Effect of Coatings on CCA Leaching From Wood in a Soil Environment

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ABSTRACT

We are conducting a study to determine the extent that coating CCA wood with a variety of paints and stains has on preventing leaching of the preservative into soil. A total of 10 boxes (27x28x14 cm) were constructed, six of which were coated. The coatings consisted of oil based, semi-transparent stains (two brands, one with and the other without alkyd resin ingredients), two clear cover coatings (two brands, one with a penetrating alkyd/acrylic formulation), an opaque acrylic deck stain, and an opaque polyurethane enamel. Two of the boxes made from CCA wood were left uncoated, as were the control box and the box made using the ACQ preserved wood. The boxes were filled with a mixture of 90% soil (sandy loam) and 10% compost, by volume, and placed out to weather on April 30, 2002. The soil was sampled using a core sampler from each side of the box, 0-3 cm from the wood, 107and 365 days after weathering. Elevated arsenic and copper levels were detected in soils from the uncoated boxes and in some cases from the coated boxes. Concentrations (mg/kg) of As in soils receiving different treatments were; No Coating (13.5±2.7) > Oil based stain with alkyd resin (13.3±2.0) > Oil based clear cover sealant (10.5±1.9) > Oil based without alkyd resin (8.6± 0.1) > Water based clear with alkyd and acrylics (7.3±1.0) > Acrylic opaque (4.9±1.2) > Polyurethane (3.7±0.3)> Control (3.1±0.2).

Key Words – CCA Wood, Arsenic, Leaching, Coating, Soil

INTRODUCTION

The potential environmental problems associated with chromated copper arsenate (CCA) wood preservative resulted in a phase out of its use in the US for residential applications effective January 2004 (1). However, wood produced prior to the phase out is expected to remain in-service for many years (2). Moreover, this formulation is still permitted for use outside the residential setting. Arsenic dispersal from the wood can occur by leaching, erosion, weathering, decay and physical dislodgement (3-10). Coating the wood could minimize this arsenic dispersal by forming a barrier between the wood and the environment.

Limited amounts of information have been published on coatings for CCA wood. Some studies have focused only on the on durability of the finish to withstand weathering (11,12), while others have focused on the ability of the finish to reduce surface dislodgeable arsenic (13,14) or leachable arsenic (15-17). In general, opaque polyurethane and acrylic finishes form the most durable coatings (11,13,14), presumably due to their ability to protect the wood surface from ultraviolet radiation and

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water penetration (11,16). Nonetheless, for some surfaces, particularly horizontal ones subjected to foot traffic, use of a penetrating stain that results in a slow wearing of the coating may be preferable. Opaque coatings applied to horizontal surfaces are prone to peeling and cracking with age. Other types of coatings could form a barrier to arsenic but not maintain its integrity over time. For example, we found that even though spar varnish formed a barrier to arsenic dislodged from the surface (>90% over 1 year), it later underwent severe deterioration after 2 years of weathering (14). Studies have been published comparing the durability of commercially available coatings in residential settings (18). However, these studies did not address the coating's potential to form a barrier to arsenic migration from the wood.

In this study we are evaluating the effectiveness of coatings to form a barrier to preservative dispersal from CCA wood in a soil environment. Soil contact uses include raised beds used in gardens, posts, and utility poles. The results over the first year of weathering are presented in this report.

EXPERIMENTAL

A total of 10 boxes (27x28x14 cm) were constructed, 8 using 3x15 cm CCA boards, one using an alternative preservative containing copper and quaternary ammonia (ACQ), and 1 control using untreated pine. The CCA containing boxes were constructed using 2.5 m x 3 cm x 15 cm pine boards, purchased at a lumber yard, nominally treated with 6.4 kg/m3 of CCA preservative by Universal Forest Products. The boards originated from three sets. The first set, consisting of 3 boards purchased in April 2002, was used to construct the two, 28 cm sides. Set 2, also purchased in April 2002, consisted of 1 board treated with water repellent plus CCA (Thompsonized), and was used to construct one 27 cm side of each box, while Set 3, consisting of 3 boards purchased in 1998, was used to construct the other 27 cm side of each of the 8 boxes.

Each paint or stain was applied in two coats on a particular box. As shown in Table 1, the coatings consisted of oil based, semi-transparent stains (two brands, one with and the other without alkyd resin ingredients), water based coatings (two brands, one with a penetrating alkyd/acrylic formulation), an acrylic solid color deck stain, and a polyurethane enamel. Two of the boxes made from CCA wood were left uncoated, as were the control box and the box made using the ACQ preserved wood.

The boxes were filled with a mixture of 90% soil (sandy loam) and 10% compost, by volume. The soil properties of this mixture are given in Table 2. The boxes were placed out to weather on April 30, 2002 (Figure 1). Natural rainfall supplied most of the water, but in times of drought, the soil in the boxes was watered at a rate of about one inch per week (0.4 inches per application). The soil was sampled using a soil corer (2.2 cm dia.) to take one sample from each of the four sides of the box, 0-3 cm from the wood to box bottom, 4 times over 2 years. The results of first two sets of soil samples, taken after 107 and 365 days of weathering are given here. The results for the 1.5 and 2 year sample sets will be given elsewhere.

The Cu, Cr, and As were determined in the soil samples by nitric acid digestion followed by analysis using Thermo Jarrell Ash ICP-AES Atom Scan 16 atomic spectrometer. In samples containing low arsenic (<0.1 mg/l in solution) the more sensitive technique of graphite furnace atomic absorption (GFAA) was employed using a Perkin Elmer 5100 instrument, as described previously (9). The Cu, Cr, and As in the wood were similarly obtained by analyzing wood composite sawdust samples from each set of boards.

Table 1 Description of Coatings

Coating/Box #	Coating*	Base	Color	Cover
1	None			
2	Sealant with Alkyd and Acrylics	Water	Clear	Clear
3	Deck and Siding Stain	Oil	Gray	Semi
4	Sealant	Oil	Clear	Clear
5	Deck Stain with Alkyd Resin	Oil	Gray	Semi
6	Solid Color Acrylic Deck Stain	Water	White	Opaque
7	Polyurethane Floor and Deck Enamel	Oil	Gray	Opaque
8	None			
ACQ	None			
Untreated Pine	None			

* ***Brand and Code.. Coating 2, Behr, 300; 3, Behr 1-765; 4, Thompson's; 5 Olympic, 53178; 6, Olympic, 53097; 7, Sapolin, 40-9309***.

Figure 1 Coated and uncoated box assemblies.

Table 2 Soil Properties

Property	Measurement	
pH	**6.0 ± 0.3**	**(n=9)**
CEC* (cmol/kg)	**8.2 ± 0.9**	**(n=6)**
P (mg/kg)	**1040 ± 80**	**(n=3)**
Fe (mg/kg)	**9090 ± 1500**	**(n=3)**
Sand (g/kg)	**712 ± 17**	**(n=2)**
Silt (g/kg)	**114 ± 55**	**(n=2)**
Clay (g/kg)	**174 ± 71**	**(n=2)**
Organic Matter (g/kg)	**52 ± 4**	**(n=2)**

Cation Exchange Capacity

RESULTS

Arsenic Leached

The average soil arsenic levels right next to the wood in the boxes over time for different treatments are given in Figures 2-4 (see table 1 for the coatings corresponding to numbers 2-7). The results from the soil samples from the uncoated CCA boxes (Box 1 and 8) were combined (n=8) in computing the averages for each weathering. All other averages were from each side from a particular box (n=4). The percent reduction was calculated by subtracting the amount of arsenic in soil from the control box from that in soil from each coated box, and dividing this by the difference between the arsenic in soils from uncoated boxes and the control boxes, i.e. 100*(Coat Value-Control Value)/(No Coat Value-Control Value). As shown in figures 2 and 3 the arsenic levels in the soil samples from the CCA boxes generally increased with time of weathering. Furthermore, the average arsenic level (13.5±2.7 mg/kg) in soil samples taken from the uncoated boxes, after 365 days of weathering exceeded State of Connecticut limit of 10 mg/kg (8). The opaque acrylic finish (#6) reduced the arsenic level by about 80% while the polyurethane based finish was virtually 100% effective over the one year time frame. Opaque finishes were also found to be the most effective coating to reduce arsenic dislodged from surfaces (13,14). The oil based deck and siding stain (#3), the sealant with alkyd and acrylics (#2) and the oil-based sealant (#4) were somewhat less effective and reduced the arsenic level by only 30-60%. The oil based stain (#5) which had no apparent effect on arsenic leaching in this soil environment, was found earlier, however, to reduce arsenic dislodged from surfaces (14).

The fact that the soil retained as much as 13 mg/kg As next to the uncoated boxes is indicative of this soils ability to trap arsenic. In effect the soil acts to integrate the amount of arsenic that comes out of the wood over time. We attribute this trapping ability to the high clay and iron content in the soil (table 2), which are known to immobilize As (10).

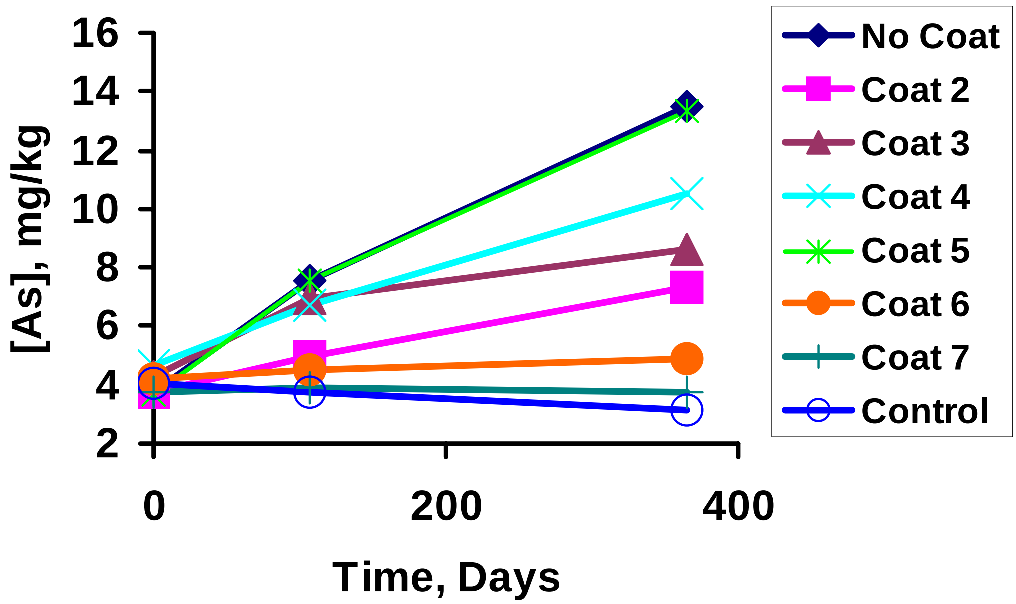

Figure 2 Comparison of soil arsenic versus time using various coatings

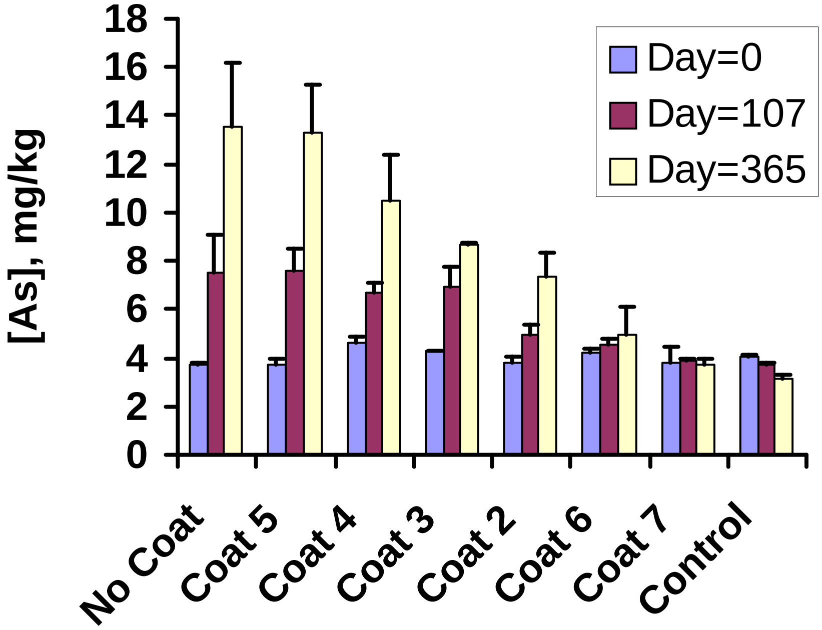

Figure 3 Average soil arsenic after 0, 107, and 365 days of weathering, ranked by coating effectiveness

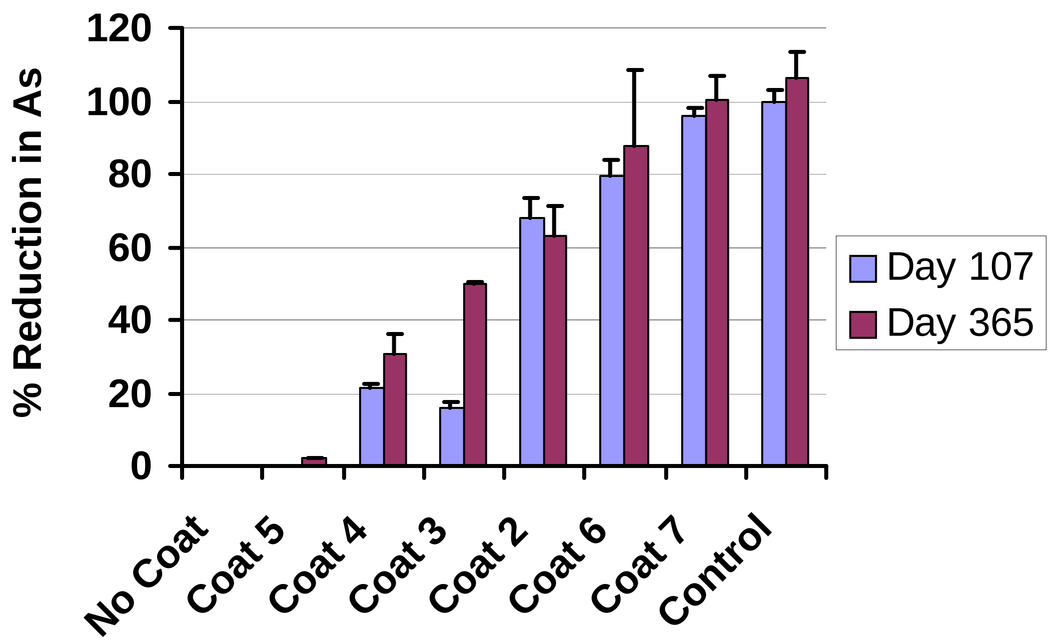

Figure 4 Percent reduction in soil arsenic levels with coating

Copper Leached

The average copper levels in soils from various treatments are given in Figure 5. The copper in the soil samples next to uncoated CCA wood exhibited only limited increases compared to the pre weathering values, making comparisons with the samples taken next to coated wood more uncertain. For example, the average increase in the arsenic content in soil samples next to the uncoated wood compared to the unweathered samples increased about 200 and 350 percent after 107 and 365 days of weathering (3.7±0.1, 7.5±1.5 and 13.5±2.7 mg/kg at day 0,107,365 respectively), while the copper increased by 130 and 123 percent over the same time period (23±1, 30±4, 28±3 mg/kg after day 0,107,365 respectively). Note that the copper tends to level off after one year weathering time, which may be due to similar leaching rates out of the wood compared to the migration rate through the soil. A tendency for the copper content to level off with time was also noted by Lebow et al. (4,15) in sediments next to boardwalks constructed with CCA wood. In order to further investigate this point we plan to take soil samples at various distances from the wood are the end of this study (two years total). Nonetheless, there were indications that opaque coatings (#6&7) formed a good barrier to copper as well as to arsenic. The copper in the soil samples next to these coated woods was within 5% of their pre- weather values on both sample dates. In contrast, the soil samples next to the ACQ treated wood increased noticeably compared to the initial value. The percentage increase in these samples was 160 and 200 after weathering 107 and 365 days, based on the copper content of 24±0.5 (day=0), 39±6 (day=107), and 50±14 (day=365). All of the copper levels in the soil samples from all treatments were less than the State of CT limit of 2500 mg/kg (8).

Chromium Leached

The average chromium levels in the soil for different treatments are given in Figure 6. Like copper, the chromium in the soil samples next to uncoated CCA wood exhibited only limited increases compared to the pre weathering values. For example the increase in the soil Cr in the uncoated wood treatment increased from an initial value (mg/kg) of 10±2, to 12±2 (day=107), and to 13±1 (day 365). These small increases coupled with the variation in baseline Cr (range 9-11 mg/kg) makes evaluation of the coatings effectiveness for Cr leaching more uncertain compared to the arsenic data. In no case did the Cr level approach the State of CT limit (8) of 100 mg/kg (hexavalent Cr) or 3900 for trivalent Cr (8).

Summary of Copper, Chromium and Arsenic Leached

A summary of the amounts of Cu, Cr, and As in the soil samples after one year of weathering is given in Table 3. The concentration of As in the soil ranged from 3 to 13 mg/kg, depending on the effectiveness of the coating material used. In uncoated wood and in treatment 4 (clear oil based sealant) and 5 (semi-transparent oil based deck stain), the As levels exceeded the 10 mg/kg Connecticut State limit. In contrast to As, the relatively minor increases in Cu, and Cr, reflects one, the relatively low amount of Cu in the wood (next section), and two, the lower leaching rate of Cr (8,10).

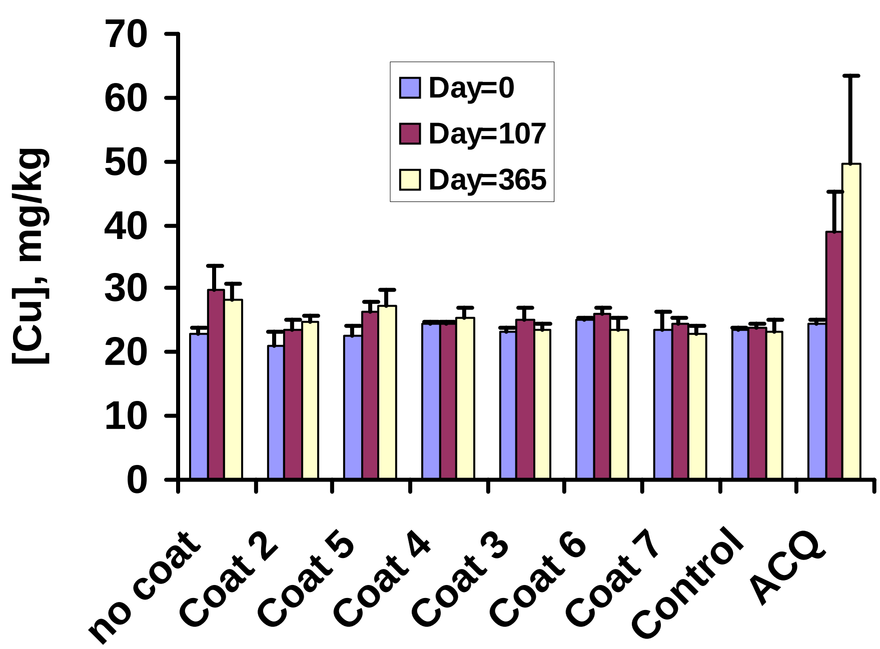

Figure 5 Average soil copper after 0, 107, and 365 days of weathering, ranked by coating effectiveness

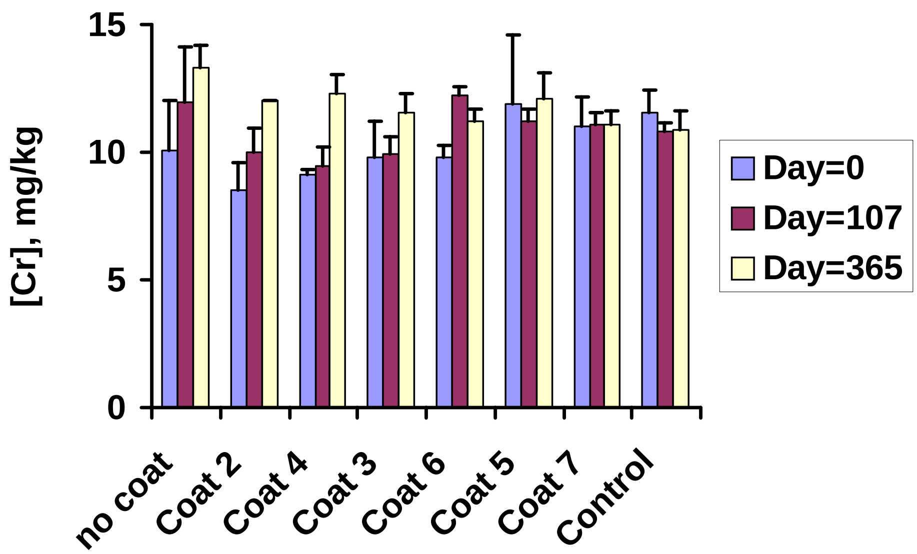

Figure 6 Average soil chromium after 0, 107, and 365 days of weathering, ranked by coating effectiveness

TABLE 3 Effects of Coating on the Cu, Cr, and As (mg/kg) Content in Soil after 1 Year of Weathering

Coating #	Concentration* (mg/kg)		
	Cu	Cr	As
Untreated	23.1 ± 2.0	10.9 ± 0.7	3.1 ± 0.2
7	22.8 ± 1.3	11.1 ± 0.5	3.7 ± 0.3
6	23.6 ± 1.7	11.2 ± 0.5	4.9 ± 1.2
2	24.8 ± 0.8	12.0 ± 0.05	7.3 ± 1.0
3	23.5 ± 0.9	11.6 ± 0.7	8.6 ± 0.1
4	25.4 ± 1.6	12.3 ± 0.8	10.5 ± 1.9
5	27.3 ± 2.5	12.1 ± 1.0	13.3 ± 2.0
Uncoated CCA	28.3 ± 2.6	13.3 ± 0.9	13.5 ± 2.7
		±	±
ACQ	49.6 ± 14	10.9 ± 0.7	3.3 ± 0.2
		±	±
Before Weathering**	23.4 ± 1.2	10.2 ± 1.3	4.0 ± 0.3

*(n=4, except for uncoated CCA, n=8)

** Average in soil from all boxes (n=2 per box, n=20 total)

Variation in CCA Leaching Within Treatments

As mentioned earlier, each box was constructed from three sets of CCA boards. The Cu, Cr, and As content (mg/kg) in the wood composite samples from these board-sets were 1773±16 (Cu), 3156±68 (Cr), and 2746±56 (As) in wood from Set 1, 1263±54 (Cu), 2461±426 (Cr), and 2020±231 (As), in wood from Set 2, and 1050±307 (Cu), 1946±681 (Cr), and 1870±624 (As), in wood from Set 3. The nominal amounts for this treatment level are 1840 (Cu), 3120 (Cr) and 2800 (As). Thus, when compared to the nominal value the treatment levels in Sets 2 and 3 are somewhat low, while the level in Set 1 closely matches the nominal value. The ACQ wood contained 3073±58 (Cu), <20 (Cr), and <20 (As) (mg/kg), while the control wood and the plywood contained <20 mg/kg Cu, Cr, and As.

Note in Table 3 that the copper content in the soil samples next to the ACQ wood increased by 26 mg/kg, compared to a 5-mg/kg increase in soils next to the CCA wood. Thus, there was about 5 fold increase in the soil copper next to the ACQ wood compared to the soil next to the uncoated CCA wood with only a 2.25 fold increase in the copper in ACQ versus CCA wood. These results suggest that copper may leach to a greater extent, on a percentage basis, in the ACQ wood, as also noted by Townsend et al. (19).

The amount of arsenic in soil samples taken after 365 days of weathering is shown in Figure 7 as a function of board-set and coating. Each box was made from two pieces of wood from set 1, one from set 2, and one from set 3, so the results in the figure are the average arsenic in set 1 and a single measurement in set 2 and 3. Though the As levels in the wood from set 1 was about 40% higher, the amounts of arsenic in set 1 soil samples exceeded those in set 2 and 3 in only one instance. Similar results were obtained after weathering for 107 days, where the arsenic in soil from set 1 exceeded the others only once. The amounts of copper in the soil samples from set 1 exceeded the others 4 times in the samples after 107 days and one time in samples after 365 days. These findings suggest that the As and Cu content in the soil may not be directly proportional to the amount in the wood. Clearly, the concentration in the wood is not the only factor determining its migration into the soil.

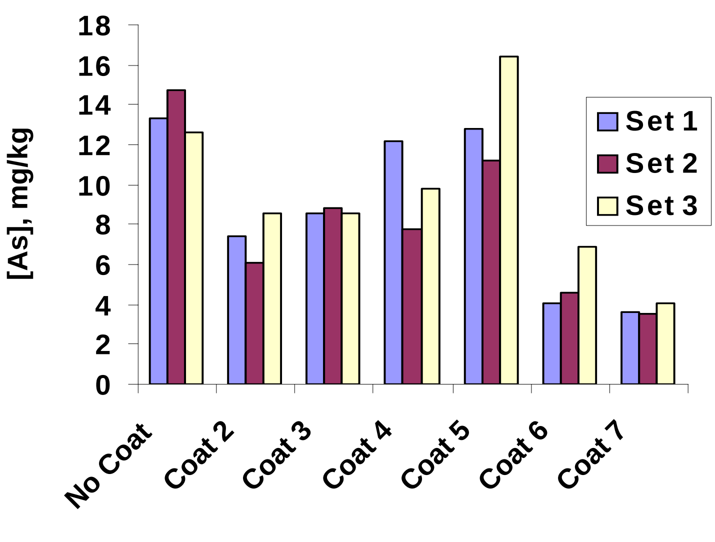

Figure 7 Effects of arsenic in soil next to board-sets after 365 days of weathering. Average As in the wood (mg/kg), 2746±56 (Set 1), 2020±231 (Set 2), 1870±624 (Set 3)

CONCLUSIONS

Opaque coatings formulated using acrylics or polyurethane when applied to CCA wood reduced the migration of arsenic from the wood into the surrounding soil over a one year time period by 80% to virtually 100%. Other coatings, either oil or water based, but with clear or semitransparent coverage, reduced the arsenic migration by only 60% or less. The arsenic next to uncoated CCA wood increased to levels exceeding the State of Connecticut limit of 10 mg/kg within one year of weathering. On the other hand, only minor increases in the copper and chromium content occurred in the soil next to CCA wood over this one-year period. Variation in the soil arsenic levels within a treatment suggest that other factors, as yet unknown, than merely the bulk concentration of As in the wood influence its migration into the surrounding soil.

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