FIELD TESTING OF WOOD PRESERVATIVES IN CANADA. V. PERFORMANCE OF WESTERN RED CEDAR SHAKES AND SHINGLES

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Abstract

Several field tests have been set up since 1973 to determine the increase in service life of western red cedar shakes and shingles resulting from pressure treatment with wood preservatives. After 20 years exposure at Haney B.C., shakes pressure-treated with chromated copper arsenate (CCA) types B (3.8 kg/m^3) and C, or with two formulations of ammoniacal copper arsenate (ACA), were free from visible decay. In contrast untreated shakes showed moderate to advanced decay. The untreated test roof, if in service on a house, would require replacement at this stage. Tim-Bor® diffusion-treated shakes showed more advanced decay than the controls. Chemical analyses of shake samples at intervals over the first 15 years showed rapid depletion of thujaplicins from the butts of untreated shakes. There was also rapid depletion of Tim-Bor®, early depletion of CCA-B followed by stabilisation, and slow but continuous depletion of ACA and modified ACA. CCA-C showed negligible losses except for very minor depletion of copper from the butts. After 15 years exposure in Vancouver, untreated shakes and shakes treated with CCA-C, modified ACA and acid copper chromate were all still sounds. Similarly treated shingles installed at the same time at Vancouver and Haney were also in good condition after 15 years. After only 11 years exposure in Singapore, untreated shingles were virtually destroyed by termites and decay. CCA-C treated shingles with an assay retention of 3.9 kg/m^3 were still virtually sound at this tropical site.

Based on these results, pressure treatment with CCA is expected to at least double the service life of western red cedar shakes. A 40-year service life is predicted in moderate decay hazard areas. Furthermore, the results suggest that the retention specified for shakes and shingles can be reduced from 6.4 to 4.0 kg/m^3.

1. Introduction

Western red cedar (*Thuja plicata* D. Donn), due to its natural durability and dimensional stability, has for many years been the preferred species for the manufacture of wood roofing materials. More recently, markets for non-durable species such as southern pine (Barnes, Buchanan and Amburgey, 1985; American Wood Preservers' Association 1994) and lodgepole pine (Canadian Standards Association, 1993) have developed through the use of pressure treatment with preservatives. Other species have been tested experimentally with non-pressure

(Miller, 1986) or pressure treatment (Plackett, Chittenden and Preston 1994; DeGroot, 1994; Morris and McFarling 1995). While the durability of all of these species can be upgraded to an adequate level, their dimensional stability is usually less than that of western red cedar.

The outer heartwood of old-growth western red cedar trees contains high levels of fungicidal extractives, thujaplicins, providing natural durability. These extractives are, however, slightly water soluble and, in high rainfall areas, such as Vancouver, British Columbia, thujaplicins may be completely removed from the butts of shakes after only 5 years exposure (Johnson and Cserjesi, 1980). Under conditions of moderate to high decay potential, such as in the shade and drip of trees, untreated cedar roofs have failed within 10 years (Smith and Swann, 1975). To supplement the natural decay resistance of shingles and shakes, preservative treatments have been recommended for high-decay-hazard environments (Canadian Standards Association, 1980, 1988). Such treatments may become more desirable with the increased use of second growth trees containing lower concentrations of fungicidal extractives (Swan, Kellogg and Smith, 1988).

Western red cedar is resistant to pressure treatment, but longitudinal preservative penetration into shake/shingle butts can be achieved. This is the zone where extractive depletion is most rapid and where decay is most likely to begin (Smith and Swann, 1975). A series of field tests was initiated in 1973 by the Western Forest Products Laboratory (WFPL), now Forintek's Western laboratory, in order to study the service life of pressure-treated red cedar shingles and shakes.

In 1973 treated and untreated shakes were installed at Haney B.C., 30km west of Vancouver. In 1980 more shakes were installed at Westham Island, and shingles were installed at both Westham Island and Haney. Finally, shingles and shakes were installed in Singapore in 1983 to support a perceived market opportunity in the Pacific Rim.

Up to 1995, the use of pressure treatment has only been included as an appendix to the shingle and shake standard (Canadian Standards Association 1980, 1988) providing for a gauge retention where treatment may be specified by the customer. The field tests reported here were installed during the period when a gauge retention of 9.6 kg/m^3 was recommended. There is now a desire to develop a standard within CSA O80 and an assay retention is therefore required. The data from these field tests will assist in determining the most appropriate retention.

2. Materials And Methods

Shakes Installed in 1973

Experimental roof panels were constructed using commercial "barn shakes", approximately 10 mm in maximum thickness by 450 mm long, laid on 1.2 m x 1.2 m squares of 19 mm plywood (Cserjesi, 1976). Seven treatments were used, plus untreated controls, and three panels were prepared per preservative treatment. One panel was intended for long-term performance evaluation, while the other two panels were intended for chemical analysis at suitable intervals. Application of the shakes to the panels was according to procedures recommended by the Council of Forest Industries of British Columbia (COFI, 1972). The shakes were nailed to plywood panels using a building paper interlayment.

The preservatives used were: chromated copper arsenate Type-B (CCA-B), chromated copper arsenate Type-C (CCA-C), ammoniacal copper arsenate (ACA, a 50:50 ratio of copper to arsenic as oxides), modified ACA (a 60:40 ratio of copper to arsenic), Tim-Bor® wood preservative, and pentachlorophenol (PCP) in oil and in liquified petroleum gas. The last two treatments will not be considered here since PCP is no longer recommended for wood products in domestic applications. In addition, PCP accelerated the erosion rate of the shakes (Byrne, Cserjesi, and Johnson, 1987). Inspection of the PCP-treated material was discontinued 11 years after installation.

Treatments with CCA-C and ACA were done commercially and retentions are expressed on an uptake basis (Table 1). The target retention of 9.6 kg/m^3 for these treatments (Canadian Standards Association, 1980) was not met accurately due to the small quantities of test material being included in commercial charges. Modified ACA treatments were performed at the Eastern Forest Products Laboratory (subsequently Forintek's Eastern Laboratory) in Ottawa. Tim-Bor® wood preservative treatments were done at the WFPL, by dipping freshly cut, unseasoned shakes for three minutes in 35% Tim-Bor® solution heated to 55^o C. After treatment these shakes were stored under cover for one week to allow diffusion to occur. Retentions determined by uptake and by analysis are given in Table 1. Analysis samples were full cross sections, one 0-25 mm from the butt and one from the middle of the face. Analyses of Tim-Bor® was done using water extraction in a Soxhlet apparatus and sodium hydroxide titration (Winters, undated). Analyses of CCA and ACA were performed using X-ray fluorescence spectroscopy.

The test panels were installed at the University of British Columbia Research Forest, Haney, B.C., on frames about one metre above ground level, sloped 20^o to the horizontal, facing south, and without obstruction to sunlight.

Samples of the test material were removed and analyzed for preservative retention after 0, 1, 3, 5, 8, 11, and 15 years exposure (Morris, 1989). In 1994 the single panels remaining for each preservative were visually evaluated for physical condition, appearance and the presence of decay. Each panel was then photographed.

Shakes Installed in 1980

The preservatives used were: CCA-C, modified ACA, and acid copper chromate (ACC). The pressure treatments were done at Forintek's laboratory in Vancouver. Retentions were based on uptake and are given in Table 3. Chemical analysis, construction and installation of experimental roof panels were carried out as described above. The majority of panels were located for 11 years at Forintek's field test site at Westham Island, B.C. These racks were moved in 1991 to the rear of the Forintek facility in Vancouver. ACC treated shakes were also installed at Haney B.C. The panels when installed at Haney were all in full sun but in the ensuing 15 years the surrounding trees have grown so that one of the ACC-treated panels is in partial shade, providing an additional variable to the test.

Shingles Installed in 1980

The preservatives used were: CCA-C, modified ACA, and ACC. The pressure treatments were done at Forintek's laboratory in Vancouver. Retentions were based on gauge uptake and are given in Table 5. Chemical analysis, construction and installation of experimental roof panels were carried out as described above. The majority of panels were located for 11 years at Forintek's field test site at Westham Island, B.C. These racks were moved in 1991 to the rear of the Forintek facility in Vancouver. A comparable set of untreated and treated shingles were also installed at Haney B.C. As with the ACC-treated shakes, described above, some of the panels are in full sun but some are now partially shaded.

Shakes and Shingles Installed in Singapore in 1983

The initiation of this test was described in detail by Smith *et al.* (1985). The western red cedar roofing material was supplied by the Council of Forest Industries of British Columbia. It consisted of 600 x 13 mm resawn No. 1 shakes and 450 mm No. 1 shingles. Three bundles of shakes and two bundles of shingles were pressure treated with CCA by Pacific Wood Preservation Services. The target gauge retention was 10 kg/m^3, just above the retention specified at that time for Canadian use (Canadian Standards Association 1980). Two bundles each of shakes and shingles were left untreated.

The test material, together with all the material required to make up the panels and support structure, was shipped to Singapore. The test was set up in the grounds of the Kwong Maw Sawmill Co. Pte. Ltd. Three panels were constructed: one made entirely of treated shingles (panel A), one with half the panel made from treated shingles and half from untreated shingles (panel B), and one with half treated and half untreated shakes (Panel C). Shakes were laid at 190 mm (7.5 inches) to the weather (exposed) and shingles at 140 mm (5.5 inches) to the weather. They were nailed directly onto plywood and no felt interlayment was used. The panels were mounted, at a pitch of one in three, on a support structure made from pressure treated (non-incised) hem-fir lumber.

During construction, fifteen pieces of each set of material were selected at random and returned to Forintek for analysis. Analysis samples were taken at 0 to 25 mm from the butt and at the mid point of the shingle or shake. For the shingles, the entire cross section was taken at the mid point. For the resawn shakes half the depth from the split face was taken. This was done because it was known that preservative penetration is deeper on sawn faces than on split faces. The samples were analyzed by X-ray fluorescence spectroscopy. Preservative retentions are given in Table 8.

The material was inspected and sampled after one year exposure (Smith *et al.* 1985) but was not examined again until 1994 when the opportunity arose for staff to visit the site. At this time the material remaining was visually evaluated for physical condition and appearance and the presence of decay, and each panel was photographed.

Test Sites

Haney B.C.:- The Haney test site is situated in a small clearing in the University of British Columbia Research Forest. This is an area of relatively high rainfall (over 2000 mm per year), and relatively high sunshine. The site falls within the moderate decay hazard zone using Scheffer's (1971) climate index (Setliff, 1986). Calculations from data provided by Environment Canada show that the site has a decay hazard index of 55.

Westham Island/Vancouver:- Westham Island divides the middle and south arms of the Fraser River where it empties into the Strait of Georgia. The Vancouver site is at the rear of the Forintek building on the campus of the UBC just north of the north arm of the Fraser River. The Westham Island and Vancouver sites have very similar climates, with about 1900 hours of bright sunshine and approximately 1250 mm of precipitation per year. The climate index for both sites is 45 (Setliff, 1986).

Singapore:- The Singapore test site is in the corner of the yard of the Kwong Maw Sawmill. This test had not received any attention for 10 years. In consequence vegetation had grown over and around the test material creating a very high decay hazard. The site was also overhung by trees and shaded by buildings. The UV hazard would thus have been lower than normal for Singapore. The site receives around 2355 mm of rain per year. The climate index at this location is 219, calculated from climate data supplied by the Meteorological Service of Singapore.

Evaluation method

The individual shakes were rate separately for decay, termite damage, erosion and splitting based on the following criteria:

	Decay	Termite*	Erosion	Splitting
Rating 0	none	none	none	none
Rating 1	trace	cosmetic	< 1 mm	0-10 mm
Rating 2	moderate	penetration	1-3 mm	10-50 mm
Rating 3	advanced	severe	3-5 mm	50mm- full exposure
Rating 4	through	through	> 5 mm	full length

* Singapore only

Erosion was not evaluated for the top row of shakes since there was no covered uneroded part of the shake for comparison. Splitting from shrinkage due to decay was not included under splitting but was taken into account in the decay rating. Statistical analyses of the data were performed using Student's t test.

3. Results And Discussion

Shakes Installed in 1973 at Haney

The shakes in the untreated control panel ranged from completely sound to completely failed with a mean decay rating of 1.7 after 20 years exposure (Table 2). Severe erosion was also present, with extensive growth of moss, algae and lichen. Advanced decay had already been noted in a few of the untreated shakes which on a real roof would have necessitated extensive repair after 15 years exposure (Morris 1989). At 20 years this roof panel would require replacement due to a combination of decay, erosion and splitting. Interestingly, untreated shakes used on a building in the UBC Research Forest, using similar construction methods to the field test, were recently replaced after 16 years in service (Sanders 1994).

Depletion of thujaplicins, the naturally occurring wood extractives responsible for the decay resistance of western red cedar, may offer an explanation for the deterioration of the untreated panels. Chemical analyses for thujaplicins by gas chromatography (Johnson and Cserjesi 1975) were done after 1, 3, 5 and 8 years of exposure (Johnson and Cserjesi 1980). Thujaplicins were rapidly depleted from the butts so that after three years of exposure only trace quantities (less than 0.005%) were detected (Figure 1). Although thujaplicins were also depleted from other parts of the shakes the rate of decrease was slower and even after 8 years exposure a level of 0.05% was present in the upper and mid-portions of the shakes. However the isolation of fungi (Setliff and Chung 1985) indicates that this concentration of thujaplicins may be too low to protect against biodeterioration.

The condition of the Tim-Bor®-treated panel was worse than that of the untreated control panel with a mean rating for decay of 2.1. Borates are known to be leachable from small-dimension commodities exposed to rain and retention analyses on the butts showed levels of only 1/10th the original treatment level after only one year of exposure (Cserjesi 1976 and Figure 2). After 8 years in test exposed sections of the shakes showed depletion to 1 kg/m^3 boric acid equivalent, well below its effective concentration (Byrne et al, 1987). Despite the leachability of this preservative, performance worse than the controls was unexpected.

Shakes treated with CCA-C were generally in excellent condition with only two shakes showing a trace of decay in the butts. Erosion was less than in the controls. The similarity in splitting between CCA-treated and untreated shakes was somewhat unexpected given the general impression in the industry that treatment promotes splitting. Growth of moss and lichen was slight. The chemical analysis data for this material is not easy to interpret. Byrne, Cserjesi and Johnson (1987) and latterly Morris (1989) found a great deal of variability in the preservative content of all these shakes. This was due to the variation in uptake between shakes and the low number of replicates (12 to 15 per sampling). This variability tends to mask trends in the data nevertheless some conclusions can be drawn. Despite the high initial loadings of CCA-C, there was little detectable depletion of preservative except for a very minor loss of copper from the butts over 15 years of exposure (Morris 1989). Figure 3 shows the CCA-C retention of the shakes over this period.

As with the high retention CCA-C, CCA-B at 3.8 kg/m^3 had no visible decay after 20 years. The ratings for erosion and splitting were similar to those for the CCA-C treated shakes. Sparse moss and lichen growth was evident but not of concern. During the first year of exposure all three components of the CCA-B formulation were depleted to between one half and two-thirds of their original retentions regardless of position within the shakes (Figure 4). Part of this depletion probably represents erosion of the highly treated surface layer but there was selective loss of copper and arsenic while chromium was relatively well fixed. The early drop in preservative content probably due to the high arsenic content of this formulation preventing optimum fixation (Hartford, Fahlstrom and Colley, 1982).

ACA and modified ACA treatments were also good condition with respect to decay after 20 years. The ratings for erosion and splitting were again similar to those for the CCA-treated shakes. Despite between-sample variation, substantial depletion of ACA and modified ACA could be seen (Figures 5 and 6). Only 60% of the copper and 2% of the arsenic remained in the butts of ACA-treated shakes after 15 years exposure. Since these shakes continued to perform well after 20 years with virtually no arsenic present, some of the new non-arsenical copper based formulations might be expected to be similarly effective in this application.

Shakes Installed in 1980 at Vancouver

The untreated control shakes located at Vancouver contained no decay (Table 4), and erosion was minor. Splitting was also moderate overall. Shakes treated with CCA-C exposed at Vancouver were almost free from decay, with just one sample with a trace of decay, rated 1. Erosion was negligible. Splitting was significantly more extensive than in the untreated controls using a two sample *t*-test, with seven shakes split through the whole length.

Shakes at Vancouver treated with modified ACA and ACC contained no visible decay. Erosion of both ACA- and ACC-treated shakes was significantly more extensive than in the CCA-treated material using a two sample *t*-test, and was at a similar level to the untreated controls. Splitting of shakes treated with these preservatives was comparable to CCA treatments.
Untreated shakes and shakes treated with CCA-C and modified ACA were installed in 1973 at Haney and were examined after 15 years exposure (Morris, 1989). Detailed ratings of decay, erosion, and splitting were not done, but generally it appeared that the treated shakes were in good condition while the untreated shakes were in worse condition than untreated shakes examined in 1995 at the Vancouver site. This difference could be due to the higher climate index at Haney or to the different sources of wood being used in the shake test set up in 1973 and the latter test initiated in 1980.

Shakes Installed in 1980 at Haney

No decay was present on the ACC-treated panels exposed at Haney (Table 4). There was no significant difference in splitting of the ACC-treated shakes between the Haney and Vancouver sites, using a two-sample *t*-test. Erosion of samples on the panel in the sun was worse ($t < 0.05$) than on those in the shade and was comparable to erosion of shakes exposed at Vancouver. This may be an illustration of the photodegradation effect of sun on the surface of wood.

<u>Shingles Installed in 1980 at Vancouver and Haney</u>

The untreated control panels, while still serviceable, contained the most decay (Tables 6 and 7). Eight shingles were rated 1 at Vancouver. Three were rated 1 and three were rated 2 at Haney on the panel in the shade. The panel more exposed to sun at Haney had only one untreated shingle rated 1. Erosion of these untreated shingles was moderate, ranging from 1.0 at Vancouver (Table 7) to 1.3 (shade) and 2.1 (sun) at Haney (Table 6). Splitting was also moderate overall.

Shingles treated with CCA-C were completely free from decay, and erosion was minor with none rated more than 1. Comparisons were again made between treated and untreated shingles in terms of splitting. At the wetter Haney site, untreated shingles were significantly less split ($t < 0.05$) than the CCA-treated samples after 15 years of exposure, using a two sample t-test. However, at the Vancouver site, splitting of untreated and CCA-treated shingles was not significantly different. Samples at the Haney site remain wet for longer periods than at Vancouver, which would tend to discourage splitting, compared to more frequent wetting/drying cycles at Vancouver.

Shingles that had been treated with modified ACA and ACC were in a similar condition to those treated with CCA, with no decay visible except on one ACA-treated sample at Haney (rated 1). Neither of the modified ACA-treated panels had become shaded at Haney. No samples were rated greater than 1 for erosion.

ACA-treated shingles at the Vancouver site were slightly more eroded than those treated with CCA or ACC. This difference was found to be significant using a two sample t-test. This could be due to the protection from ultra-violet (UV) radiation provided by the chromium component of CCA and ACC. All of the chemically treated samples were less eroded than the untreated ones, although only the CCA- and ACA-treated sets were significantly different ($t < 0.05$) from the controls. At Haney all treatments provided protection from erosion, since all treated panels both in sun and shade were significantly less eroded than the untreated controls ($t < 0.05$). The significantly greater erosion seen on the untreated panels at Haney compared to Vancouver ($t < 0.05$) can be attributed to the greater rainfall at Haney.

The untreated shakes installed in 1973 at Haney appeared to have been in worse condition after 15 years exposure (Morris, 1989) than the untreated shingles installed in 1980 were in 1995. This may be a function of a change in climate but is more likely due to variation in the natural durability of the wood being used in the two tests.

Shakes and Shingles Installed in 1983 at Singapore

After 11 years, the untreated shingles were heavily damaged by decay and termites (Table 9). The shingles would have ceased to function as a roof some years earlier. The untreated shakes were in better shape particularly with respect to termite attack but they had also been attacked by rats. According to one sawmill employee, this happened while they were covered with a metal sheet for an unspecified time period. From his description, this would have protected the untreated and treated shakes from rainfall. The shingles would not have been affected. The CCA-treated shingles and shakes were completely free of decay (Table 9). There was scattered minor cosmetic damage due to termites on the two panels of shingles. Such damage was noted on only five of the 90 shingles on panel A.

The untreated shingles showed the worst erosion of any of the samples but this may have been due in part to biodegradation of surface layers. As expected, the CCA-treated shingles and shakes appeared to have suffered more from splitting than the untreated material but there was no statistically significant difference between ratings for the two groups.

The presence of termites in Singapore and not at our site in B.C. makes direct comparison of the extent of deterioration somewhat difficult. Furthermore, since the shakes in Singapore had some protection for an unknown time, a direct comparison cannot be made with the results described above. Some comparisons can, however, be made for the data on treated and untreated shingles.

At Haney results from assessment of untreated shingles were similar to those from shingles exposed for 11 years in Singapore in terms of erosion and splitting, although decay was far more advanced in the untreated controls at Singapore. A comparison of CCA-treated samples at Haney and Singapore showed no decay present at either site, slightly worse erosion at Singapore, and worse splitting at Haney. This could reflect the higher rainfall and humidity at the tropical site since samples at the Singapore site may remain wet for longer periods than at Vancouver, which would tend to discourage splitting when compared to situations with more frequent wetting/drying cycles. The higher rainfall could also promote erosion of the wood surface.

4. General Discussion

The results of the work reported here have implications in terms of marketing as well as standards development. Recently there has been an upsurge of interest in pressure treating western red cedar shingles and shakes. The B.C. Independent Shake and Shingle Manufacturers Association now recommends the use of pressure treatment for roofs in B.C. Washington, Oregon and the entire east coast of the USA. There is also interest in developing a new standard for pressure treatment of western red cedar roofing materials.

One reason for these changes may be the reduced service life of untreated roofs resulting from changes in construction practice. Historical examples of service lives of 30 years or more for untreated shakes come mostly from roofs constructed with well ventilated spaced decking. The solid plywood decking and building paper interlayment used in the tests described here are considered to create a higher decay hazard than spaced decking even though water shedding is more efficient (Barnes, Buchanan and Amburgey, 1985). This is presumed to be due to a slower drying rate after rainfall resulting from reduced ventilation. The construction method used in these tests is much more representative of how shakes and shingles are now being applied. The results can therefore be used with confidence to support the development of a standard for pressure treatment of shingles and shakes by the CSA O80 Technical Committee on Wood Preservation.

The gauge retention recommended for shingles and shakes was originally set at 9.6 kg/m^3 (Canadian Standards Association, 1980) because of concern about the soft rot observed by Smith and Swann (1975). Subsequently this was lowered to 6.4 kg/m^3 (Canadian Standards Association, 1988). By comparing gauge and assay retentions in Tables 1, 3, 5 and 8, a gauge retention of 6.4 kg/m^3 would give an assay retention of about 6.4 kg/m^3 in sawn shingles and 5.0 kg/m^3 in split shakes. The difference is due to the deeper preservative penetration into the endgrain exposed in sawn shingles.

With the development of a new standard within CSA O80 the opportunity arises to set an assay retention based on the available performance data rather than on historical precedent. In this regard, the much lower assay retentions for CCA-B and modified ACA than for CCA-C and ACA in the 1973 shake installations, though unplanned, has proved fortunate. In this test an assay retention of 3.8 kg/m^3 of CCA-B has proved effective for 20 years. This is very close to the 4.0 kg/m^3 normally specified for lumber in use above ground (Canadian Standard Association 1989). CCA-B is no longer used in Canada but CCA-C, a better balanced formulation, would be expected to perform better than CCA-B (Hartford, Fahlstrom and Colley 1982).

Further support for a retention of 4.0 kg/m^3 comes from the excellent performance data on shingles exposed in Singapore. The assay retention in this material was 3.9 kg/m^3. Although this test has only been in place for 11 years the rate of decay at this site would be expected to be much faster than in a temperate climate.

A final consideration is that the recently published AWPA standard for shingles and shakes specifies 6.4 kg/m^3 for southern pine, which consists predominantly of perishable sapwood. Presumably western red cedar, with considerable natural durability, would not require such a high loading for adequate performance. A lower retention provides the opportunity not only to reduce costs but also to minimize any environmental impact.

Some indications of the expected service life of pressure-treated shakes and shingles can also be obtained from these tests. Considering that the 20-year old preservative-treated shakes still appear to be sound and the untreated shakes have failed, preservative treatment might be expected to at least double the service life of the product. This is based on the assumption that the rate of decay of the treated wood will be no faster than the rate of decay of the untreated wood. A service life for pressure-treated shakes of over 40 years in the Vancouver area is therefore quite possible.

This estimate is backed up by the data from Singapore, where the exposure period is relatively short but the biodeterioration rate is much faster. The organisms causing biodeterioration may be different in Singapore thus this data can only be considered as support for the data from the local test sites. The degree of acceleration of the Singapore test compared to the local sites can be obtained from comparing climate indices (Scheffer 1971). The climate index for Singapore is 219 while that for our Haney B.C. test site is 55. This might suggest that 11 years in Singapore would be equivalent to 44 years in B.C. Looking at this another way, the average temperature for Singapore is 26.7^{o} C which is around the optimum temperature for the growth of many fungi. It is almost three times the average temperature at the Research Forest, 9.4^{o} C. Many biological systems undergo a doubling of the activity with a 10^{o} C rise in temperature. We might therefore expect the rate of decay in Singapore to be around 3.3 times faster than in B.C. Eleven years exposure in Singapore would therefore relate to 36 years exposure in B.C. Since the treated material was still in good condition and would be expected to last several years longer these findings support the minimum 40 years service life predicted for pressure-treated shakes in the Vancouver area.

The reduced erosion due to CCA treatment in all these tests is a secondary benefit of pressure treatment in extending the service life of western red cedar roofing materials. This effect can be ascribed to the ultraviolet light (UV) stabilizing effect of chromium (Feist and Ross 1989). The protection afforded by ACA must be due to the effect of the copper (Liu, Ruddick and Jin 1994). There may also be some contribution to reduced erosion from prevention of biological attack on wood surfaces delignified by UV.

The one drawback to pressure treatment often put forward is an increased amount of surface checking and splitting. The data reported here suggests that the wetting and drying inherent in pressure treatment merely accelerates the splitting that would occur naturally in service. Where conditions are less conducive to splitting in service, a CCA-treated roof could be worse that an untreated roof. Where drying after rain is more rapid, or after extended service, the difference between treated and untreated roofs may not be noticeable in the long run. A good roofing company will replace any shakes or shingles that split within a limited time. In the case of treated material, this may dramatically reduce any future problems whereas untreated material may end up splitting after several years.

Hobbs (1983) showed that pressure treatment would provide value for money if treated shingles and shakes gave the expected service life of 40 years. In the Vancouver area, it is estimated that about 15% of shingles and shakes are currently pressure treated. Untreated shingles are commonly used on new housing developments where construction costs are paramount. In contrast, replacement shingle or shake roofs are more often constructed with pressure-treated shingles, presumably because the owners are familiar with the service life of untreated shingles and shakes.

5. Conclusions

1. Treatment specifications for shakes and shingles can be changed from a gauge retention of 6.4 to an assay retention of 4.0 Kg/m^3

2. Pressure-treated shingles and shakes may have a service life of over 40 years in the Vancouver area and areas with similar climate index.

3. Copper- and chromium-based preservative treatments used in this research appear to reduce the surface erosion of shakes and shingles.

4. Copper- and chromium-based pressure treatment used in this research appear to accelerate the rate of initial splitting of shakes and shingles but not the overall extent to which these products split in service.

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TABLE 1
INITIAL UPTAKE AND ASSAY RETENTIONS OF SHAKES INSTALLED IN 1973

PRESERVATIVE	RETENTION		
	UPTAKE kg/m^3	ASSAY kg/m^3	
		BUTT	FACE
TIM-BOR®	N/A	16.0	3.3
CCA-C	11.1	29.2	8.8
CCA-B	4.7	16.5	3.8
ACA	9.3	21.6	4.7
MOD. ACA	4.7	11.3	2.1

TABLE 2
SHAKE RATINGS AFTER 20 YEARS EXPOSURE AT HANEY

PRESERVATIVE	REPS.	MEAN RATING*		
		DECAY	EROSION	SPLITTING
CONTROL	49	1.7 (0.9)	2.4 (0.4)	1.5 (1.5)
TIMBOR®	58	2.1 (0.5)	2.6 (0.5)	1.6 (1.5)
CCA-C	43	0.05(0.2)	1.2 (0.4)	1.7 (1.6)
CCA-B	46	0.0 (0.0)	1.3 (1.3)	1.2 (1.5)
ACA	39	0.0 (0.0)	1.4 (0.6)	2.0 (1.3)
MOD. ACA	43	0.0 (0.0)	1.3 (0.5)	1.6 (1.4)

* Standard deviation in parentheses.

TABLE 3
INITIAL UPTAKE AND ASSAY RETENTIONS OF SHAKES INSTALLED IN 1980

PRESERVATIVE	GAUGE RETENTION kg/m³	ASSAY RETENTION kg/m³	
		FACE	BUTT
CCA-C	9.7	8.0	26.3
MODIFIED ACA	13.9	9.9	30.2
ACC	13.0	9.5	30.9

TABLE 4
SHAKE RATINGS AFTER 15 YEARS EXPOSURE AT WESTHAM ISLAND/VANCOUVER AND HANEY, B.C.

PRESERVATIVE	REPS.	MEAN RATING*		
		DECAY	EROSION	SPLITTING
<u>A) WESTHAM ISLAND/VANCOUVER TEST</u>				
SITE				
CONTROL	47	0.0 (0.0)	1.0 (0.2)	0.8 (1.1)
CCA-C	43	0.02(0.2)	0.02(0.2)	1.5 (1.5)
MODIFIED ACA	33	0.0 (0.0)	1.0 (0.2)	1.4 (1.4)
ACC	35	0.0 (0.0)	0.9 (0.4)	1.4 (1.3)
<u>B) HANEY TEST SITE</u>				
ACC - SUN	38	0.0 (0.0)	1.0 (0.4)	1.1 (1.2)
ACC - SHADED	37	0.0 (0.0)	0.5 (0.5)	1.2 (1.5)

* Standard deviations are given in parentheses

TABLE 5
INITIAL UPTAKE AND ASSAY RETENTIONS OF SHINGLES INSTALLED IN 1980

PRESERVATIVE	GAUGE RETENTION	ASSAY RETENTION kg/m³	
	kg/m³	FACE	BUTT
CCA-C	17.6	18.0	31.0
MODIFIED ACA	17.0	14.3	32.3
ACC	14.6	15.6	19.4

TABLE 6
SHINGLE RATINGS AFTER 15 YEARS EXPOSURE AT HANEY, B.C.

PRESERVATIVE	REPS.	MEAN RATING*		
		DECAY	EROSION	SPLITTING
CONTROL - SUN	38	0.02(0.2)	2.1 (0.3)	0.3 (0.9)
CONTROL - SHADED	40	0.2 (0.5)	1.3 (0.5)	0.2 (0.7)
CCA-C - SUN	45	0.0 (0.0)	0.7 (0.5)	1.4 (1.6)
CCA-C - SHADED	45	0.0 (0.0)	0.9 (0.3)	1.6 (1.7)
MODIFIED ACA	44	0.02(0.1)	0.8 (0.4)	1.4 (1.5)
ACC - SUN	40	0.0 (0.0)	0.9 (0.3)	1.7 (1.6)
ACC - SHADED	38	0.0 (0.0)	0.9 (0.3)	1.0 (1.5)

TABLE 7
SHINGLE RATINGS AFTER 15 YEARS EXPOSURE AT WESTHAM ISLAND/VANCOUVER, B.C.

PRESERVATIVE	REPS.	MEAN RATING*		
		DECAY	EROSION	SPLITTING
CONTROL	38	0.2 (0.4)	1.0 (0.0)	0.9 (1.4)
CCA-C	37	0.0 (0.0)	0.7 (0.5)	1.2 (1.4)
MODIFIED ACA	44	0.0 (0.0)	0.9 (0.2)	1.1 (1.5)
ACC	40	0.0 (0.0)	0.6 (0.5)	1.9 (1.7)

* Standard deviations are given in parentheses.

TABLE 8
TARGET AND ANALYSIS RETENTIONS FOR SHINGLES AND SHAKES INSTALLED IN 1983*

MATERIAL	RETENTION		
	TARGET kg/m^3	ASSAY kg/m^3**	
		BUTT	FACE
SHINGLES	10.0	16.7 (4.7)	10.3 (4.5)
SHAKES	10.0	15.7 (3.4)	3.9 (2.4)

* Data taken from Smith et al (1985)
** Means with standard deviations in parentheses

TABLE 9
SHINGLES AND SHAKE RATINGS AFTER 11 YEARS EXPOSURE IN SINGAPORE

			MEAN RATING*			
MATERIAL	TREATMENT	REPS.	DECAY	TERMITE	EROSION	SPLITTING
SHINGLES	NONE	21	3.4 (0.7)	2.6 (1.3)	2.4 (0.7)	0.3 (1.1)
SHAKES	NONE	13	2.6 (0.5)	0.5 (0.7)	1.0 (0.4)	0.4 (1.0)
SHINGLES	CCA	20	0.0 (0.0)	0.1 (0.4)	1.0 (0.0)	0.9 (1.3)
SHAKES	CCA	17	0.0 (0.0)	0.0 (0.0)	0.9 (0.6)	0.8 (1.6)
SHINGLES	** CCA	90	0.0 (0.0)	0.1 (0.3)	0.9 (0.4)	0.8 (1.5)

* Standard deviations in parentheses
** Panel A, the full panel of shingles

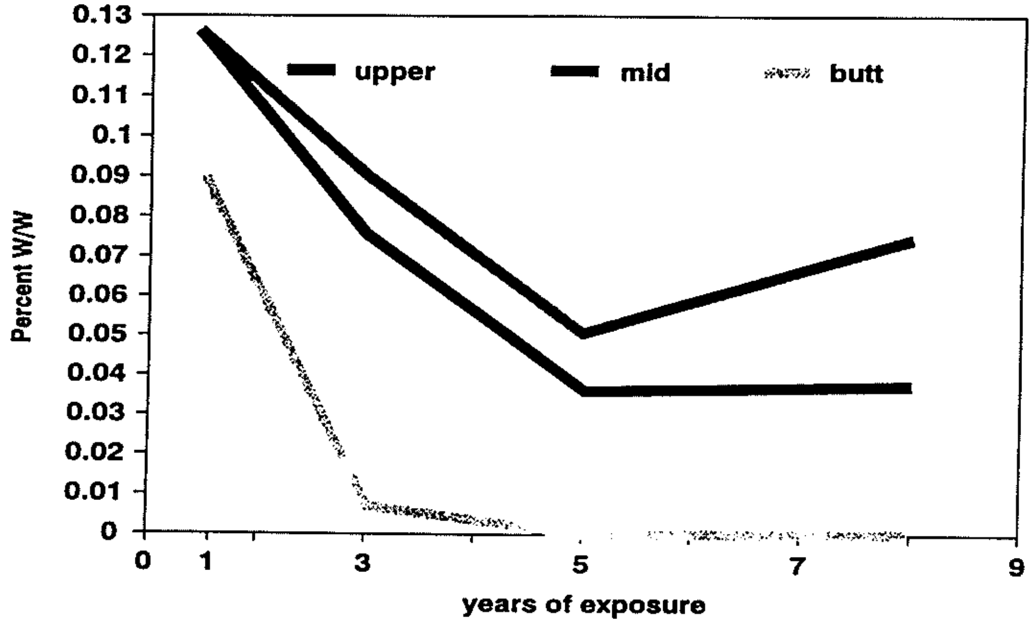

Figure 1: Analyses data, from Johnson and Cserjesi 1980, for thujaplicins, of test shakes installed in 1973

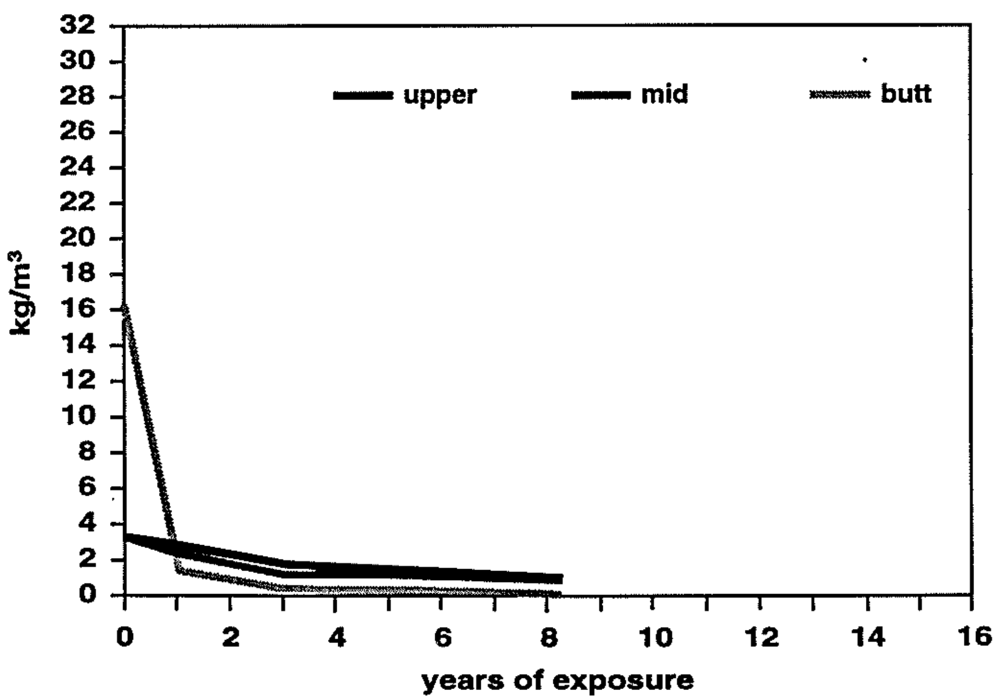

Figure 2: Analyses, for Tim-Bor, of test shakes installed in 1973

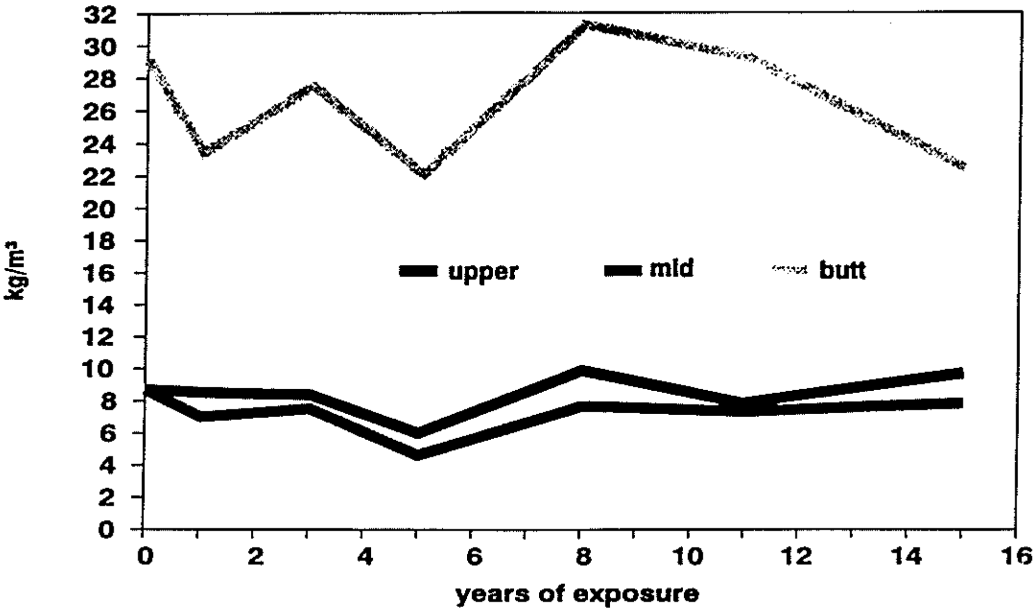

Figure 3: Analyses data, for CCA-C, of test shakes installed in 1973

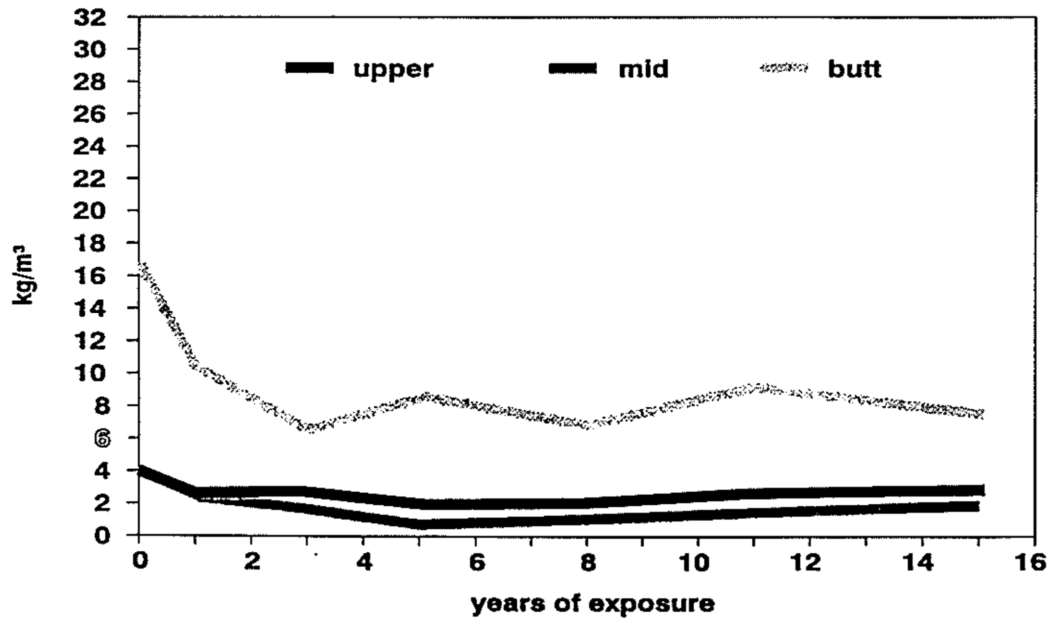

Figure 4: Analyses data, for CCA-B, of test shakes installed in 1973

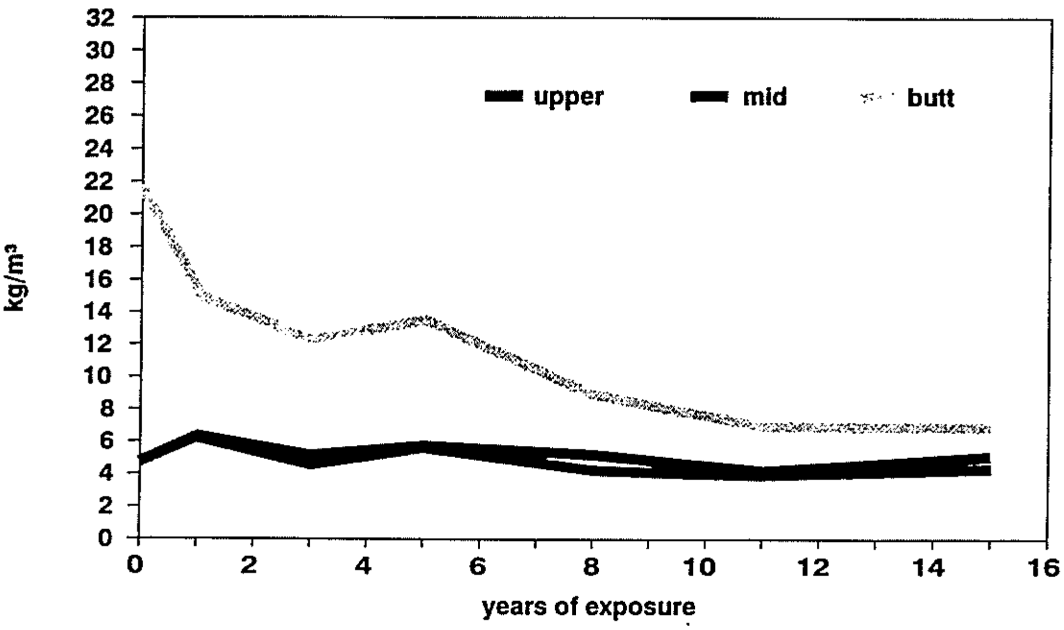

Figure 5: Analyses data, for ACA, of test shakes installed in 1973

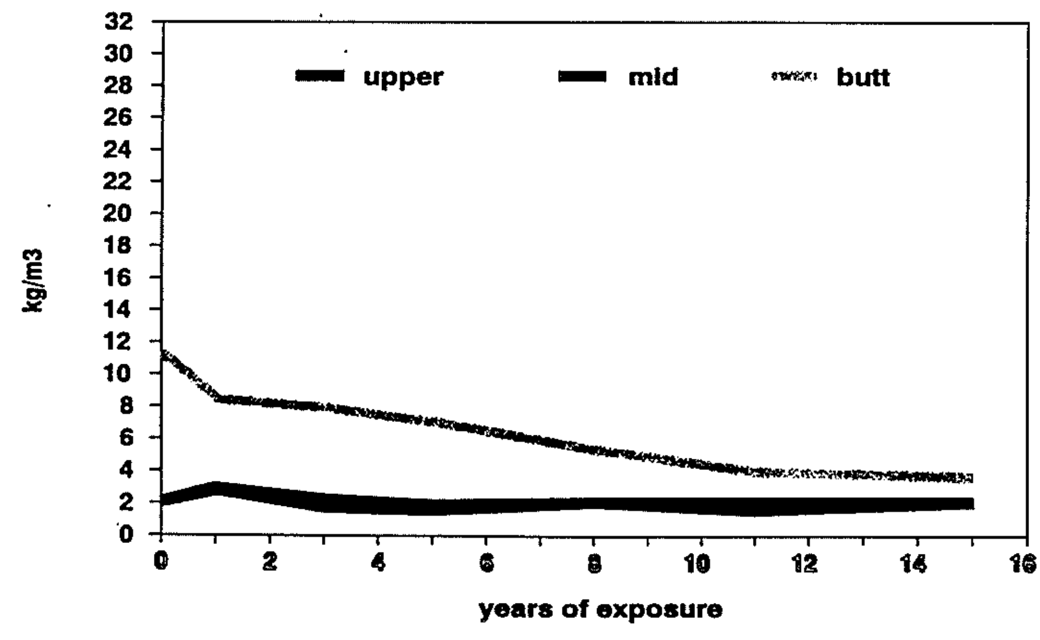

Figure 6: Analyses data, for modified ACA, of test shakes installed in 1973