight at 60°C. The beams were then allowed to stabilize at 23°C and 65 percent RH for an additional 7 days before being evaluated for fastener withdrawal resistance and water droplet behavior as previously described. This process was repeated two additional times, for four total tests over three moisture cycles.

Analysis

The results were used to calculate means and standard deviations for each treatment and wood species. The MOR data were then subjected to an analysis of variance, followed by unpaired *t*-tests comparing creosote treatment with either creosote polymer or copper naphthenate treatment. Fastener withdrawal prior to soaking–drying was compared with values after one, two, or three soak–dry cycles. The droplet data were evaluated at the 25-minute interval to compare treatments and wood species.

Results and Discussion

Preservative uptake varied widely between wood species, reflecting the differential receptivity of the wood species to

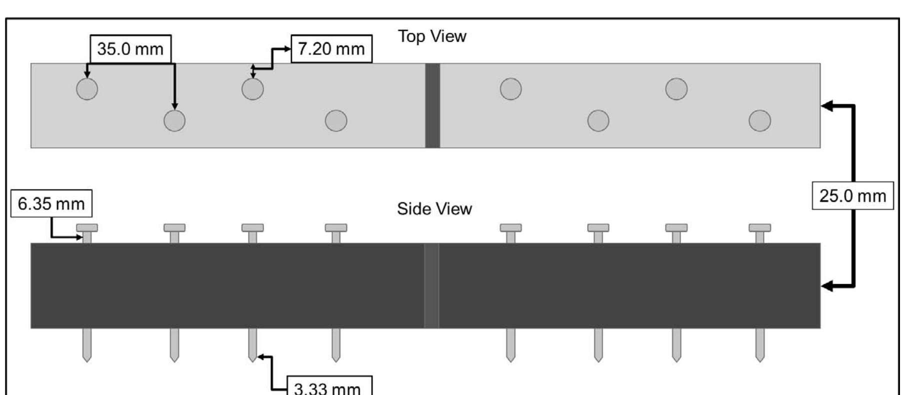

Figure 1.—Sample preparation for evaluating nail-withdrawal.

impregnation (Table 1; USDA 2010). The target retentions for these ties were 112 kg/m^3 for the mixed hardwoods and red oak, and 128 kg/m^3 for Douglas-fir and ponderosa pine. Creosote retentions ranged from 51.7 kg/m^3 for soft maple to 205.8 kg/m^3 for red oak. Only red oak, hard maple, and Douglas-fir were treated to the target retention. Ponderosa pine is considered to be a highly permeable wood and it is surprising that retentions were lower in this species than in Douglas-fir, which is considered to be more resistant to impregnation (USDA 2010). With the exception of Douglas-fir, the addition of the polymer to creosote was associated with lower retentions, suggesting that the polymer interfered with creosote movement. Heating the solution to a higher temperature would have reduced solution viscosity and might have helped improve treatment. All of the copper naphthenate retentions met the required 0.88 or 0.96 kg/m^3 (as Cu) for oak and the other species tested, respectively. The solution strength used for these treatments was much higher than would typically be used commercially. Soft maple proved to be most resistant to impregnation.

Flexural properties differed markedly with wood species, but there were few significant differences in MOE or MOR with treatment (Table 1). MORs for copper naphthenate and creosote–polymer-treated red oak, ponderosa pine, and Douglas-fir were significantly higher than those for creosote-treated specimens of the same species. It is unclear why these species were affected while black gum and the two maples were not. The relatively mild treatment conditions might have limited any potential effects, but the results indicate that polymer addition had no effect on flexural properties

Fastener withdrawal values also differed markedly between wood species (Table 2). Wood density should strongly affect fastener behavior; however, black gum, which has one of the lowest densities of the species tested, had the highest withdrawal resistance. The interlocking grain of this species may have played a role in withdrawal resistance (Panshin and DeZeeuw 1980). The remaining species had withdrawal resistance values that would be consistent with their density. Treatments had a marked effect on withdrawal resistance. With the exception of soft maple, the addition of the polymer to creosote was associated with decreased withdrawal resistance. Given that the polymer was also associated with reduced retentions, it is unclear whether the differences were due to the polymer or the lower creosote uptakes; however, the results clearly suggest a negative effect of polymer addition on fastener behavior.

Table 1.—Effect of treatment with copper naphthenate (CuNaph), creosote, or creosote with a polymer (Creosote–Poly) additive on modulus of elasticity (MOE) and modulus of rupture (MOR) of beams of 6 different wood species.[a]

Wood species	Treatment	Retention (kg/m^3)	MOE (GPa)	MOR (MPa)
Hard maple	Creosote	113.1 (23.4)	31.8 (1.3)	131.2 (14.3)
	Creosote–Poly	75.5 (4.3)	28.4 (2.0)	128.3 (6.7)
	CuNaph	6.1 (0.2)	28.4 (1.3)	139.7 (7.2)
Soft maple	Creosote	51.7 (33.3)	22.6 (3.0)	111.0 (11.9)
	Creosote–Poly	11.5 (11.4)	21.7 (2.6)	108.0 (12.1)
	CuNaph	2.9 (2.6)	22.2 (1.7)	107.3 (5.5)
Red oak	Creosote	205.8 (23.5)	21.0 (1.1)	93.1 (10.0)
	Creosote–Poly	156.5 (13.1)	21.5 (1.3)	112.4 (12.5)*
	CuNaph	6.2 (0.5)	21.8 (1.5)	100.7 (9.6)*
Black gum	Creosote	82.9 (27.7)	20.8 (3.7)	94.7 (17.9)
	Creosote–Poly	74.1 (4.0)	22.9 (1.5)	101.5 (11.6)
	CuNaph	6.6 (0.3)	22.6 (1.5)	99.8 (18.7)
Ponderosa pine	Creosote	115.5 (17.6)	14.7 (4.4)	63.7 (7.8)
	Creosote–Poly	29.4 (5.6)	14.7 (3.0)	59.1 (8.7)*
	CuNaph	9.0 (0.2)	17.1 (1.1)	75.7 (4.4)*
Douglas-fir	Creosote	131.4 (68.5)	24.6 (2.0)	89.2 (11.1)
	Creosote–Poly	202.2 (18.4)	26.1 (2.6)	100.8 (7.7)*
	CuNaph	6.6 (2.1)	26.9 (3.2)	97.5 (9.1)*

[a] Values represent means of 15 samples/treatment while figures in parentheses represent one standard deviation. MOR values with an asterisk are significantly different from the creosote treatment at $\alpha = 0.05$.

Exposure of beams to one to three wet–dry cycles produced a consistent increase in withdrawal resistance (Table 2). These differences were significant ($\alpha = 0.05$) for all but the black gum samples treated with creosote; all of the creosote polymer treatments; and the soft maple, hard maple, and ponderosa pine samples treated with copper naphthenate. The addition of the polymer to creosote had an inconsistent effect on withdrawal resistance, with wetting suggesting that other factors affected withdrawal. Wetting should result in swelling of the wood around the fastener, which would increase withdrawal resistance; however, this effect should decline as the wood returns to the oven-dry state after drying. Withdrawal resistance remained lower in all creosote polymer treatments after the first wet–dry cycle, but resistance was higher in the polymer additive beams for ponderosa pine, black gum, and red oak after the second cycle. The differences, however, tended to be small, suggesting that the polymer had only a minimal effect on withdrawal resistance over time.

Wetting and the subsequent storage under warm, moist conditions should have resulted in some corrosion on the fasteners, leading to increased withdrawal resistance. Previous studies with rail spikes in ties treated with ammoniacal copper zinc arsenate showed that spike withdrawal resistance increased markedly with exterior exposures (Morrell et al. 2012). This process is beneficial as long as the corrosion does not continue to the point where the fastener is weakened. Exposure to the second moisture cycle produced increases in withdrawal resistance in many treatments, but the differences were less dramatic than those found with the initial wet–dry cycle. All of the fasteners exhibited some degree of surface corrosion at the end of the wet–dry cycles, but there were no noticeable differences between the treatments for a given species.

Ideally, a preservative treatment used for railroad ties would provide some level of water repellency that would limit extreme changes in moisture content that induce swelling and shrinkage leading to the development of deep checks. Water repellency is a subjective measurement that is dependent on wood species, surface quality, grain orientation, the presence of preservative, and a host of other factors. The droplet approach used in this study is subjective, but rapid, and provides a relative assessment of surface moisture behavior. For the purposes of our assessment, the results 25 minutes after droplet application were used to compare treatments and species. The tests should show a decrease in water droplet ratings as the materials are wetted and dried if the applied treatment affected surface moisture behavior (i.e., lower water repellency). Wetting and drying should result in surface

Table 2.—Effect of wood species, initial wood treatment (creosote, creosote with a polymer, and copper naphthenate [CuNaph]), and wet–dry cycling on nail withdrawal resistance.

Wood species	Treatment	Maximum withdrawal load (N)[a]			
		Initial level	1 wet–dry cycle	2 wet–dry cycles	3 wet–dry cycles
Hard maple	Creosote	1,381.9 (221.7)	2,076.8 (135.8)	2,065.3 (162.5)	1,672.02 (217.9)
	Creosote–polymer	1,081.0 (209.4)	1,644.5 (104.0)	1,897.4 (310.9)	1,479.22 (107.2)
	CuNaph	1,759.6 (64.8)	2,120.6 (149.3)	1,873.9 (224.8)	1,101.1 (89.2)
Soft maple	Creosote	935.6 (180.7)	1,972.4 (227.6)	2,218.6 (245.7)	2,199.26 (474.2)
	Creosote–polymer	1,021.4 (89.1)	1,738.1 (299.9)	2,068.9 (149.2)	2,029.38 (317.3)
	CuNaph	1,186.0 (276.2)	1,632.4 (121.5)	1,840.1 (76.5)	1,698.06 (188.4)
Red oak	Creosote	976.8 (133.4)	1,725.4 (215.5)	1,478.6 (386.5)	1,628.18 (257.7)
	Creosote–polymer	719.4 (148.1)	1,407.4 (123.3)	1,588.6 (280.5)	1,427.36 (565.3)
	CuNaph	1,335.8 (286.3)	1,572.4 (125.1)	1,655.3 (255.2)	1,498.12 (423.6)
Black gum	Creosote	1,474.4 (192.7)	1,564.1 (475.1)	1,121.9 (498.6)	838.96 (98.5)
	Creosote–polymer	690.9 (112.2)	1,127.9 (13.0)	1,296.8 (180.5)	1,031.48 (149.0)
	CuNaph	1,399.8 (194.5)	1,406.5 (181.9)	1,488.9 (284.8)	546.9 (41.9)
Ponderosa pine	Creosote	452.8 (129.9)	732.5 (152.0)	849.8 (133.6)	1,943.94 (322.5)
	Creosote–polymer	385.4 (67.5)	844.6 (152.6)	1,030.2 (154.9)	1,936.72 (283.5)
	CuNaph	546.7 (100.9)	733.7 (85.1)	790.4 (169.4)	1,772.92 (329.3)
Douglas-fir	Creosote	922.8 (156.4)	1,193.9 (220.6)	1,371.4 (492.0)	1,234.16 (348.7)
	Creosote–polymer	457.9 (95.9)	586.6 (105.0)	604.4 (121.7)	552.34 (75.0)
	CuNaph	959.5 (185.2)	1,119.7 (239.4)	1,076.3 (193.0)	700.42 (249.0)

[a] Values represent averages of 5 specimens/species–treatment combination. Figures in parentheses represent one standard deviation.

preservatives being released into the treatment water, thereby altering water repellency. Our results were inconsistent with regard to wood species and treatment (Table 3). For example, water droplet ratings increased with moisture cycling in 8 of the 18 species–treatment combinations, increased and then decreased in 5 treatment combinations, decreased in 3 treatments, and did not change in the remaining 3 treatments. The results suggest that none of the treatments consistently differed in the ability to act as a water repellent. The results should be considered preliminary because previous studies found that >6 wet–dry cycles were required to produce consistent changes in water repellency on smaller samples (Beck et al. 2014). However, the lack of consistency suggests that the addition of the polymer to creosote had no noticeable effect on this property.

Table 3.—Effect of treatment with creosote, creosote with a polymer, or copper naphthenate (CuNaph), and repeated wet–dry cycles on water repellency of various wood species.

Wood species	Treatment	Average water droplet rating at 25 min[a]			
		No cycle	1 wet–dry cycle	2 wet–dry cycles	3 wet–dry cycles
Hard maple	Creosote	1.3	1.0	3.2	1.0
	Creosote–polymer	2.2	3.2	1.0	1.0
	CuNaph	2.2	1.5	3.3	4.7
Soft maple	Creosote	1.3	3.5	1.7	3.7
	Creosote–polymer	1.3	1.7	4.0	2.3
	CuNaph	3.5	2.0	3.3	4.0
Red oak	Creosote	1.7	1.2	2.5	1.0
	Creosote–polymer	3.3	2.5	1.3	4.3
	CuNaph	3.3	3.5	3.3	4.3
Black gum	Creosote	1.0	1.0	1.5	1.0
	Creosote–polymer	1.0	1.5	1.0	1.0
	CuNaph	2.7	2.0	1.3	3.3
Ponderosa pine	Creosote	1.0	1.2	2.0	1.0
	Creosote–polymer	1.0	1.2	3.2	1.3
	CuNaph	1.0	3.2	3.0	1.3
Douglas-fir	Creosote	1.0	2.2	3.0	2.7
	Creosote–polymer	4.2	3.0	3.3	2.3
	CuNaph	2.5	1.2	2.0	2.3

[a] Values represent averages of 5 replicates/treatment where 5.0 signifies an ovoid drop on the wood surface, while 1.0 signifies a drop that was absorbed by the wood.

Conclusions

The addition of a polyethylene polymer to creosote had no significant effect on flexural properties, fastener withdrawal resistance, or water repellency of wood compared with creosote treatment alone for the six species tested and appeared to result in reduced creosote uptake. The results suggest that the polymer did little to improve material properties of the species tested.

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