Long-term Durability of CCA and ACA: How is 0.4 Doing?

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ABSTRACT

For decades the phrase "point 4" was synonymous with wood treated for use in contact with the ground. In this paper we review how and why the 0.4 lb/ft³ (6.4 kg/m³) retention became such an accepted standard, and then evaluate how well this retention has performed in long term stake testing. Data from plots near Saucier, Mississippi that contained southern pine 2 by 4 nominal (38 by 89 mm) stakes pressure treated with either ACA, CCA-A, CCA-B or CCA-C were evaluated. The plots ranged in age from 20 to 61 years. The data indicate that the 0.4 lb/ft³ (6.4 kg/m³) retention has provided good, but not unlimited, protection of wood placed in ground contact. Durability was notably diminished at retentions below 0.4 lb/ft³ (6.4 kg/m³) and durability was greater for retentions above 0.4 lb/ft³ (6.4 kg/m³). The 0.4 lb/ft³ (6.4 kg/m³) retention appears to be near the minimum for long-term ground contact, and the selection of 0.4 lb/ft³ (6.4 kg/m³) for general ground contact applications and 0.6 lb/ft³ (9.6 kg/m³) for critical applications appears to have been a wise choice. The data also indicates that the 0.4 lb/ft³ (6.4 kg/m³) CCA retention is not excessive, and is an appropriate choice for comparison to test formulations intended for use in ground contact applications.

Keywords: durability, long-term, ACA, CCA-A, CCA-B, CCA-C, 0.4

INTRODUCTION

For decades, chromated copper arsenate (CCA) and ammoniacal copper arsenate (ACA) preservatives stood as the gold standard for waterborne preservative treatments. The common "0.4"ground contact retention has become so familiar that users of treated wood, ranging from home owners to federal agencies, continue to attempt to specify treated wood simply as "green-treated" and "point 4".

The derivation of the 0.4 lb/ft³ (6.4 kg/m³) retention is much more complicated than the value itself. The use of CCA and ACA in the U.S. can be traced back to the introduction of "Greensalt" and "Chemonite" the 1930's and 1940's. Bell Telephone Company acquired the US patent rights to a CCA formulation referred to as "Ascu" in 1938, and began routinely using the formulation they called Greensalt to treat utility poles in the early 1940's (DeVenzio, 1998). In 1942 Bell Laboratories presented a report summarizing the properties of Greensalt (later referred to as CCA Type A) at the AWPA annual meeting in Minneapolis (McMahon, et al, 1942) and in 1949 requested a listing of Greensalt in AWPA standards. The proponents stated that they had been using Greensalt retentions between 0.75 and 1.0 lb/ft³ (12.0 and 16.0 kg/m³) for wood in contact with the ground and 0.25 to 0.35 lb/ft³ (4.0 to 5.6 kg/m³) for wood used above ground (Anon, 1949). As part of the request they referenced data on posts, pole stubs and saplings treated to retentions of either 0.5 or 1.0 lb/ft³ (8.0 or 16.0 kg/m³). Data from South Africa on post stubs treated to an average retention of 0.73 lb/ft³ (1 1.7 kg/m³) and buried horizontally was also provided. Stake tests that had recently been initiated by the US Forest Products Laboratory at their test site in southern Mississippi were also mentioned (Anon, 1949; Blew, 1948). Based on this submission Committee P-4 recommended a provisional standard for CCA-A at the ground-contact retention of 0.75 lb/ft³ (12.0 kg/m³) and the above-ground retention of 0.35 lb/ft³ (5.6 kg/m³) (based on total salts). In that same year proponents of Chemonite (ACA) also approached Committee P-4 requesting a listing in AWPA Standards. Chemonite had been used commercially on the West Coast since 1935 (Gordon, 1947; Fritz, 1947) and both experimental and in-service data was presented to the association at the 1947 meeting (Fritz, 1947). That data included a complex array of specimens and commodities treated to retentions ranging from 0.12 to 1.0 lb/ft³ (1.9 to 16.0 kg/m³). As part of the proposal to P-4 at the 1949 meeting the proponents reported that they were currently using minimum retentions of 0.3 lb/ft³ (4.8 kg/m³) for wood above ground, 0.35 lb/ft³

(5.6 kg/m³) for wood in contact with the ground under average conditions, 0.4 lb/ft³ (6.4 kg/m³) for severe exposures, and 0.5 lb/ft³ (8.0 kg/m³) for some heavy timbers (retentions expressed as copper hydroxide plus arsenic trioxide). The retentions subsequently standardized (provisionally) by AWPA were 0.30 (4.8 kg/m³) for above ground use and 0.50 (8.0 kg/m³) for ground contact applications. The subcommittee reports do not reflect extensive discussion on either the CCA-A or ACA proposals, nor does there appear to have been an effort to analyze the data to select the optimum retention. Instead, it appears that the committee simply adopted retentions currently being used by the suppliers in their commercial operations. CCA-A and ACA were fully standardized in 1953 at these same retentions (Anon, 1953).

The CCA-B formulation (Boliden K-33) was brought before AWPA Committee P-4 in 1963 (Anon, 1963). CCA-B evolved from an older formulation, chromated zinc arsenate, which contained zinc instead of copper. CZA had been recommended for use at the relatively high retentions of 0.5 lb/ft³ (8.0 kg/m³) for above-ground exposures and 1.0 lb/ft³ (16.0 kg/m³) for ground-contact (Anon, 1949). The CCA-B proponents provided a fairly extensive data packet (Anon, 1963), similar to that described in AWPA's current Appendix A (AWPA, 2009). Agar block tests using several fungi indicated threshold retentions ranging from 0.01 to 0.29 lb/ft³ (0.16 to 4.6 kg/m³), although the proponents noted that this test "is of questionable significance". Field tests included stake tests of over 10 years in Sweden at retentions of 0.35 and 0.53 lb/ft³ (5.6 and 8.5 kg/m³), 7 year stake and post tests in Spartanburg, SC and Gainesville, F1 at retentions of 0.25, 0.5 and 0.75 lb/ft³ (4.0, 8.0 and 12.0 kg/m³) and 12 year stake: tests in Madison, WI and Saucier, MS at retentions of 0.35 and 0.49 lb/ft³ (0.56 and 7.8 kg/m³) (Anon, 1963). Although CCA-B was being used commercially at that time in Europe, in-service durability data was not included in the proposal. Interestingly, the proponents requested standardization at retentions identical to ACA (0.3 lb/ft³ (4.8 kg/m³) for above-ground and 0.5 lb/ft³ (8.0 kg/m³) for ground-contact), with CCA-E expressed on the basis of the paste composition. The rationale for selecting those specific retentions was not provided in the report, but those retentions were standardized the following year (Anon, 1964). However, they were subsequently expressed on their equivalent anhydrous basis, which resulted in retentions of 0.25 lb/ft³ (4.0 kg/m³) for above-ground use and 0.42 lb/ft³ (6.7 kg/m³) for ground-contact applications.

The next major development in CCA and ACA retentions was the 1969 standardization of CCA-C, and the accompanying move to express all of the water-borne salt formulations on their equivalent oxide basis (Anon, 1969). CCA-C (Tanalith C) was first proposed as a formulation that could serve as a single standard CCA formulation (Anon, 1968; Wallace, 1968). Data submitted to P-4 in 1968 included leached soil block tests which indicated that CCA-B and CCA-C prevented attack by *Gleophyllum trabeum* at roughly equivalent retentions (0.19 lb/ft³ (3.0 kg/m³) and 0.22 lb/ft³ (3.5 kg/m³) respectively) while a slightly greater retention (0.35 lb/ft³ (5.6 kg/m³)) of CCA-A was required. CCA.-C stake data from sites in Finland, the Philippines, and Charleston, SC were provided at retentions ranging from 0.38 to 1.24 lb/ft³ (6.1 to 19.8 kg/m³). Stakes treated with CCA-C to 0.38 lb/ft³ (6.1 kg/m³) were in nearly perfect condition after about 8 years in Charleston, but most stakes treated to 0.40 lb/ft³ (6.4 kg/m³) were destroyed within 6 years in the Philippines. Interestingly, stakes treated to 0.41 (6.6 kg/m³) and placed in Finland decayed to only 70% soundness after 5 years. In 1969, Committee P-4 recommended creating a third standard CCA formulation (CCA-C) rather than a single standard for CCA (Anon, 1969). An effort to convert the water-borne formulations to their oxide basis had been underway within Committee €'-4 for several years, but it appears that the proposed standardization of an additional type of CCA may have provided the impetus for finalizing the conversion. As shown in Table 1, when converted to the oxide basis the ground contact retentions varied from 0.38 lb/ft³ (6.1 kg/m³) for CCA-B to 0.48 lb/ft³ (7.7 kg/m³) for ACA (Anon, 1969).

Table 1. Committee P-4 proposed conversion of retentions to oxide basis (Anon, 1969)

	Retention Before and After Conversion to Oxide Basis (lb/ft³ (kg/m³))			
	Above Ground		Ground Contact	
Preservative	Previous	Oxide	Previous	Oxide
ACA	0.3 (4.8)	0.29 (4.6)	0.5 (8.0)	0.48 (7.7)
CCA-A	0.35 (5.6)	0.20 (3.2)	0.75 (12)	0.44 (7.0)
CCA-B	0.25 (4.0)	0.23(3.7)	0.42 (6.7)	0.38 (6.1)
CCA-C	Not listed	0.23 (3.7)	Not listed	0.40 (6.4)

The P and T Committees then took another key step that resulted in creation of the ubiquitous 0.4 lb/ft³ (6.4 kg/m³) ground contact retention. Noting that ACA and the three types of CCA all had ground contact retentions between 0.38 and 0.48 lb/ft³ (6.1 and 7.7 kg/m³), they recommended that ground contact retentions be unified at 0.4 lb/ft³ (oxide basis)(1969a, 1969b). They additionally recommended that the above ground retentions be unified at 0.23' lb/ft³ (3.7 kg/m³), and that a 0.60 lb/ft³ (9.6 kg/m³) retention be created for critical ground-contact applications. Soil block tests conducted at the Ottawa Forest Products Laboratory were provided to justify the uniform retentions, with those authors concluding that *"No significant difference in the effectiveness of CCA Type A as compared to CCA Type C preservatives was shown"* (1969a). Attempts to determine the threshold values were more ambiguous, with the authors at one point in the text stating that *"... the critical threshold value at which the minimum preservative retentions can prevent decay due to fungal attack is 0.50 pcf"*, but stating in the conclusions that *"The threshold value was shown by visual inspection to be at a retention level of 0.25 pcf or greater"* (1969a). Changes to CCA and ACA retentions were considered again in the late 1980's when an industry association asked AWPA to consider merging the above ground and ground contact retentions into a single intermediate retention. A proposed uniform retention of 0.3 lb/ft³ (4.8 kg/m³) was discussed in Subcommittee T-2, but the unified retention concept was eventually dropped after a study found that 80% of lumber treated with CCA was currently being treated to 0.4 lb/ft³ (6.4 kg/m³) (Anon, 1991).

AWPA had traveled a long path to reach the "point 4" retention that came to represent water-borne preservative treatments for so many years. It appears that the two most important influences in reaching this retention were the recommended retentions for CCA-A and ACA in 1949. Testing and standardization of CCA-B and CCA-C were also key, but it is possible that some higher or lower retentions of these latter preservatives would have been tested and standardized without the benchmarks established by CCA-A and ACA. We now have luxury of examining the "point 4" retention in hindsight, with the benefit of long-term durability data. In this paper we review the effect of retention on the durability of CCA-A, CCA-B, CCA-C and ACA treated stakes exposed at FPL's test site near Saucier, Mississippi.

MATERIALS AND METHODS

Stake Plots Considered

Data analysis was limited to plots in Harrison Experimental Forest that contained solid sawn southern pine stakes pressure treated with either ACA, CCA-A, CCA-B or CCA-C. A total of 8 plots met these criteria. Three plots ranging in age from 34 - 60 years were evaluated for ACA, two plots of 40 and 60 years were evaluated for CCA-A, two plots of 40 and 61 years were evaluated for CCA-B, and 3 plots of 20, 29 and 35 years for evaluated for CCA-C. The 40 year-old plot (Plot 67) contained stakes treated with ACA, CCA-A and CCA-B.

[1]In 1975 the above-ground retention was adjusted to 0.25 lb/ft³ (4.0 kg/m³) to conform to the listing in Federal Specification TT-W-571 (Anon, 1975).

Site Characteristic

Harrison Experimental Forest is pine woodland with sandy loam soil and an average annual rainfall of 62 in. (1,580 mm) per year (Crawford et al. 2002). The relatively high annual rainfall and warm temperatures (average annual temperature of 19.6 C (67 F)) create a severe decay environment. In addition, native subterranean termites are active at the site. Copper-tolerant fungi are also present, but they are not uniformly distributed through all areas of all plots. The location is within AWPA Deterioration Zone 5, Severe Hazard (AWPA, 2009).

Preparation of Stakes

All of the stakes evaluated in this study had dimensions of 1.5 by 3.5 by 18 in. (38 by 89 by 457 mm). They were cut from the sapwood of lumber from the Southern Pine species group. The stakes were treated with a full cell process using a pressure period of sufficient duration and intensity to ensure complete penetration. Each stake was weighed immediately before and after treatment to determine preservative uptake; the retention was calculated by multiplying the gross solution uptake by the solution concentration. A range of retentions for each preservative was obtained by adjusting the solution concentration. In most cases 10 replicate stakes most closely matching the target retention were selected for installation, but 20 replicates were installed for the ACA plot that has been evaluated for 34 years. Following treatment, the stakes were allowed to air dry and were then buried, standing upright, to a depth of 9 in. (225 mm) in soil in the respective test plots. Placement of stakes was randomized within the plot.

Rating of Stakes

The stakes were periodically removed and lightly scraped to remove soil and facilitate inspection. The stakes were then rated separately for decay and termite attack. Prior to 1985 a numerical and letter rating scale was used but this rating scale was transitioned to the current numerical rating scale (Table 2) between 1985 and 1991. A rating scale similar to that shown in Table 2 was subsequently standardized by the AWPA (Anon, 1993).

Table 2. Summary of rating scale used to evaluate stake condition. [a]

Rating	Decay Rating Description	Termite Rating Description
10	Sound. Suspicion of decay permitted	Sound. 1 to 2 small nibbles permitted
9	Trace decay to 3% of cross section	Slight evidence of feeding to 3% of cross section
8	Decay from 3% to 10% of cross section	Attack from 3% to 10% of cross section
7	Decay from 10% to 30% of cross section	Attack from 10% to 30% of cross section
6	Decay from 30% to 50% of cross section	Attack from 30% to 50% of cross section
4	Decay from 50% to 75% of cross section	Attack from 50% to 75% of cross section
0	Failure	Failure

[a] The additional rating of "9.5" added to AWPA Standard E7 in 2007 was not used in these plots.

Data Analysis

The ratings for each plot/preservative/retention combination were analyzed to determine when failures occurred (if any) and the year at which 25% of the stakes were given a rating of 7 or below (if ever). The number of stakes remaining and the median rating at the most recent inspection were also calculated (Table 3). Average ratings were also calculated for the most recent inspection of each plot (Figure 2).

RESULTS AND DISCUSSION

Of the treatments evaluated in this study, the oldest is an ACA plot installed in 1944. That plot, which contained ACA stakes treated to average retentions of 0.24. 0.51, 0.97 and 1.25 lb/ft^3 (3.8, 8.2, 15.5 and 20 kg/m^3) has been rated for 60 years (Table 3). The performance of the two highest retentions of ACA in this plot have been impressive, with no failures and median ratings of 9 or above after 60 years. Durability of the 0.51 lb/ft^3 (8.2 kg/m^3) retention was not quite as stellar, with one failure at 38 years and the lowest

quartile dropping to ratings of 7 or below at 49 years. Durability of the 0.24 lb/ft³ (3.8 kg/m³) retention was markedly lower, with 2 failures occurring within 22 years. ACA treated stakes appeared more vulnerable in the two younger plots, although the durability was again greatly affected by retention. In the 40 year-old plot (Table 3, Figure 1) one of the stakes treated to 0.45 lb/ft³ (7.2 kg/m³) failed within IS years, and the lowest quartile reached ratings of 7 within 25 years. The first quartile reached ratings of 7 within 24 years in stakes treated to slightly below ground contact retention (0.33 lb/ft³ (5.3 kg/m³)), with the first failure in that retention coming at 27 years. Stakes treated to 0.66 lb/ft³ (10.6 kg/m³) performed better, with the first quartile dropping below 7 at 34 years and the first failure occurring at 38 years. In the youngest plot (34 years), stakes treated to slightly above ground-contact retention had two failures within 30 years. Stakes treated to a 0.66 lb/ft³ (10.6 kg/m³) retention have had no failures, but the lowest quartile dropped to ratings of 7 in less than 35 years, and the median decay rating of the 0.66 retention has declined to "8". Stakes treated to the much higher 1.35 lb/ft³ (21.6 kg/m³) retention continue to perform well. Overall, the durability of stakes ACA treated stakes treated to near 0.4 lb/ft³ (6.4 kg/m³) was very good in the oldest plot, but less impressive in the two more recent plots.

The durability of the ACA treated stakes was closely tied to retention, and as shown in Figure 2, ACA may have benefited from the use of a standard retention closer to 0.6 lb/ft^3 (9.6 kg/m³). Thus, the implementation of the higher 0.6 lb/ft³ (9.6 kg/m³) retention for critical structures appears well-founded. It is interesting to note that the original standardized ground contact retention for ACA was 0.48 lb/ft³ (7.7 kg/m³) (oxide basis), and that the retention was lowered to 0.4 as part of the effort to simplify retentions in the late 1960's.

Table 3. Summary of durability characteristics by preservative, plot and retention.

Plot No.	Total Years	Retention, lb/ft^3 (kg/m^3)	Years to 1st Failure	Years to 1st Quartile =7[a]	Total Failures	Median Rating of Survivors	
						Decay	Termites
ACA							
14	60	0.24 (3.84)	22	22	10	Gone	Gone
14	60	0.51 (8.16)	39	49	1	8	10
14	60	0.97 (15.52)	No Fails	Above 7	0	9	10
14	60	1.25 (20.00)	No Fails		0	9	10
67	40	0.25 (4.00)	11	24	6	6.5	10
67	40	0.45 (7.20)	14	25	2	7.5	10
67	40	0.66 (10.56)	38	34	1	8	10
73[b]	34	0.17 (2.72)	7	13	20	Gone	Gone
73	34	0.23 (3.68)	12	17	19	7	10
73	34	0.33 (5.28)	26	24	7	7	10
73	34	0.46 (7.36)	29	29	4	8	10
73	34	0.66 (10.56)	No Fails	34	0	8	10
73	34	1.35 (21.60)	No Fails	Above 7	0	9	10
CCA-A							
15	60	0.15 (2.40)	15	15	10	Gone	Gone
15	60	0.29 (4.64)	43	44	3	7	8
15	60	0.44 (7.04)	43	Above 7	2	9	9
67	40	0.22 (3.52)	13	13	5	7	10
67	40	0.44 (7.04)	19	Above 7	1	9	10
67	40	0.66 (10.56)	No Fails	Above 7	0	10	10
CCA-B							
28	61	0.26 (4.16)	No Fails	42	0	7	9
28	61	0.37 (5.92)	No Fails	46	0	8	9
28	61	0.79 (12.64)	No Fails	Above 7	0	9	10
28	61	1.04 (16.64)	No Fails	Above 7	0	9	10
67	40	0.23 (3.68)	13	15	3	8	10
67	40	0.38 (6.08)	20	24	2	8	10
67	40	0.55 (8.80)	No Fails	Above 7	0	9	10
CCA-C							
68	35	0.20 (3.20)	No Fails	28	0	8	10
68	35	0.40 (6.40)	No Fails	Above 7	0	9	10
68	35	0.60 (9.60)	No Fails	Above 7	0	10	10
80	29	0.14 (2.24)	No Fails	17	0	7	10
80	29	0.27 (4.32)	25	Above 7	1	8	10
80	29	0.40 (6.40)	No Fails	Above 7	0	8.5	10
80	29	0.62 (9.92)	No Fails	Above 7	0	10	10
80	29	0.79 (12.64)	No Fails	Above 7	0	10	10
99	20	0.10 (1.60)	13	7	10	Gone	Gone
99	20	0.25 (4.00)	17	20	2	9	10
99	20	0.40 (6.40)	No Fails	Above 7	0	10	10
99	20	0.61 (9.76)	No Fails	Above 7	0	10	10

[a]Years in test when the ratings of 25% of the stakes declined to 7 or below.

[b]Retentions in Plot 73 were replicated with 20 stakes. All other plots utilized 10 replicates.

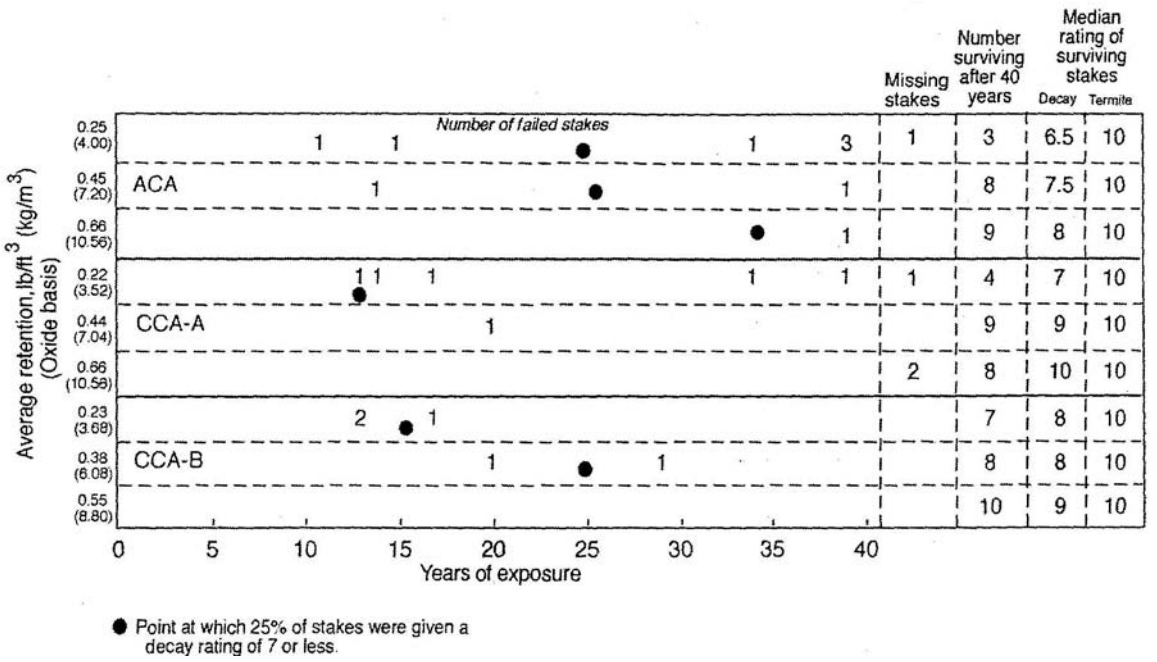

Figure 1. Effect of retention on durability of ACA, CCA-A or CCA-B stakes treated to retentions of 0.22 lb/ft³ (3.5 kg/m³) or greater after 40 years (Plot 67).

Very long term data is also available for CCA-A, with the first plot installed in 1945 and rated after 60 years (Table 3). The highest retention in that plot ((0.44 lb/ft³ (7.0 kg/m³)) continues to have high median ratings after 60 years, although failures did occur at 43 and 47 years. Stakes treated to 0.29 lb/ft³ (4.6 kg/m³) also performed well for the first 40 years. In contrast, stakes treated to the lowest retention (0.15 lb/ft³ (2.4 kg/m³)) had a failure after only 15 years. The other plot available with **CCA-A** treated stakes has been rated for 40 years (Figure 1). Performance of CCA-A in that plot is more ambiguous. **A** failure occurred within 20 years at a retention slightly above ground contact, but no failures have occurred since that time and the median decay ratings for that group remain at 9. Ratings of stakes treated to 0.66 lb/ft³ (10.6 kg/m³) continue to be excellent after 40 years. In contrast to the durability of stakes treated to 0.29 lb/ft³ (4.6 kg/m³) in the oldest plot (Table 3) stakes treated to 0.22 lb/ft³ (3.5 kg/m³) in the 40 year plot exhibited poor durability (Figure 1), with substantial decay occurring within 15 years. With only two plots and fewer retentions evaluated, the trend of average rating versus retention is less clear for **CCA-A** than for ACA (Figure 2). However, it is apparent that retentions slightly above 0.4 lb/ft³ (6.4 kg/m³) are performing much better than retentions below 0.4 lb/ft³ (6.4 kg/m³). In the one plot where it was evaluated, the use of the higher 0.66 lb/ft³ (10.6 kg/m³) retention does appear to have provided increased durability relative to the 0.4 lb/ft³ (6.4 kg/m³) retention.

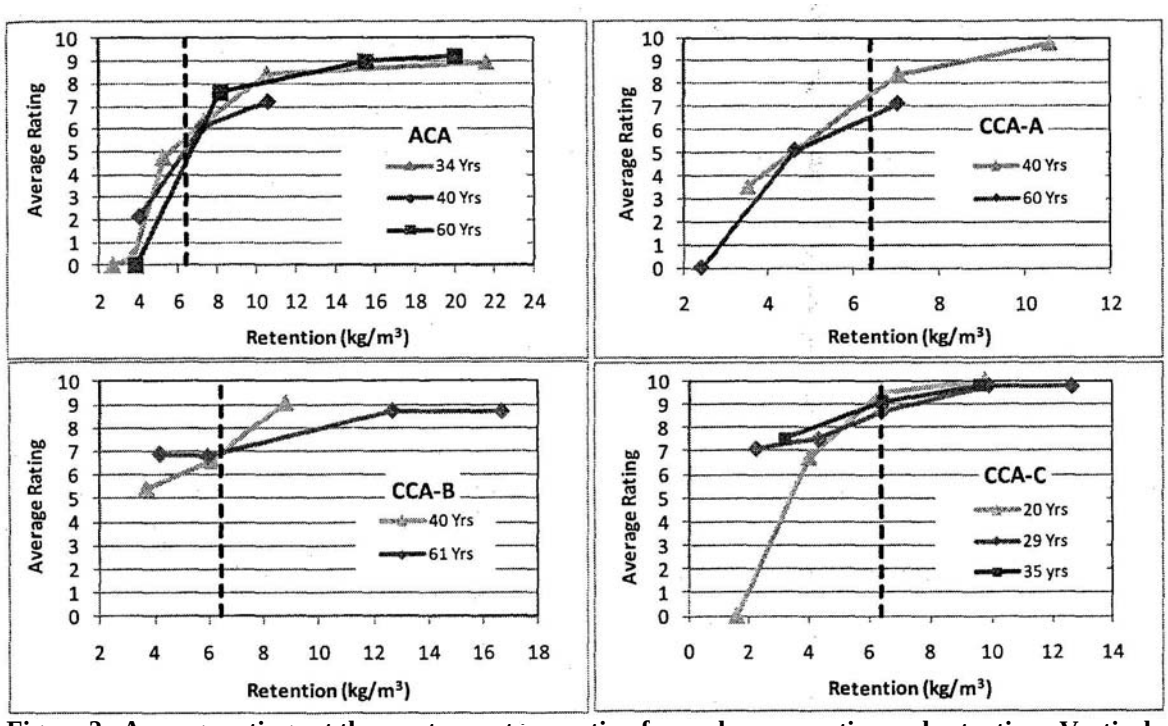

Figure 2. Average ratings at the most recent inspection for each preservative and retention. Vertical dashed lines show the 0.4 lb/ft³ (6.4 kg/m³) retention.

Plots containing stakes treated with the CCA-B formulation have been rated for 61 or 40 years (Table 3, Figure 1). The 61 year plot is remarkable for the absence of any failures, even at the 0.26 lb/ft³ (4.16 kg/m³) retention (Table 3). Both ACA and CCA-A treated stakes had multiple failures over 60 years at a similar retention. Only a slight improvement was achieved by increasing the CCA-B retention to 0.37 lb/ft³ (5.92 kg/m³), but the stakes treated to the two highest retentions were notably more durable (Table 3). In contrast to the 61 year plot, failures of CCA-B stakes treated to the two lowest retentions have been observed in the 40 year plot (Table 3, Figure 1). Stakes treated to approximately the ground contact retention had one failure within 20 years and the first quartile reached ratings of 7 within 25 years. Stakes treated to 0.23 lb/ft³ (3.7 kg/m³) were even less durable, with two failures occurring within 15 years. However, stakes treated to 0.55 lb/ft³ (8.8 kg/m³), are performing well, with no failures and a median decay rating of "9" after 40 years. When average rating is plotted versus retention for the two CCA-B plots (Figure 2) it is apparent that retentions of 0.4 lb/ft³ (6.4 kg/m³) and below are not as durable as higher retentions. Data from both plots indicates that 0.4 lb/ft³ (6.4 kg/m³) does not provide complete protection over the very long term and supports the use of the higher 0.6 lb/ft³ (9.6 kg/m³) retention for more critical structures.

As might be expected, fewer years of data are available for CCA-C than for the older formulations. The oldest CCA-C plot, which has been rated for 35 years, has retentions of 0.20, 0.40 and 0.60 lb/ft³ (3.2, 6.4 and 9.6 kg/m³) (Table 3). No failures have occurred for any of these retentions, and only the 0.20 lb/ft³ (3.2 kg/m³) retention has had ratings of the first quartile of stakes drop to "7". Stakes treated to the ground contact retention have a median rating of "9", and those treated to 0.6 lb/ft³ (9.6 kg/m³) maintain a median rating of "10". In the 29 year plot, one failure occurred after 25 years at the 0.27 lb/ft³ (4.3 kg/m³) retention, and the median rating at that retention has declined to "8". No failures have occurred at the 0.40 lb/ft³ (6.4 kg/m³) retention, but the median decay rating has declined to "8.5". Stakes treated to 0.62 lb/ft³ (9.9 kg/m³) and 0.79 lb/ft³ (12.6 kg/m³) are in excellent condition after 29 years. In the most recent plot (rated for 20 years) two failures have occurred at the 0.25 lb/ft³ (4.0 kg/m³) retention, but stakes treated to retentions of 0.40 lb/ft³ (6.4 kg/m³) and 0.61 lb/ft³ (9.8 kg/m³) are in excellent condition. When retention is plotted against average rating (Figure 2) it appears that 0.4 lb/ft³ (6.4 kg/m³) is nearly the optimum

retention, with only slight increases in ratings with higher retentions. However it must be noted that these trends are only relevant for the time periods considered, and that the CCA-C plots have been evaluated for fewer years than the ACA, CCA-A and CCA-B plots. It is probable that as the CCA-C plots age, durability differences will emerge between 0.4 lb/ft³ (6.4 kg/m³) and the higher retentions. It is already clear that 0.4 lb/ft^3 (6.4 kg/m³) is providing substantial durability benefit over lower retentions, such as the above-ground retention.

As a whole, the data indicates that the well-known 0.4 lb/ft³ (6.4 kg/m³) retention is providing substantial, but not unlimited, protection of wood placed in contact with the ground. It also appears that durability is notably diminished at retentions below 0.4 lb/ft³ (6.4 kg/m³) and that there is some durability benefit in using retentions above 0.4 lb/ft³ (6.4 kg/m³). Thus, 0.4 lb/ft³ (6.4 kg/m³) appears to be near the minimum for long-term ground contact, and the choice of 0.4 lb/ft³ (6.4 kg/m³) for general ground contact applications and 0.6 lb/ft³ (9.6 kg/m³) for critical applications seems to have been a wise one. It is also notable that the specimens in these plots were selected to be very close to the target retention. In commercial practice there is greater variation in retention, with the retention in individual pieces falling below that specified for ground contact (Schultz, et al. 2004). There is also a point for each formulation where increased retentions appear to provide little additional benefit, as was noted by DeGroot and Evans (1999). However, this discussion must be viewed in the context of acceptable service-life. As the desired service life increases, the minimum retention also increases. If the desired service life is only 10 years then 0.2 lb/ft³ (3.2 kg/m³) might be the minimum retention, but once expected service life exceeds approximately 20 - 30 years 0.4 lb/ft³ (6.4 kg/m³) might be more appropriate, and so on.

The long term performance of the 0.4 lb/ft³ (6.4 kg/m³) CCA formulations does provide some guidance on evaluating new formulations intended for use in contact with the ground. There has sometimes been reluctance to compare test formulations to CCA because of the impression that 0.4 lb/ft³ (6.4 kg/m³) CCA sets the bar too high, is excessive, and/or reflects a different time when "more was better". However, the findings in this evaluation indicate that although 0.4 lb/ft³ (6.4 kg/m³) CCA treatments impart good durability, this retention is not excessive and the performance of lower retentions is notably diminished. Thus it appears that 0.4 lb/ft³ (6.4 kg/m³) CCA continues to be an appropriate choice for comparison to test formulations, and that use of lower CCA retentions in testing may not be sufficiently conservative for many ground-contact applications.

CONCLUSIONS

The selection of 0.4 lb/ft³ (6.4 kg/m³) as the general ground contact retention and 0.6 lb/ft³ (9.6 kg/m³) as the critical ground contact retention for CCA and ACA appears to have evolved through a combination of science, experience, and compromise. The long-term stake data for ACA, CCA-A, CCA-B and CCA-C indicates that those retentions were well-chosen. Stakes treated with retentions below 0.4 lb/ft³ (6.4 kg/m³) were noticeably less durable, indicating that standardization of a retention below 0.4 lb/ft³ (6.4 kg/m³) may have resulted in less satisfactory service life.' Similarly, stakes treated to retentions above 0.4 lb/ft³ (6.4 kg/m³) appeared slightly more durable, confirming the value of higher retentions for more critical applications. The 0.4 lb/ft³ (6.4 kg/m³) retention does not appear to be excessive or "over-kill" and thus the 0.4 lb/ft³ (6.4 kg/m³) CCA remains an appropriate comparison for testing new formulations intended for use in contact with the ground.

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