Improving the Performance of Waterborne Preservatives in Infrastructure Applications

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Abstract

This article explores the benefits covering waterborne preservative systems that include an oil emulsion treatment. Waterborne preservatives have a long history of protecting wood products in severe exposures. Enhancing the surface of these products can increase their service life. Oil emulsion treatments were originally developed to improve the climbability of waterborne poles by utility linemen. Over time, these products have shown that they can improve other surface characteristics, such as checking, flammability, and, with added pigments, ultraviolet exposure.

This article discusses waterborne preservatives used in infrastructure applications and the ongoing research to improve their performance. Waterborne preservatives used in the United States infrastructure were developed in the late 1920s and early 1930s. However, there was little use of these systems until the 1970s, when two major events occurred that spurred their growth: the advent of treated wood decks and the Arab oil embargo. This triggered the proliferation of wood-preserving plants that would treat with waterborne preservatives, thus making a significant entry into what had been an industry of creosote and oil-borne preservative systems.

Early advantages of waterborne preservatives were surface cleanliness, the lack of smell, the ability to paint or stain, and restricted leaching and migration compared with oil/oil-borne preservatives, such as creosote and pentachlorophenol (penta). The two main waterborne preservatives used for infrastructure treatment today are chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA). CCA is used primarily in the eastern United States for nonresidential uses. CCA was developed in India by Dr. Sonti Kamesam (Kamesam 1938) and was brought to the United States by Bell Labs for use in telephone poles. Its initial use was along the eastern seaboard. Known in the early days as ASCU (Fig. 1), or ''Green Salts,'' CCA is treated at ambient temperatures and flows easily into wood, depending on wood cell structure and moisture content. Pines in particular accept treatment readily when moisture has been removed to allow it to be pressured through the sapwood. Although used extensively today for poles, posts, piling, and structural timbers 6 by 6 or larger, CCA was not an instant commercial success. During the 1930s and 1940s, Bell Telephone Company treated nearly 20,000 utility poles with CCA, but economics favored other treatments. Two decades after the formulation of this preservative, CCA-treated wood was no longer being produced in the United States. It was not until the late 1950s that CCA began to be used again in the United States for treating dimensional lumber; the initial use was for cooling-tower lumber. Statistics from 1968 show that 35 years after Kamesam's invention, CCA was still a little-used preservative in the United States. Its resurgence to prominence began in the 1970s with the pressure treatment of utility poles and the introduction of pressure-treated wood decking. Although the use of CCA for residential applications has been eliminated, its use in the utility pole, piling, and agricultural products market has continued to grow (DeVenzio 1998).

ACA was formulated at the University of California, Berkeley, for the treatment of live fruit/nut trees to fend off attack by organisms. Unfortunately, the trees did not survive; however, once the project was over, the remains of the trees that were left in the ground for years were found

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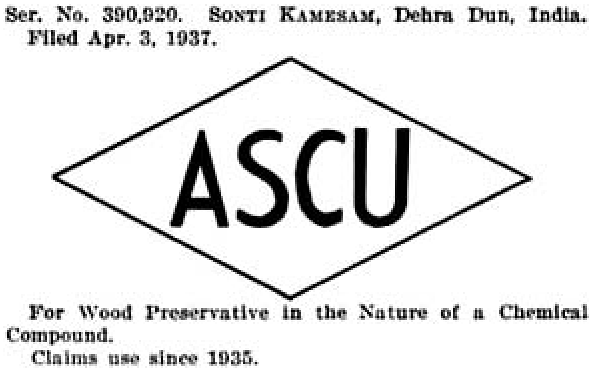

Ser. No. 390,920. Sonti Kamesam, Dehra Dun, India.
Filed Apr. 3, 1937.

ASCU

For Wood Preservative in the Nature of a Chemical Compound.
Claims use since 1935.

Figure 1.—ASCU trademark issued by the US Patent and Trademark Office (1937).

to be solid. ACA, used primarily in the western United States starting in the 1930s and known as Chemonite, was reformulated in the 1980s into ammoniacal copper zinc arsenate (ACZA) with a zinc component replacing half of the arsenate component (Patel and Kuswanto 2014).

If waterbornes were so good, what took them so long to be used? Humans are drawn to the known, so while some experimented and played with these new concepts, the oil/oil-borne preservatives creosote and penta remained dominant in the protection of infrastructure materials. What changed? Two major events in the 1970s in the United States made them desirable. First, there was a housing boom and the introduction of treated wood for residential applications, such as decks and fencing. Oil-borne preservatives were not desirable for this market, so treating plants were being built for waterborne preservative systems. The next thing that happened that more directly affected the infrastructure market was the Arab oil embargo of 1973. Up to this point, pentachlorophenol, which had supplanted creosote in many infrastructure applications, was the major preservative system, and it was delivered in a diesel fuel/cosolvent carrier into the wood. In the 1970s, diesel was not available for this use, and the original CCA test poles from early 1940s were still doing well, so the building of waterborne preservative plants made the conversion easier.

Some advantages of waterborne preservatives include ambient to low-heat treating cycles. Waterborne preservatives “fix” in the wood, which means they become difficult to dislodge and remove from the treated product. They are “dry” to the touch once the water is evacuated from the structure. They have no strong odor and are paintable if desired. They are typically lower in cost since the carrier system of the treating solution is water. One can analyze for the actual components in determining the retention of the preservative in the wood. Penetration is also easily determined by color change or the use of penetration indicators that trace the copper component into the wood.

Some of the challenges of waterborne systems include that the wood must be dry to accept treatment. Sterilization prior to treatment is important since there is no heat to sterilize during the treating process as with oil-borne preservatives. As the wood dries after treatment, it will check as it shrinks. Waterborne-treated poles tend to be “harder” than those treated with oil-borne products because there is no oil to lend lubricity to the wood. Waterborne preservatives leave the wood in its natural state aside from color. Because of its chromium content, CCA-treated poles and posts are prone to continued burning, or “afterglow,” when the ignition source is removed. ACZA does not have this issue because it has no chromium. Afterglow can be reduced by using aftermarket products; either a paint or coating can be applied to the surface or precoated products can be affixed to the surface. An oil emulsion product has also provided some help reducing the effect. Adding borate to the treating solution will also minimize afterglow (W. C. Kelso and H. M. Barnes, unpublished data, 1980).

In addressing these challenges, the biggest forward movement was in the development of dry kilns and dry kiln schedules for large-diameter and long-infrastructure-sized materials. This addressed the issue of sterilization prior to treatment and the establishment of holding time between kiln drying and treating to prevent potential infestation. Kiln drying also addresses the concerns over checks by opening them up prior to treatment. In this way, treatment would protect that area and beyond the depth of checking.

Current Infrastructure Chemistries

The process of restricting movement of the two systems is referred to as “fixation.” CCA goes through a chemical reaction process where the chromium oxide component reacts with the wood sugars in the cell and bonds the copper oxide and arsenate within the cell walls (Wallace 1968; Dahlgren 1972, 1974, 1975a, 1975b, 1975c; Dahlgren and Hartford 1972a, 1972b, 1972c). This leads to long-lasting preservative protection for the wood product and makes it excellent for use in infrastructure applications where difficult exposure and long service life are expected. With ACZA, fixation is done by solubilizing the metal in ammonia and then mixing with water to form a solution (Lebow and Morrell 1993). On completion of the treating process, the ammonia is released and captured through a final vacuum, leaving the solubilized metals behind in the wood cells. Based on their protection systems, these waterborne preservatives are used in marine environments on both coasts of the United States.

Emulsion Treatment Development

The use of additives to improve the performance of treated wood has a long history of research effort. Belford and Nicholson, in two papers to the British (1968) and American (1969) Wood Preservation Associations, summarized much of the early work with emulsion technology and CCA-treated wood. They concluded their extensive review and research by saying that “CCA-emulsion treatment represents a significant step forward in the wider utilization of salt-type preservatives and effectively extends their range of performance into more severe conditions of climatic exposure.”

Levi et al. (1970) indicated that in pines, the water repellent (WR) concentrates in the latewood rays, the most susceptible tissue to weathering. This leads to long-term effectiveness at low WR retentions. WR additives have reduced pole hardness (Preston et al. 1989) and improved the weathering characteristics of shingles (Plackett et al. 1984). The authors demonstrated that submicrometer-sized WR in CCA showed long-term weatherability.

Fowlie et al. (1990) showed that WR additives enhanced weathering and had no deleterious effects on biodeterioration and mold growth or paintability. On the negative side, nail withdrawal was lower, as was gaff penetration. The gaff data were taken as a positive. Zahora and Rector (1990) showed that WR additions to CCA enhanced weathering characteristics, hardness, and runoff and had no detrimental effect on protection from biodegrading organisms. They found that solution stability varied greatly, depending on both surfactant and hydrophobe composition. Particle size of the emulsion formulation was critical to the rapid penetration of the water repellent/preservative and was species dependent. Zahora (1991) showed that nonpolar emulsified additives to CCA reduced both the swelling rate and total swelling in immersion tests compared to untreated or CCA-treated wood alone.

Waterbornes are not the only systems to which emulsion technology has been applied. Blew and Panek (1964) discussed water repellents and oil-borne systems such as penta/oil. Perhaps the greatest push has been in Australia with the development of pigmented emulsified colored creosote (Watkins 1977; Greaves 1980, 1986; Chin et al. 1983; Greaves et al. 1984), resulting in a patent (Watkins et al. 1992).

Performance Enhancement Evaluation

Some of the additives that have been tried include water repellant used to stabilize residential deck lumber. These work by allowing moisture to slowly leave the piece of wood and not allowing it to return, preventing the expanding and shrinking cycles of exposed lumber and reducing the checking that would occur. In the case of poles, while it did reduce checking, once the moisture was gone, the water repellant prohibited moisture movement back into the wood, thus maintaining stability. This led to hardened pole surfaces and poles being difficult to climb. Polyethylene glycol formulas were also tried, but they were almost the opposite of the water repellants, as they were very hygroscopic (Trumble and Messina 1985, 1986, 1987). They were so hygroscopic that treatment left water in the pole. Later, versions were made that worked better, especially with the special processing requirement applications in Canada.

By the mid-1980s, it was determined that a water–oil emulsion offered the best opportunity to replicate the ''oil'' conditioning obtained with oil-borne preservative systems. Along with full-size pole testing at the Conley, Georgia, Technical Center, field test stakes were treated and monitored by Mississippi State University. The use of the CCA/oil emulsion technology for poles, now known as Wolman ET (McIntyre and Pasek 1990), was introduced at the American Wood-Preservers' Association (AWPA) Symposium on Review of Current Wood Preservation Research in North America by Craig McIntyre (1989). In an extensive report to AWPA, McIntyre and Fox (1990) reported no deleterious effects for 6-month and 1-year climbing evaluations as well as results of strength, corrosion, conductivity, migration, fixation, and preservative testing of the CCA/oil system.

Climbing Evaluations

While early lab testing showed the positive effects of oil emulsion, the main use for climbing enhancement led to having full-size poles installed and having linemen climb and rate their experience. While subjective, it proved to be the most appropriate method of testing, as it was being evaluated in a real-world scenario. In this test, poles treated with oil-borne (pentachlorophenol and creosote) preservatives as well as unmodified CCA and CCA with the water–oil emulsion at various levels were treated and installed in 1988 in Conley, Georgia. All poles were treated at the same facility, ensuring a similar wood substrate no matter the preservative system used.

A major part of the infrastructure are the power and communication grids for supplying power and connections to people. By many estimates, there are over 160 million poles serving these two aspects of the infrastructure. For over half the grids' existence, wires have been connected to the poles by linemen who climbed and attached them to the poles. Even today with the plethora of bucket trucks available, there are a number of poles that must be climbed due to topography and storm response. Almost as soon as waterborne poles began to be a part of the grid, there was an interest in proving their climbing characteristics. A number of additives, ranging from water repellants to polyethylene glycol to oils, and their levels were evaluated.

The focus of this article is the work that has been done and that continues to address the surface issues of waterborne-treated wood products used in infrastructure applications. Initially, readings from a Pylodine were used to measure the ease of entry into the wood surface. It was quickly learned that when information was shared with utilities, their linemen did not trust the instrument readings. It was soon realized that full-size poles were needed that would allow linemen to put their gaffs into them and rate the pole themselves. While Pylodine numbers are listed in this report, the numbers that are indicative of their actual use of the poles are what they go by.

Table 1 lists the results from a trial conducted by the Philadelphia Electric Company (Lacey 1989). The poles were rated on a 1-to-10 scale with 10 being the best in each category and 1 being the worst. The intent was always to improve the surface of CCA-treated poles, but there will always be a comparison with oil-borne pentachlorophenol-treated poles. The inclusion of an oil emulsion in CCA yielded a 59 percent rating improvement over CCA alone and was 84 percent of the penta-treated pole value.

Engdahl et al. (1992) reported on a study of 1,379 CCA/oil- and CCA-treated poles installed on American Electric Power service lines. Results from the 892 returned surveys indicated that linemen preferred the CCA/oil-treated poles to regular CCA. Even at the lowest retention, the oil additive improved the climbability of the CCA poles. Carey (2009) discussed the history of climbing trials with poles treated with CCA/oil and presented new 20-year data (Carey 2010).

Based on the earlier climbing trials, criteria were developed for a pole climb rating form. The first section of the form requests general information, such as date, temperature, scorer, utility, name of evaluator, weight, gaff type, years of climbing experience, and years of climbing CCA experience. The second part of the form deals directly with the performance of the pole. Since this part of the evaluation was critical, instructions (Table 2) were given to the scorers and evaluators. These questionnaires were used in continuing trials at the Conley, Georgia, Technical Center.

Figure 2 shows linemen in climbing trials. To get an idea of what a climbing trial looks like, here is a link to a video that was made at the 25-year trial: https://youtu.be/ww9TSwHo7KE. To get a lineman's perspective, here is a

Table 1.—1988 Philadelphia Electric Company climbing trials of pine utility poles with various treatments (Lacey 1989).[a]

Parameter	CCA (0.6 pcf) + oil emulsion (2 pcf)						Penta (0.38 pcf)		CCA (0.6 pcf) + PEG		CCA (0.6 pcf)	
Climbability												
1. Comfort while climbing	8	7	5	7	7	7	8	9	5	6	3	5
2. Gaff penetration	7	6	5	7	6	6	7	9	5	3	2	2
Workability												
3. Confidence while working	8	8	4	7	7	7	8	9	7	5	5	4
4. Hole boring brace and bit	6	9	7	4	9	6	6	8	8	8	7	7
5. Lag driving	8	7	6	3	7	5	7	7	4	6	2	3
6. Staple driving	8	8	7	5	8	5	8	8	6	5	1	6
Treatment average	6.6						7.8		5.7[b]		3.9	
Pylodine reading	10.8	9.3	10.8	10.5	9.3	9.8	13.3	12.5	9.0	9.5	6.5	6.5

[a] CCA = chromated copper arsenate; PEG = polyethylene glycol.

[b] Previous testing did not rate these poles this high. Softening and easier climbing may have resulted from 2 years of exposure.

Table 2.—Developed questionnaire used to evaluate climbability of poles.

Column	Item (10 = excellent, 1 = unacceptable)
1	Pole no.
2	Gaff penetration (how easy is it to puncture surface?) 1–10 ○ 1. Was the pole hard? ○ 2. Was extra effort needed to climb pole?
3	Once punctured, how easy to get to a ‘‘working’’ depth? 1–10 ○ 1. Was extra effort needed to set gaffs?
4	Ease of gaff withdrawal 1–10 ○ 1. Did gaffs stick?
5	Confidence in working pole 1–10 ○ 1. Do you have to look before taking a step? ○ 2. Did you have a feeling of ‘‘cutting out’’?
6	Based on your experience, overall, how does this pole compare? 1–10

GoPro video of climbing a pole: https://youtu.be/ea5VoSUHRmg.

Table 3 shows the overall values for 30 years of climbing trials. The improvement over CCA-only poles is evident and is very close to the oil-borne penta value. In most of these trials, the linemen involved were used to climbing oil-borne poles and had a negative perception of ‘‘green’’ or CCA poles from anecdotal information. The fact that they rated the CCA/oil poles so high indicates that they were surprised by the climbability of the oil emulsion poles. This was confirmed by their comments after the trials.

Fire Retardancy

As mentioned earlier, it is the chrome component and the heartwood resins that contribute to this phenomenon in CCA-treated wood, particularly a concern for poles used in infrastructure applications. Although several organizations are working on testing procedures, the Australian brush fire test is currently close to an industry standard, showing product performance in grass wildfire scenarios (Evans et al. 1994). Simulated typical brush fires based on an Australian test method were achieved through the placing of wire containment 4 feet in diameter. A post is then surrounded with 6-inch-high wheat straw to simulate a typical brush fire. To simulate a severe brush fire, a post is surrounded with 2-foot-high wheat straw within the 4-foot-diameter wire containment (Fig. 3). Posts are used in this test instead of poles, as they have less volume of wood to resist fire, thus giving a more severe test than an actual piece of pole-size material.

Figure 4 shows the afterglow effect from (a) continued internal burning and smoke generation to (c) complete failure of a CCA-only post from inside-out burning. Studies were conducted in Australia on slash pine (*Pinus elliotii*) fence posts. The treatments were untreated, CCA/creosote, CCA/wax, CCA/oil, and creosote. Treated and untreated posts were planted in the ground in a randomized block


(a) (b) (c)

Figure 2.—Climbing trials: (a) evaluating questionnaire and (b and c) trials in progress.

Table 3.—Overall average ratings for 30 years of various climbing trials.[a]

Treatment	1997 9 yr	2002 14 yr	2002[b] 14 yr	2008 20 yr	2011 23 yr	2013 25 yr	2018 30 yr
CCA	4.8	5.5	4.6	5.6	5.1	5.1	6.75
CCA + wax			4.7				
Penta	7.2	7.0	N/A	7.6	5.7	6.9	7.91
CCA/oil emulsion	7.6	7.3	6.8	7.6	6.8	6.1	7.7

[a] CCA = chromated copper arsenate.

[b] Utility wanted to compare CCA, CCA + wax, and CCA/oil emulsion treatments only.

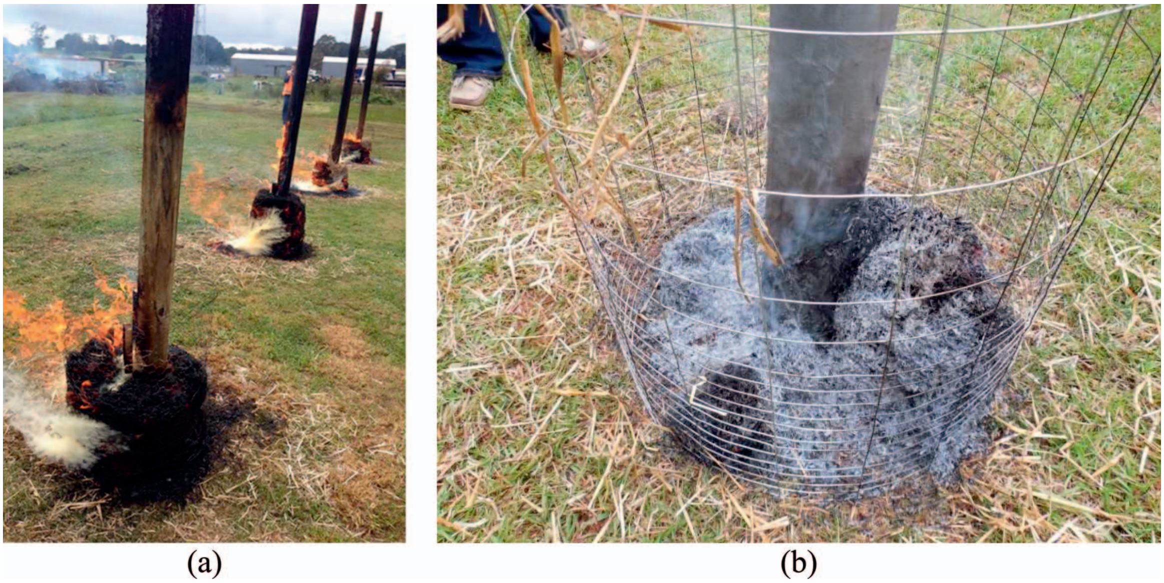
(a) (b)

Figure 3.—Severe burn setup (a) for brush fire test and (b) after testing.

design, weathered for 6 months, and then subjected to a controlled burning test using two fuel loads. Creosote treatment increases the time that the posts were alight, whereas CCA treatment had no such effect. However, CCA-treated posts smoldered until destruction of the majority occurred. Posts treated with CCA/oil took longer for destruction to occur than posts treated with CCA/creosote or CCA/wax. CCA/oil-treated posts were less likely than CCA/creosote- or CCA/wax-treated posts to be destroyed after 2 hours of smoldering.

Checking

Another area of concern is checking. While checks are open during the drying process and then closed during the

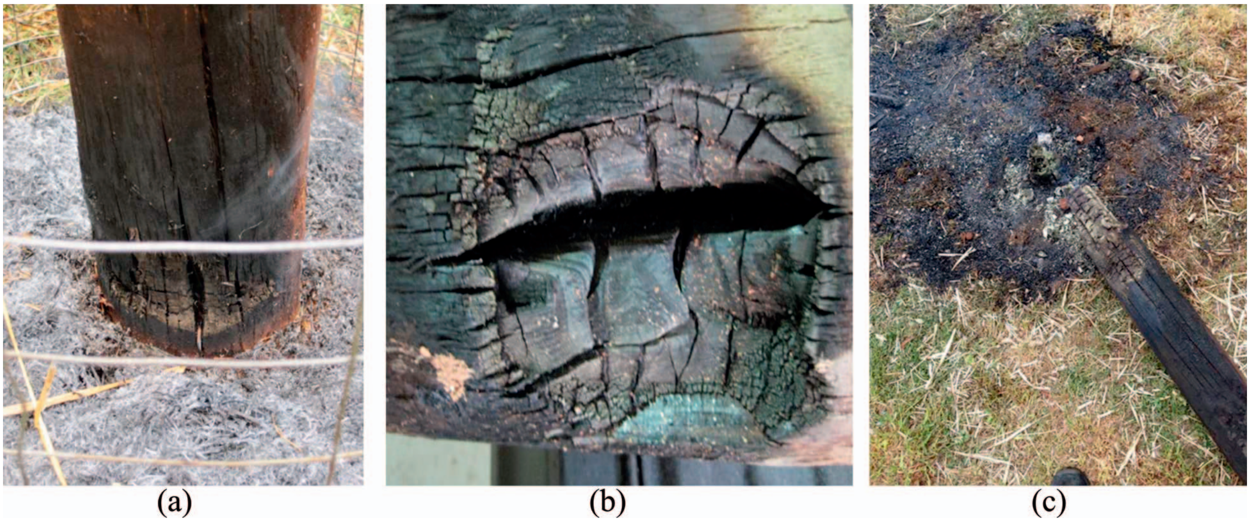
(a) (b) (c)

Figure 4.—Afterglow effect showing (a) smoldering after ignition source is gone, (b) severe checking, and (c) chromated copper arsenate post felled because of afterglow.

treating process, they will reopen again as the wood dries. Reducing these effects in poles in particular is a safety issue for linemen. It is a longevity issue for structural members in construction.

Poles: A pole study with 36 poles was developed to investigate checking. The 36 poles were divided into six mixed groups, each group including poles treated with oil/penta and CCA and four retentions of CCA/oil ranging from a low to a high oil concentration. The six poles in each group were compared with each other and ranked for checking severity from 1 (least severe) to 6 (most). After all six groups were evaluated, the pole grades were averaged for each preservative solution. The results are given in Table 4.

It is important to note here that most of these poles were surrounded by trees with approximately 50 percent of the pole exposed to the sun. It was difficult, with the exception of the oil/penta, to make a determination of what effect the oil really had on checking between the groups where the poles were shrouded in tree cover. Therefore, the evaluation was made with respect to the sunny side of each pole. The oil/penta poles showed the worst checking with CCA next. The least checking was noted in the CCA/oil poles.

Fence boards: A commercial treater that uses CCA with oil that includes a brown pigment was used for some fence boards. The fencing was installed at their property on the back bay in Biloxi, Mississippi. Due to the environment and the thinness of fence boards, they have not held up for very long. The boards in Figure 5 have been in exposure for more than 8 years. No checking has been seen on either the exposed side or the protected side.

Crosstie Studies

Ties in southwestern Florida are being evaluated. Railroad personnel indicated that they were getting only 7 years of service out of creosote-treated hardwood ties (Fig. 6). The treatments are ACZA, ACZA + ET, ACZA + disodium octaborate tetrahydrate (DOT), and ACZA + DOT + ET. These test ties are in radius track, thus putting additional stress on the ties (Fig. 7). The ballast under the ties is nonexistent, leaving the ties to ''pump'' up and down into the sandy soil. After 8 years, the test ties are having no problem with the intense biodeterioration that caused the creosote-treated ties to fail in 7 years. Additional test ties in track are being evaluated in southeastern Georgia and eastern North Carolina.

Table 4.—Checking comparison for pole treatments.[a]

Group	Oil/penta	CCA/creosote	CCA/creosote with 1 pcf oil
1	6	5	3
2	6	5	3
3	6	5	1
4	6	5	2
5	6	4	3
6	6	5	3
Average	6	4.8	2.5

[a] CCA = chromated copper arsenate.

Trials with Eucalyptus

Based on the success in the United States on softwood poles and hardwood tie trials, a trial has been started in Argentina on eucalyptus poles and timbers to determine if CCA + ET can reduce the severe checking in eucalyptus used in infrastructure applications. Tests were initiated in July 2018. Figure 7 shows some treated eucalyptus bridge timbers and typical checking.

Figure 5.—No checking on chromated copper arsenate/oil–treated fence boards on the exposed (left) or protected (right) side after more than 8 years of exposure.

Figure 6.—Test ties in track (left) showing poor ballast and radius track (right).

Bioefficacy

In December 1990, a series of AWPA (1990) E7 southern pine field stakes were treated and installed in Mississippi State University's field test sites at the Harrison Experimental Forest (Saucier; AWPA Zone 5) and Starr Memorial Forest (Dorman Lake; AWPA Zone 4). Stakes were treated using a full-cell cycle of 30 minutes full vacuum and 60 minutes at 150 psig. Stakes were assigned to treatment groups such that each group had equal density distributions. Ten replicates per combination were treated. Stakes were rated annually for decay and termite attack using the AWPA E7 rating scale.

Figure 8 shows the depreciation curves for CCA and two CCA + ET at five CCA retentions. ET provides improved performance at retentions less than the ground contact standardized retention (<0.4 pcf). This means that ''weak sisters'' found in a normal distribution of retentions within a treatment charge may perform as well as those treated to standard. A slight improvement is shown at the ground contact retention (0.4 pcf) . At the pole retention of 0.6 pcf, CCA and 2 pcf ET are the same, but 1 pcf ET is slightly higher. This suggests that commercial charges should go to 1 pcf ET, a less expensive raw material cost to the treater. Similar trends are seen in the Saucier test plot curves in Figure 9.

Dose–response curves at 5 and 20 years are shown in Figure 10. At Dorman Lake, the main deterioration agents are decay fungi. The protection is enhanced by the addition of ET. The benefits are greater for low retentions at year 5 but better for high retentions at year 20. Overall, ET at 1 pcf is better.

At the Saucier plot, termite attack is greater except for 2 pcf ET at year 5. ET has a positive effect at year 5, but there is no difference among treatments at year 20. The deterioration is greater at the Saucier site, reflective of the AWPA hazard zone differences between the two sites: HZ4 for Dorman and HZ5 for Saucier.

Summary and Conclusions

- Even with the history of good performance that waterborne preservatives have in infrastructure applications, there are still opportunities to improve their performance.

Figure 7.—Treated eucalyptus bridge timbers (left) and typical checking in eucalyptus (right).

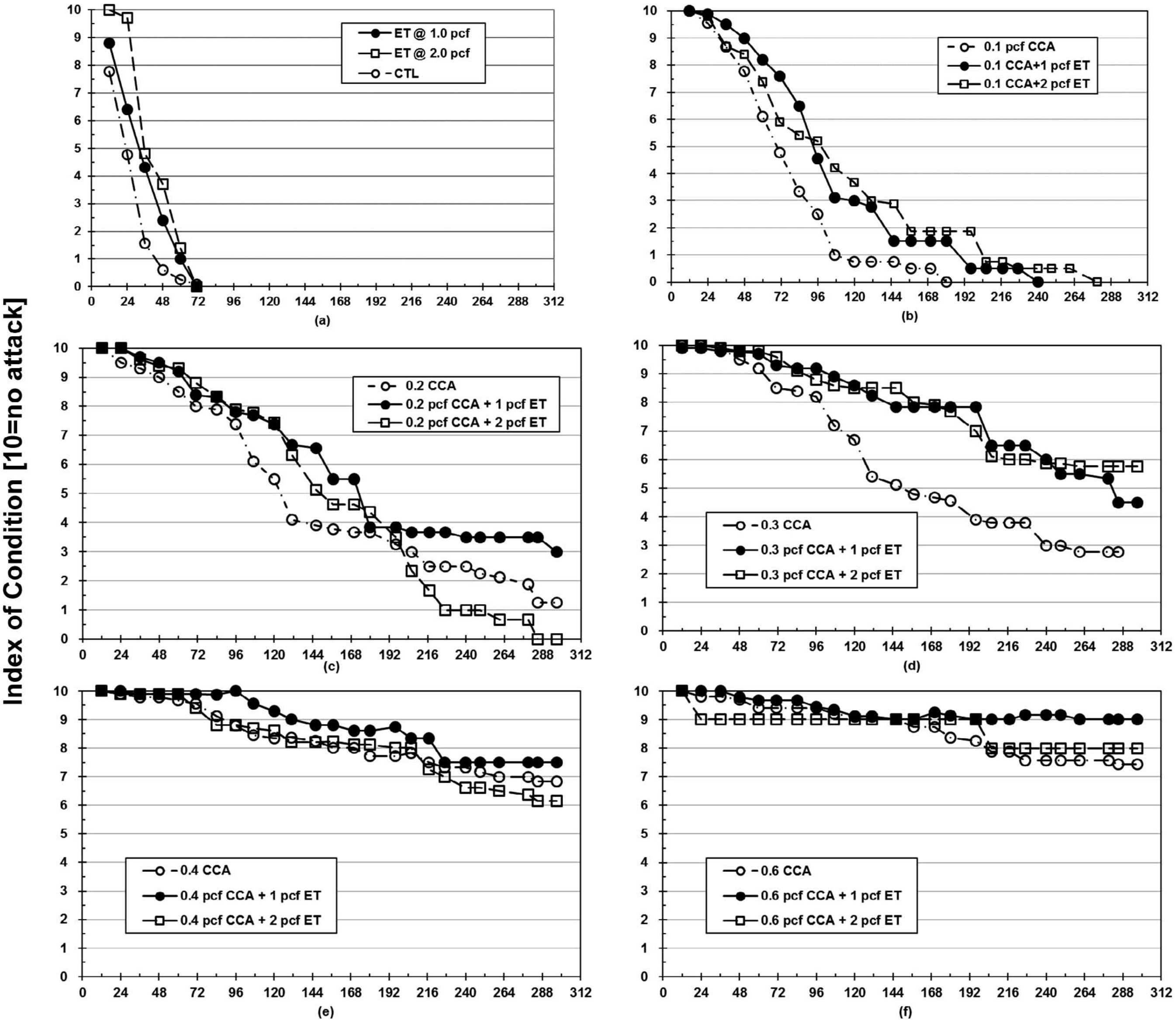

Figure 8.—Depreciation curves in the Dorman Lake test plot.

- The application of emulsified oil treatments has shown the ability to improve service life and surface characteristics of waterborne-treated wood products.
- Borates and their ability to fortify the preservative efficacy is another ongoing evaluation project.
- Evaluation of these technologies across species, waterborne preservatives, and product applications continues.

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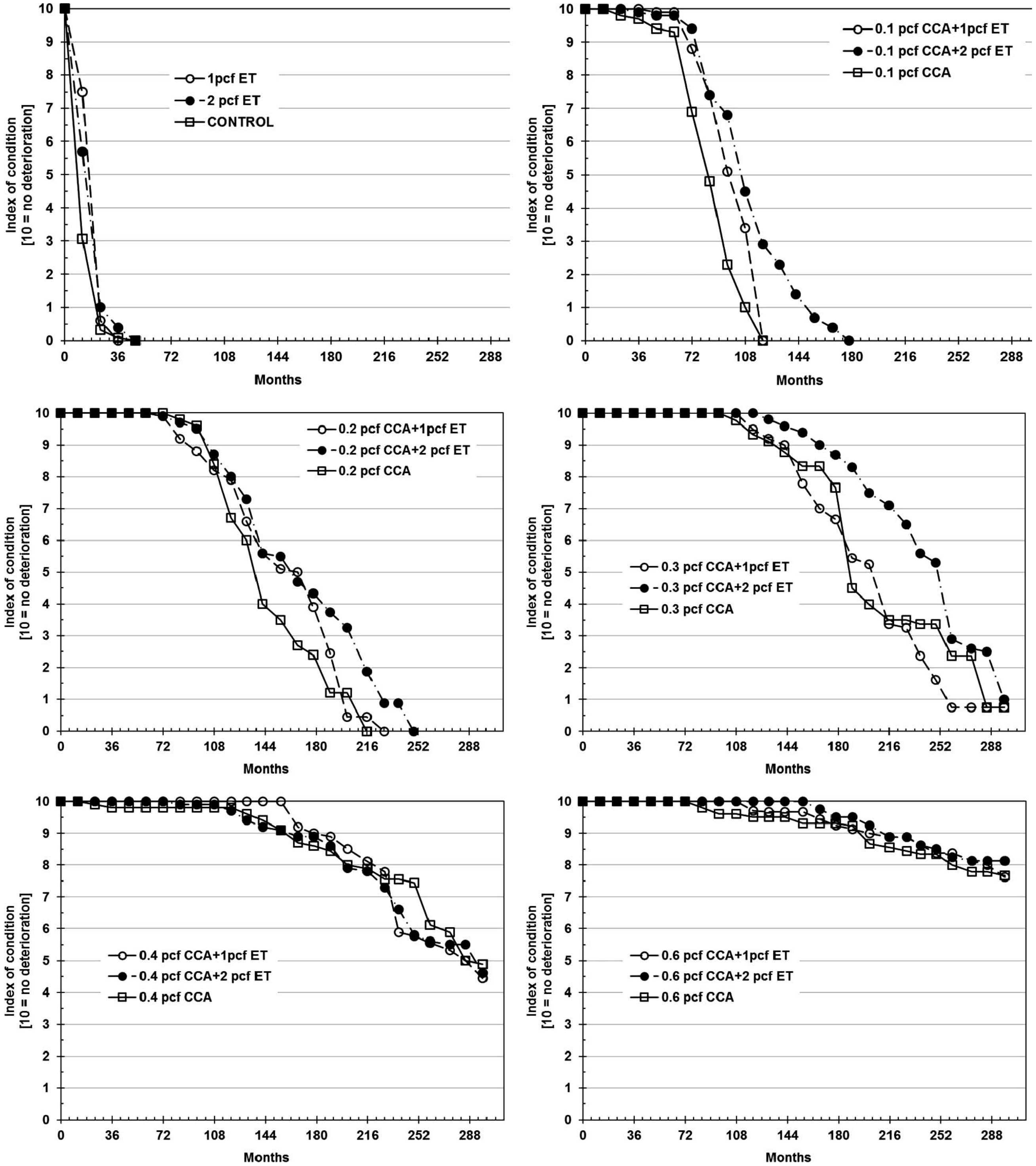

Figure 9.–Depreciation curves in the Saucier test plot.

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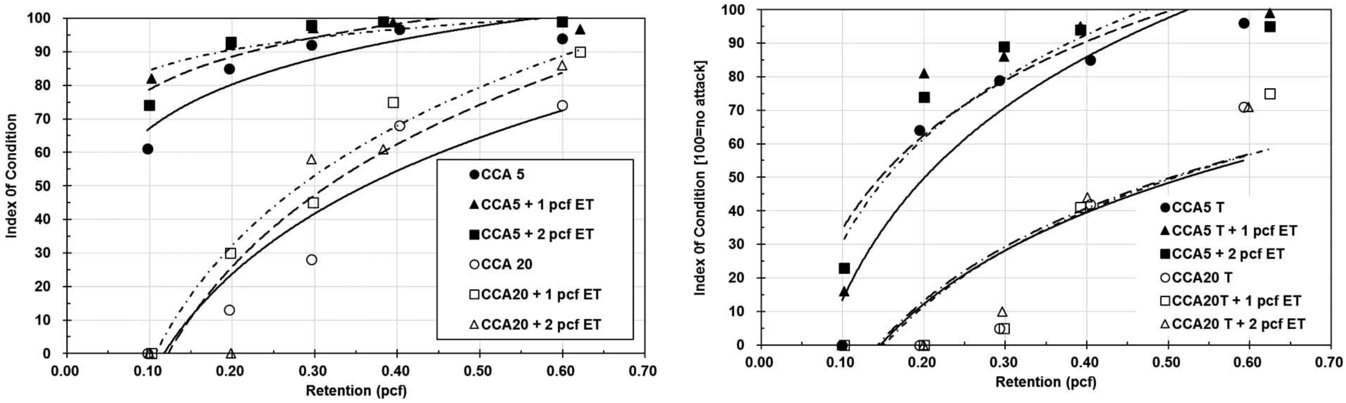

Figure 10.—Dose–response curves at 5 years and 20 years (Index of Condition normalized to a 100-point scale) for the Dorman (left) and Saucier (right) test plots.

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