EXTERIOR WEATHERING TRIALS ON PINUS RADIATA ROOFING SHINGLES

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ABSTRACT

A series of test roofs clad with radiata pine (**Pinus radiata** D. Don) shingles that had been pressure-treated with various water-borne preservative formulations were installed at a Forest Research Institute test site in Rotorua in 1977. A further series of test roofs installed in 1978 included radiata pine shingles pressure-treated with a commercial light organic solvent preservative.

Evaluation of selected radiata pine shingle test roofs in early 1984 showed that, although preservative leaching had occurred from shingles treated with an alkyl ammonium compound, a copper-chrome-arsenic preservative, and a light organic solvent preservative, the shingles appeared sound when examined microscopically. Slight lichen growth was evident on some shingles. In contrast, untreated radiata pine shingles displayed marked fungal infection, early stages of decay, and plentiful mould and lichen growth. Untreated western red cedar (**Thuja plicata** D. Don) shingles, which were used as a reference point from which to judge radiata pine shingles, showed lichen and mould growth after 7 years' exposure. Checking and cupping of western red cedar shingles were attributable in part to the inclusion of some flat-sawn material.

INTRODUCTION

In North America wooden shingles or hand-split shakes have been in use for many years as roofing or exterior cladding material. These products give an appealing rustic character to housing and are often preferred to alternative roofing materials from an aesthetic standpoint.

The good durability, dimensional stability, and light weight of western red cedar makes this species especially suitable for manufacture of shingles and shakes. The decay resistance of western red cedar has been discussed by Roff *et al.* (1963); its chemistry and utilisation have been described by Barton & MacDonald (1971). Although western red cedar is considered to have high durability, it is well known that western red cedar shingle roofs do not provide the anticipated service life in mild, humid climates and that roof replacement may be necessary at an unacceptably early stage (Smith 1964). The durability of western red cedar roofs in the Pacific Northwest has been discussed by Smith *et al.* (1980) and they indicated that serious decay can occur within a period of 10 to 15 years.

The shortened service life of western red cedar roofs can be attributed to leaching of heartwood extractives under damp climatic conditions and subsequent colonisation by wood-decaying fungi. There is some evidence that the service life of western red cedar roofs may be improved by spraying with a suitable fungicide (e.g., 1% copper naphthenate or zinc naphthenate in oil). However, in practice there are few home-owners who will take such measures. The desirability of pressure-treating western red cedar shingles with copper-chrome-arsenic (CCA) preservative was suggested in the late 1960s in the United Kingdom (Anon. 1968).

In New Zealand, western red cedar shingles have been imported and used as a premium cladding material for many years. Present annual usage is approximately 9000 m^2 in terms of roof coverage (M. Scott, pers. comm.). Western red cedar shingles have traditionally been imported into New Zealand in untreated form; however, CCA treatment may become a future option in New Zealand.

Since the late 1970s a New Zealand-based company has been producing radiata pine shingles for the domestic and export markets. To overcome the low natural durability of radiata pine, the shingles were originally treated with a CCA preservative. However, concern over use of rainwater run-off for drinking water, corrosion of fasteners, and premature substrate checking have since led to the use of copper naphthenate-based light organic solvent preservatives (LOSP). Use of preservative-treated radiata pine shingles has expanded since the New Zealand Standard Model Building By-law (NZS 1900) was amended in 1979 to allow use of wooden roofing material at the discretion of the appropriate local authority. Anticipated production of radiata pine shingles in 1984–85 is in excess of 12 000 m^2 in terms of roof coverage for domestic and export markets combined (O. Lockerbie, pers. comm.).

In response to increasing public and commercial interest in wooden roofing shingles, a trial was established at the Forest Research Institute to provide information on the weatherability and durability of radiata pine shingles. This trial was started in March 1977 and has been briefly described previously (Forest Research Institute 1977). The evaluation of the condition of selected test roofs from the trial in 1984, described in this paper, was prompted by industrial concern over the increasing cost of LOSP treatment and interest in changing to more economical water-borne preservative treatment of radiata pine shingles.

MATERIALS AND METHOD

Shingles

Radiata pine shingles for the trial were band-sawn from 400-mm lengths of 150 × 25-mm or 100 × 25-mm quarter-sawn timber. Two tapered shingles measuring 150 × 400 mm or 100 × 400 mm with 15-mm butt thickness and 6-mm tip thickness were obtained from each 400-mm length. The shingles were dried to 16% moisture content and sets of approximately 150 shingles were pressure-treated with one of a series of eight water-borne preservative solutions and one solvent-borne preservative solution using the Bethell or full-cell treatment process. After re-drying, the sets of shingles were installed on wooden exposure racks as shown in Fig. 1, 2, and 3. In addition,

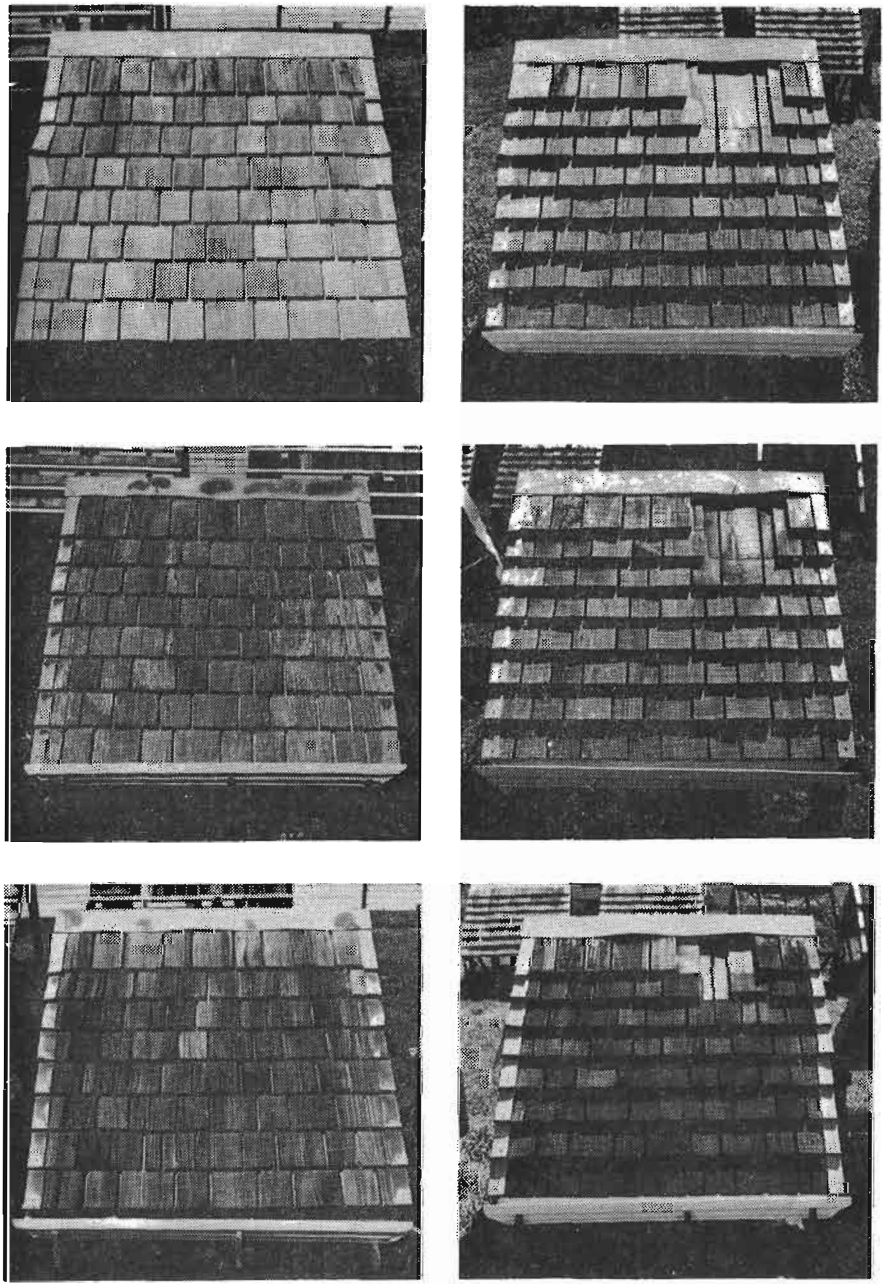

FIG. 1—Treatments and exposure conditions for radiata pine shingle test roofs. Top left: Bioquat 501, north facing. Top right: Bioquat 501, south-facing. Middle left: Bioquat 501(+), north-facing. Middle right: Bioquat 501(+), south-facing. Bottom left: Tanalith NCA, north-facing. Bottom right: Tanalith NCA, south-facing.

Note: Shingles missing from south-facing roofs were removed for sampling.

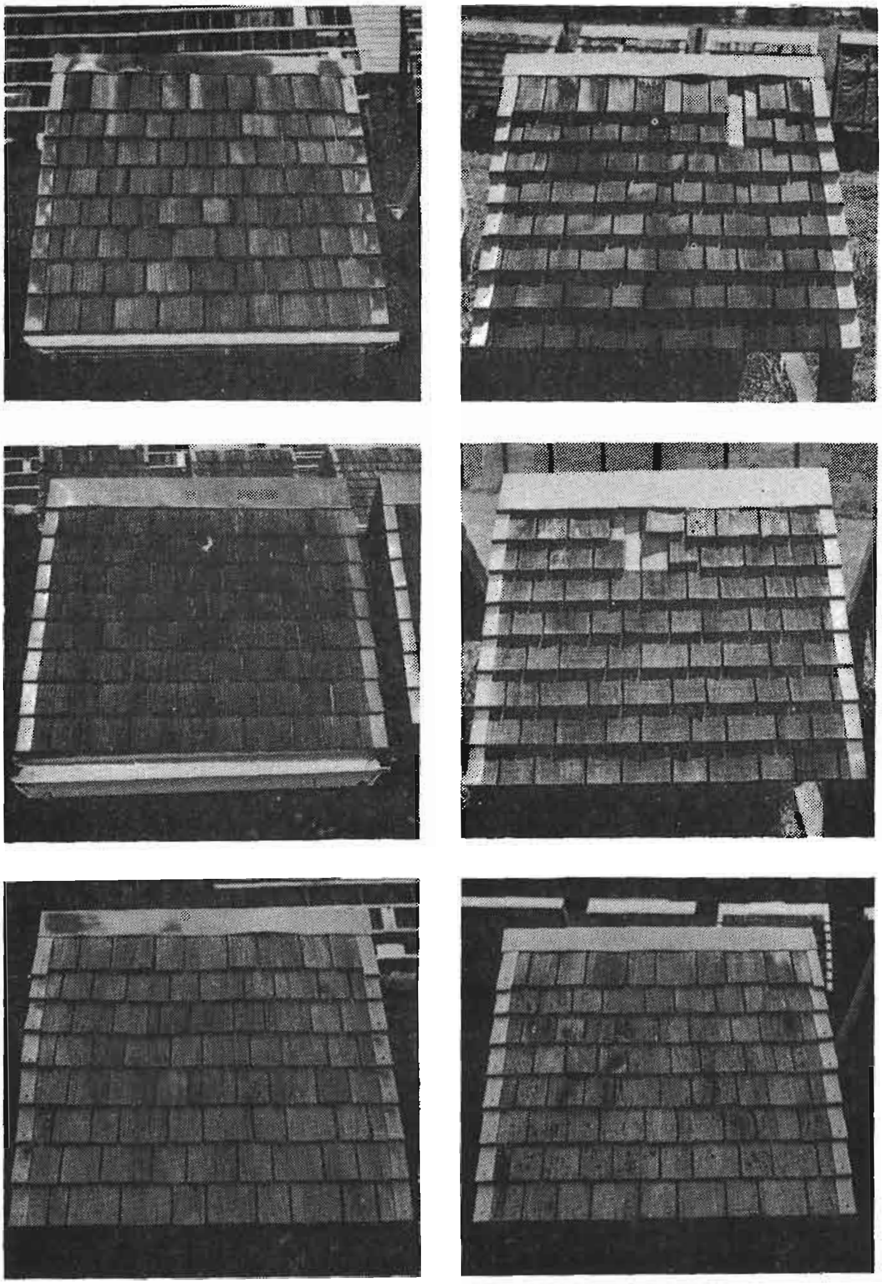

FIG. 2—Treatments and exposure conditions for radiata pine shingle test roofs. Top left: Tanalith NCA(+), north-facing. Top right: Tanalith NCA(+), south-facing. Middle left: Tricunol, north-facing. Middle right: Tricunol, south-facing. Bottom left: untreated, north-facing. Bottom right: untreated, south-facing.

Note: Shingles missing from south-facing roofs were removed for sampling.

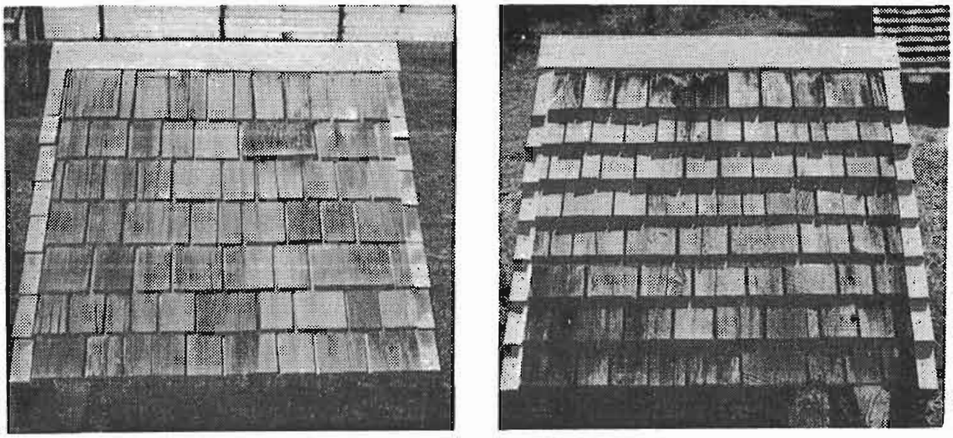

FIG. 3—Exposure conditions for western red cedar shingle test roofs.
Left: untreated, north-facing.
Right: untreated, south-facing.

test racks clad with untreated radiata pine shingles and with untreated imported western red cedar shingles were constructed. The commercial, randomly sawn, western red cedar shingles measured 150 × 400 mm or 100 × 400 mm with 8-mm butt thickness and 2-mm tip thickness.

The 11 original test roofs clad with preservative-treated radiata pine shingles, untreated radiata pine shingles, or untreated western red cedar shingles were built at the Forest Research Institute in Rotorua in March 1977. A further 11 roofs were built in March 1978. This second series of roofs incorporated shingles cut from other wood species and commercially obtained radiata pine shingles treated with Tricunol, a LOSP containing copper naphthenate and tri-butyl tin oxide as active ingredients. The commercial LOSP-treated radiata pine shingles were of the same dimensions as the western red cedar shingles.

Preservative Treatments

The radiata pine shingles were pressure-treated with preservatives using a treating cycle inovlving an initial vacuum of –85 kPa for 25 minutes followed by a pressure period of 1 hour at 1400 kPa. The shingles were weighed before and after treatment to determine preservative uptake and then air-dried before installation on racks at the test site.

Test roofs clad with radiata pine shingles treated with the following preservatives were chosen for evaluation in 1984 on the basis of current commercial interest:

(1) Bioquat 501 (0.8% w/w active ingredient), an alkyl ammonium compound (AAC) formulation containing alkyl (64% C12, 30% C14, 6% C16) dimethylbenzyl-ammonium chloride (benzalkonium chloride) as active ingredient;

(2) Bioquat 501 (0.8 w/w active ingredient) modified by inclusion of 1.0% w/w polyethylene wax emulsion;

(3) Tanalith NCA (0.8% commercial salts), a CCA formulation containing copper sulphate ($CuSO_4$), sodium dichromate ($Na_2Cr_2O_7$), arsenic pentoxide ($As_2O_5.2H_2O$), and sodium arsenate ($Na_2HAsO_4.7H_2O$) in proportions to give relative percentage elements by weight of 27%, 28%, and 45% for copper, chromium, and arsenic respectively;

(4) Tanalith NCA modified by inclusion of 1% w/w Paracol 404 paraffin wax emulsion.

The evaluation also included the test roof clad with Tricunol-treated radiata pine shingles and roofs clad with untreated radiata pine shingles and untreated western red cedar shingles. The Tricunol preservative in commercial use in 1978 contained 0.4% copper naphthenate and 1.0% tri-butyl tin oxide as active ingredients in white spirit as well as additives to impart water repellency.

Test Roof Construction and Exposure

Individual test roofs with north-facing and south-facing sides at a 45° pitch were exposed at the test site in Rotorua. Roof construction involved securing courses of shingles to CCA-treated 50 × 25-mm radiata pine battens that were nailed horizontally at 125-mm centres to the frame of each test rack. A layer of building paper was placed between the shingles and the pine battens. The bottom row of each shingle roof was double-layered and subsequent rows were then installed allowing 125 mm of each shingle to be exposed to the weather. Gaps of 6 mm were left between individual shingles. The shingles were pre-drilled and nailed with two 50-mm flat-head galvanised nails at 18 mm from the edges and 35 mm above the butt line of the next course (i.e., 160 mm above the butt). This construction resulted in a roof area for each treatment of 1125 × 1200 mm on both north-facing and south-facing exposures. Each roof held approximately 75 shingles in eight rows of nine or 10 shingles. Shingles measuring 150 mm or 100 mm in width were alternated in each row. The test roofs clad with preservative-treated radiata pine shingles, untreated radiata pine shingles, or untreated western red cedar shingles were capped at top and sides with PVC to prevent moisture entry. The test roof clad with Tricunol-treated radiata pine shingles was capped in a similar manner with aluminium sheet.

Area weather records over a 20-year period show that the Rotorua test site receives mean annual rainfall of 1490 mm, has mean maximum and mean minimum temperatures of 17.4°C and 8.0°C respectively, and receives a mean of 1948 sunshine hours annually.

Shingle Roof Assessments

The assessment of shingle roof condition in January 1984 included evaluation of physical degradation, biodegradation, and analyses of samples to determine preservative losses as a result of leaching from exposed shingle surfaces (i.e., those surfaces not covered by the next row of shingles).

The shingles were assessed for checking and distortion. Checking was rated according to the following scale:

1 = No checking

2 = Fine surface checks
3 = Deep surface checks not penetrating the complete butt thickness of the shingle
4 = Checks penetrating through the shingle
5 = Shingle split into two or more pieces and rated as unserviceable.

Each shingle on each roof was rated according to this scale and mean checking ratings were obtained by averaging the checking ratings on each side of each roof. Distortion was assessed by determining maximum cupping of any shingle in each row and then calculating the mean maximum cupping measured on each roof. Cupping on individual shingles in each row was measured by placing a ruler on each shingle and recording the distance between the ruler's edge and the mid-point of the shingle.

Microscopic examination to assess the extent of any biodeterioration was performed on several shingles removed from the top two layers of the south-facing side on each roof. After microscopic examination, samples were cut from three shingles in each set and analysed for the relevant preservative ingredients. Each shingle was analysed in a portion that had been exposed to the weather and also in a portion that had been covered by the next row of shingles. Shingles that had been preservative-treated with Bioquat 501 or Bioquat 501 modified by incorporation of 1% polyethylene wax emulsion were analysed for AAC content by extraction with acidic ethanol followed by a two-phase titration procedure adapted from a method used for anionic active detergents (Reid *et al.* 1967). Shingles that had been preservative-treated with Tanalith NCA or Tanalith NCA modified by incorporation of 1% paraffin wax emulsion were analysed for copper, chromium, and arsenic by sample digestion followed by wet chemical analytical methods. Shingles that had been preservative-treated with Tricunol were analysed for copper content by sample digestion followed by atomic absorption spectrophotometry.

RESULTS AND DISCUSSION

Details of the physical degradation of the shingle roofs are shown in Table 1. The mean checking ratings are tabulated in decreasing order of checking severity and have been statistically analysed. An analysis of variance showed that influences of the preservative, the roof orientation, and the interaction of preservative and roof orientation on checking ratings were highly significant. A least significant difference test applied to the analysis of variance results allowed mean checking ratings for each treatment/roof-orientation combination to be compared (Table 1).

The Tanalith NCA-treated radiata pine shingles were rated as significantly more severely checked than the other shingle sets on the basis of checking ratings on north-facing roofs. This result was expected since the promotion of timber checking by CCA preservatives is well recognised (e.g., Belford & Nicholson 1969). Tricunol, Bioquat 501, and wax emulsion-modified Tanalith NCA treatments gave significantly improved resistance to checking compared to untreated radiata pine or untreated western red cedar on north-facing roofs. The resistance to checking of shingles treated with wax emulsion-modified Bioquat 501 could not be distinguished from that of untreated pine or untreated western red cedar on the basis of this evaluation of north-facing roofs.

TABLE 1—Physical degradation of wood shingle roofs* at the FRI test site

Preservative treatment/ Wood species	Roof orientation	Mean checking rating†	Mean maximum cupping (mm)
Tanalith NCA/radiata pine	North	3.23 a	2.9
Untreated radiata pine	North	2.63 b	2.1
Untreated western red cedar	North	2.52 bc	3.9
Bioquat 501 + wax/radiata pine	North	2.36 bcd	2.8
Untreated western red cedar	South	2.27 cde	2.0
Tanalith NCA/radiata pine	South	2.27 cde	3.1
Bioquat 501/radiata pine	South	2.14 de	2.2
Tricunol/radiata pine	North	2.10 de	4.2
Tanalith NCA + wax/radiata pine	North	2.06 e	3.2
Bioquat 501/radiata pine	North	2.01 e	2.2
Untreated radiata pine	South	2.00 e	2.1
Bioquat 501 + wax/radiata pine	South	1.98 e	1.8
Tricunol/radiata pine	South	1.56 f	3.1
Tanalith NCA + wax/radiata pine	South	1.43 f	2.6

* Tricunol-treated radiata pine shingles were exposed for 6 years and other examined shingle roofs were exposed for 7 years.
† Mean checking ratings with the same letter are not significantly different at the 5% level.

Tanalith NCA-treated radiata pine shingles and untreated western red cedar shingles were rated as the most severely checked on south-facing roofs. Tricunol and wax emulsion-modified Tanalith NCA treatments gave significantly improved resistance to checking compared to shingles on other south-facing roofs and this indicates the benefit of incorporating water-repellent additives in such treatments. Bioquat 501-treated radiata pine shingles were more prone to checking on the south-facing roof than on the north-facing roof. This unexpected observation and the difference in checking resistance between shingles treated with Bioquat 501 or wax emulsion-modified Bioquat 501 may be related to preservative leaching differences, although the possibility was not addressed in this work.

In general, comparison of checking and cupping of Tricunol-treated shingles with that of other shingles was complicated by the relative thinness of the LOSP-treated commercial shingles and also by the gap of 1 year between installation of the two sets of test roofs.

Measurements of shingle cupping were expressed as the mean maximum cupping for each side of each roof (Table 1). With the Tricunol-treated radiata pine and the untreated western red cedar shingles excluded on the basis of their thinner dimension, the wax emulsion-modified Tanalith NCA-treated radiata pine shingles on the north-facing exposure showed the highest mean maximum cupping. However, differences in mean maximum cupping between treatments were slight and the data presented in Table 1 can be considered to give only a general guide to relative physical distortion of shingles treated with different preservatives. As expected (Brown *et al.* 1949) physical distortion of flat-sawn western red cedar shingles was worse than that of quarter-sawn shingles on the same roof. More detailed examination of checking and cupping of each shingle would be required to provide firmer conclusions. The evaluation method described in this paper was adopted to obtain an interim assessment of shingle condition and a guide to performance trends.

The Bioquat 501 treatment had produced an attractive silver-grey weathered appearance on the north-facing shingles after 7 years' exposure, although scattered mould patches were evident on the south-facing roof (Fig. 1). The wax emulsion-modified Bioquat 501-treated shingles were of essentially the same surface appearance as those treated with Bioquat 501 alone (Fig. 1). The Tanalith NCA-treated shingles were dark grey-green in colour and relatively clean in appearance, but showed numerous checks with slight erosion of sharp edges on the checks, especially on the north-facing roof (Fig. 1). The shingles treated with wax emulsion-modified Tanalith NCA were also clean in appearance with the only evidence of mould occurring at a few water run-off edges on the south side (Fig. 2). The Tricunol-treated shingles were dark grey-green in colour with lichen growth on some shingle edges on the south side and at water run-off points on the north side (Fig. 2). Untreated radiata pine shingles were weathered silver-grey with patches of mould and lichen widely distributed on the south side but confined mainly to water run-off edges on the north side (Fig. 2). Surface probing with a knife revealed evidence of decay in some untreated radiata pine shingles. Untreated western red cedar shingles showed significant erosion of earlywood bands in quarter-sawn shingles; this observation is consistent with the known weathering characteristics of western red cedar (Feist & Mraz 1978). Some lichen and mould growth was evident on the south side of the western red cedar roof (Fig. 3).

The upper surfaces of shingles removed from south-facing roofs were microscopically examined in areas that had been exposed to the weather as well as in areas that had been covered by the next row of shingles. The need for preservative treatment of radiata pine shingles is apparent from a comparison of treated shingles and untreated shingles (Table 2). Apart from some surface fungal spores, the Tanalith NCA-treated radiata pine and Tricunol-treated radiata pine showed negligible fungal activity. Bioquat 501-treated radiata pine showed evidence of pigmented fungal hyphae on the exposed surface. Cell wall splitting was frequently observed in samples from each treatment and this may be attributed to the effects of weathering, in particular to the ingress of water. The important role of water in wood surface degradation has been discussed by Banks & Evans (1984).

The results of chemical analyses of samples from the inspected shingle roofs are shown in Tables 3, 4, and 5. Apart from an anomalous result for arsenic, all three of the Tanalith NCA-treated samples showed leaching losses of preservative elements. Comparison of exposed with covered portions of the same shingle showed that relative leaching losses of copper, chromium, and arsenic were 11–57%, 9–50%, and 0–72% respectively in the Tanalith NCA-treated samples, and 0–17%, 8–32%, and 11–15% respectively in the wax emulsion-modified Tanalith NCA-treated samples. There is some indication that the inclusion of wax has slightly reduced copper leaching. Two of the Tanalith NCA-treated radiata pine shingles showed copper concentrations below the 0.07% w/w minimum required by the New Zealand Timber Preservation Authority (TPA) C7 specification, and one shingle showed arsenic concentration below the 0.11% w/w minimum required by the C7 specification. In contrast, none of the elemental concentrations in the wax emulsion-modified Tanalith NCA-treated samples fell below the C7 specification. However, the absolute differences in elemental concentrations are slight.

For the Bioquat 501 treatments, comparison of exposed with covered portions of the same shingle showed that relative leaching losses of 16–41% had occurred. However, initial loadings were well in excess of the current TPA C7 specification (minimum 0.55% w/w active ingredient in the retention zone) and remain so even after 7 years' weathering. In contrast, shingles treated with wax emulsion-modified Bioquat 501 showed relative leaching losses of 54–74% indicating that the inclusion of 1% polyethylene wax in the treatment has had a negative effect on preservative permanence. It is possible that the wax blocked some of the AAC preservative fixation sites in the

TABLE 2—Microscopic examination of wood shingle samples* removed from the FRI test site

Preservative treatment/ Wood species	Comments
Bioquat 501/radiata pine	Covered upper surface - wood is clean and sound. Brown flecks on underside of shingle, probably of chemical origin. Exposed upper surface - darkly pigmented spores and some hyphae evident. Some evidence of cell wall splitting, possibly aligned with cellulose microfibrils.
Bioquat 501 + wax/radiata pine	Covered upper surface - wood is clean and sound except for a few pigmented hyphae. Some splitting of cell walls. Exposed upper surface - pigmented spores and unidentifiable extraneous material in cell lumens. Some splitting of cell walls.
Tanalith NCA/radiata pine	Covered upper surface - wood is sound except for a few brown spores. Exposed upper surface - wood is sound but shows some surface lichen and spores. Surface discoloration is superficial.
Tanalith NCA + wax/radiata pine	Covered upper surface - sound. Exposed upper surface - negligible fungal activity. Some splitting of cell walls.
Tricunol/radiata pine	Covered upper surface - sound. Exposed upper surface - negligible fungal activity. Some splitting of cell walls.
Untreated radiata pine	Covered upper surface - evidence of soft-rot cavities and sapstain. Exposed upper surface - evidence of lichen, pigmented sapstain hyphae, and bore holes caused by basidiomycetes.
Untreated western red cedar	Covered upper surface - sound except for some fungal spores. No fungal hyphae. Exposed upper surface - earlywood erosion to 2 mm. Brown spores, pigmented hyphae evident.

* Tricunol-treated radiata pine shingles were exposed for 6 years and all other shingle roofs were exposed for 7 years.

TABLE 3—Chemical analyses of CCA-treated radiata pine shingle samples removed from the FRI test site after 7 years' exposure

Preservative treatment	Concentrations (% w/w)*			Shingle position
	Cu	Cr	As	
Tanalith NCA				
Exposed	0.08	0.10	0.14	Top Layer
Covered	0.09	0.12	0.11	
Exposed	0.06	0.10	0.15	Second Layer
Covered	0.13	0.20	0.16	
Exposed	0.06	0.10	0.07	Second Layer
Covered	0.14	0.11	0.25	
Tanalith NCA + wax				
Exposed	0.10	0.15	0.12	Top Layer
Covered	0.12	0.22	0.14	
Exposed	0.09	0.16	0.11	Second Layer
Covered	0.12	0.20	0.13	
Exposed	0.12	0.11	0.17	Second Layer
Covered	0.12	0.12	0.19	

* Elemental concentrations expressed as percentage-by-weight element on oven-dry wood weight basis to ± 0.01% w/w.

Note: TPA C7 specification requires minimum elemental loadings of 0.07% copper, 0.09% chromium, and 0.11% arsenic on oven-dry wood weight basis.

TABLE 4—Chemical analyses of AAC-treated radiata pine shingle samples removed from the FRI test site after 7 years' exposure

Preservative treatment	Concentrations (% w/w)* AAC	Shingle position
Bioquat 501		
Exposed	0.85	Top Layer
Covered	1.01	
Exposed	0.76	Second Layer
Covered	1.03	
Exposed	0.82	Second Layer
Covered	1.39	
Bioquat 501 + wax		
Exposed	0.31	Top Layer
Covered	0.67	
Exposed	0.35	Second Layer
Covered	0.85	
Exposed	0.37	Second Layer
Covered	1.44	

* Concentrations expressed as percentage-by-weight AAC on oven-dry wood weight basis to ± 0.01% w/w.

Note: TPA C7 specification requires minimum AAC loading of 0.55% on oven-dry wood weight basis.

TABLE 5—Chemical analyses of Tricunol-treated radiata pine shingle samples removed from the FRI test site after 6 years' exposure

Preservative treatment	Concentrations (% w/w)* Cu	Shingle position
Tricunol		
Exposed	0.03	Top Layer
Covered	0.04	
Exposed	0.04	Second Layer
Covered	0.09	
Exposed	0.04	Second Layer
Covered	0.08	

* Copper concentration expressed as percentage-by-weight element on oven-dry wood weight basis to ± 0.01% w/w.

Note: TPA C7 specification requires minimum copper loading of 0.07% on oven-dry wood weight basis.

wood, or hindered full preservation penetration. In addition, the possibility of chemical bonding between AAC and the wax cannot be excluded.

The results for each set of roofs were used to assess the consequences of changing from an LOSP treatment to CCA or AAC water-borne treatments for radiata pine shingles. The wax emulsion-modified Tanalith NCA treatment was the most effective in resisting checking, decay, and leaching of preservative elements. Although this formulation was used in the past, treating-process difficulties were encountered and it is not currently available. CCA treatments may also contribute to fastener corrosion where the fastener metal is anodic to copper (Baker 1980). Furthermore, where rain-water run-off from a roof is used for drinking water supply, the arsenic component of any roof leachate is undesirable. These factors limit the application of CCA preservatives for shingle treatments.

The Bioquat 501-treated shingles were sound after 7 years' exposure, but this finding may be attributed to the high initial loadings of preservative. Comparison of exposed and covered portions of the same Bioquat 501-treated shingles revealed leaching losses of the preservative; this is in conflict with the results of previous laboratory work (e.g., Butcher *et al.* 1977) that proved AAC-type preservatives are strongly fixed to wood.

The use of AAC preservatives in New Zealand was temporarily restricted by the TPA in August 1984 after instances of decay in AAC-treated timber in service. Most examples of decay are attributable to inadequate treatment or misuse of treated timber; however, a few samples have exhibited preservative loss from outer surfaces of timber in block storage, and this phenomenon has not been explained to date. These problems of decay in apparently well-treated wood preserved with AAC confirm that it may be premature to approve the use of a Bioquat 501-type preservative for roofing shingles. The known superior effectiveness of dialkyldimethylammonium halide preservatives (Preston & Chittenden 1982) suggests they may have a future application for this purpose.

The Tricunol-treated shingles also exhibited copper leaching losses of 25–55%; these losses reduced the copper concentration in exposed portions of sampled shingles below the 0.07% w/w minimum required by TPA C7 specification. However, although shingle cupping has occurred in some cases, checking is quite limited and the material appears sound under microscopic examination. The undesirable lichen growth on the Tricunol-treated test roofs has also been observed on roofs in service.

CONCLUSIONS

Physical inspection of the test roofs after 7 years' exposure has shown that untreated radiata pine shingles are unsatisfactory as a roofing material. Radiata pine shingles given AAC treatment have an acceptable appearance after 7 years' exposure, although it may be premature to suggest benzalkonium chloride-type AAC treatment as an alternative to copper naphthenate-based LOSP treatment. Untreated western red cedar shingles are prone to lichen and mould growth. Checking and cupping of these shingles could be lessened by the use of quarter-sawn rather than flat-sawn material. As in mild climatic zones of North America, it appears that western red cedar shingle roofs may require maintenance and the possible application of a fungicide to ensure acceptable service life in New Zealand.

Further monitoring of the condition of the Forest Research Institute test roofs is planned and another series of test roofs is being installed at the test site to allow assessment of various preservatives, wood species, and shingle profiles that are of potential interest.

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