International Biodeterioration & Biodegradation **32** (1993) 289–303

A Non-toxic Method to Combat Incipient Decay of CCA- and Creosote-Treated Poles in Soil-Contact

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(Received 30 March 1993; accepted 18 June 1993)

ABSTRACT

A non-chemical means of preventing premature pole failure in soil-contact was investigated by applying open-ended cylindrical sleeves of heat-shrink polyethylene to the soil-contact surfaces of Eucalyptus grandis *poles as physical barriers to fungal colonisation from soil in sub-tropical South Africa. The test site was managed under flood-irrigation to represent vineyard conditions. After exposure for 26 weeks all untreated unsleeved poles had failed, whereas sleeved poles were colonised by fungi but remained relatively sound. Unsleeved poles treated with 16 kg CCA* m^{-3} *were colonised by fungi at their soil-contact surfaces, whereas their sleeved counterparts were uncolonised. Unsleeved poles treated with 100 kg creosote* m^{-3} *were extensively covered by biofilm and showed incipient decay at their soil-contact surfaces, whereas their sleeved counterparts were uncolonised.*

INTRODUCTION

Preservative-treated wooden poles in soil-contact are in service throughout the world as transmission poles, and as agricultural utility poles such as fence posts, strainers, and bean and vineyard poles. The treatments used are specified in the standard methods legislated in the countries where the poles are placed in service, and the recommended preservative retention in the wood is generally considered to provide 30 years' protec-

International Biodeterioration & Biodegradation 0964-8305/94/$07·00

tion from biodeterioration in any environment. Unfortunately, in several countries premature failure of poles in soil-contact under a variety of environmental conditions is well-documented (Murira & Cockcroft, 1988; Wong *et al.*, 1992), and the problem is widespread in South Africa. Apart from the very substantial financial losses attributable to premature pole-failure, the fate of preservative elements released to the environment from mineralised wood of failed poles is a source of increasing concern.

Premature pole-failure is attributable primarily to microbiological decay, but the exact mechanisms involved in the decay of preservative-treated wood are unclear. Many research groups have examined this problem intensively (King *et al.*, 1981) and the possible causes of premature failure have been the subject of extensive debate among members of the International Research Group on Wood Preservation during the past 20 years (Nilsson *et al.*, 1988). The means by which microorganisms overcome the toxic effects of standard retentions of wood preservatives and degrade that wood are not yet fully explained. Since the problem is widespread in South African vineyards, it was decided to investigate possible solutions. In view of the current inability to explain premature failure, it was reasoned that prophylactic solutions centred on the cause of the problem, as opposed to symptomatic remedial strategies, should be examined.

Incorporation of preservatives to toxify the niche so that microbiological growth is prevented is conventional, but in the present work it was decided to consider manipulation of other environmental factors to control sub-soil decay of wood. Impenetrable physical barriers to microorganisms have been used for decades in biodeterioration control strategies to preclude colonisation of perishable foodstuffs (Ayres *et al.*, 1980). The use of an impermeable physical barrier of heat-shrink polyethylene against microbiological colonisation of poles in soil-contact was therefore investigated. Since premature failure of treated utility poles is common in vineyards under flood-irrigation in South Africa, the investigation was conducted as a field trial under such conditions.

MATERIALS AND METHODS

Poles and treatment

Standard (SABS, 1982) *Eucalyptus grandis* Hill ex Maid. poles (1200 × 60 mm) were treated to targeted standard soil-contact retentions of 16 kg CCA m^{-3} (SABS, 1987) and 100 kg creosote m^{-3} (SABS, 1980*a*) by full-cell vacuum-impregnation and empty cell impregnation processes (SABS, 1980*b*), respectively. Eight of each of CCA-treated, creosote-treated and untreated poles were selected for tests.

Impervious heat-shrink polyethylene sheet (180 μm thick) was used to construct open-ended cylindrical field liners as cylindrical sleeves 500 mm long and 70 mm in diameter. The orientation of the polyethylene was such that the sleeves would, when heated, shrink minimally in the longitudinal plane and predominantly in the transverse direction. A sleeve was placed over each of four CCA-treated, four creosote-treated and four untreated poles. The sleeves were positioned to cover the pole surfaces which would be in soil-contact, leaving the lower transverse surface uncovered, and then heated over embers to cause them to shrink and become elastomerically associated with the pole surfaces.

Field trial

The test-site was on the banks of the Palmiet River, Natal, where the composition of the Hutton soil (MacVicar *et al.*, 1977) is known (Baecker *et al.*, 1991). A soil bed 450 mm deep was excavated and all poles were placed vertically 500 mm apart in the bed, which was then refilled so that the upper ends of the sleeves on the poles protruded 50 mm above the surface. A rotary pump and irrigation system was used to flood the test-site with unchlorinated river water for 2 h twice per week for 26 weeks from mid-summer to winter. The ambient temperature varied from 3 to 39°C. Weeds were removed from the site as they developed.

Analyses

At the end of the exposure period, the poles were carefully removed, and visually inspected. In the laboratory, their surface appearance was photographically recorded, and small sections were taken from the soil-contact surfaces of unsleeved poles. The sleeves were then cut and removed to expose the wood-sleeve interface, and a photographic record was made of the wood surfaces that had been sheathed.

The sections that had been sampled were fixed for 8 h in 3% glutaraldehyde in 0·05 M cacodylate buffer (pH 7·2), dehydrated in a graded ethanol series, critical-point dried in CO_2, coated with 15 nm gold, and examined using a Hitachi S-570 scanning electron microscope.

RESULTS

At the end of the 26-week exposure, the untreated unsleeved poles had failed and collapsed owing to decay below the ground line (Fig. 1). On

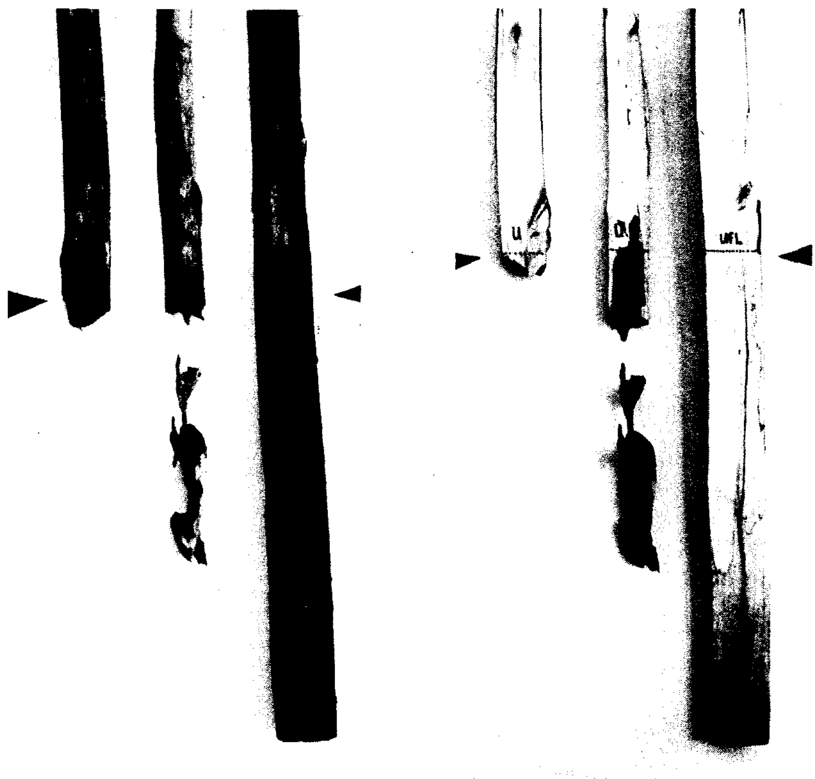
Fig. 1. Poles in soil contact at the test site after exposure to flood irrigation for 26 weeks. An untreated unsleeved pole had failed and collapsed at the point arrowed.

removal from soil, all other poles appeared intact, although those without sleeves generally retained firmly attached soil on their sub-soil surfaces. When the soil was brushed from these surfaces prior to laboratory tests it was found that biofilms tenaciously adhered to the wood at the wood–soil interfaces.

Untreated poles

The sub-soil wood of three of the untreated unsleeved poles had been totally mineralised so that it was impossible to perform any analyses on these samples. The detached remains of the sub-soil section of the fourth pole in this group (Fig. 2(a)) manifested subterranean termite and fungal attack.

The sleeved poles showed no termite attack (Fig. 2(b)), but their wood–sleeve interfaces were discoloured by white rot fungi (Fig. 3(a)) which had also produced much mycelium on the wood at these interfaces. The inner sleeve surfaces at these interfaces were also colonised by fungal mycelium. Longitudinal sections showed that the fungal attack had penetrated throughout the sub-soil portions of these poles while the deepest portions and those over 20 mm above the ground line remained relatively undecayed (Fig. 3(b)).



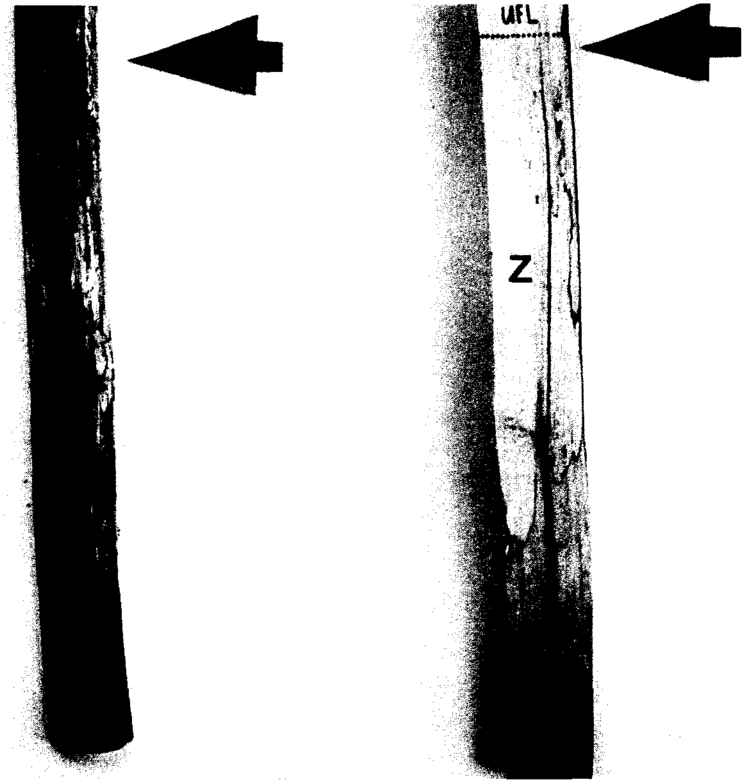
(a) (b)

Fig. 2. Appearance of (a) soil contact surfaces and (b) longitudinal sections of untreated poles after removal from soil. The unsleeved pole on the left in each case is the failed specimen shown in Fig. 1 and all material previously below the (arrowed) ground line had been mineralised. Remnants of the unsleeved pole in the centre showed termite and fungal attack whereas the sleeved pole (right) had remained intact.

CCA-treated poles

The sub-soil wood of the unsleeved CCA-treated poles was dark in colour when the adherent soil was removed (Fig. 4). Fungal mycelium of the adherent biofilm was widespread on the wood–soil interfaces (Fig. 5) and hyphae penetrated or emanated from the many microscopic fissures observed on these wood surfaces. The wood surfaces above the ground line appeared intact and relatively sound.

In contrast to the above, the wood at interfaces with sleeves on CCA-treated poles were uncolonised and appeared identical to the surfaces of these poles which had been above the ground line (Fig. 6). The sleeve surfaces at the interfaces were uncolonised.



(a) (b)

Fig. 3 Appearance of (a) a wood–sleeve interface and (b) a longitudinal section of the untreated sleeved pole shown in Fig. 2. Limited white rot was visible on the surface of the pole and within a zone (Z) of the pole that had been below the (arrowed) ground line.

Creosote-treated poles

The surfaces of both sleeved and unsleeved creosote-treated poles that had been above the ground line were weathered, although undecayed (Fig. 7(a)).

The most striking observation made in the present work was the unchanged appearance of the surfaces of creosote-treated poles at wood–sleeve interfaces when sleeves were removed (Fig. 7(b)). Indeed, these surfaces were indistinguishable in appearance from those of freshly treated poles.

When the adherent soil was removed from unsleeved creosote-treated poles after excavation, the sub-soil surfaces of these appeared faded and similar in colour to the weathered surfaces that had been above the

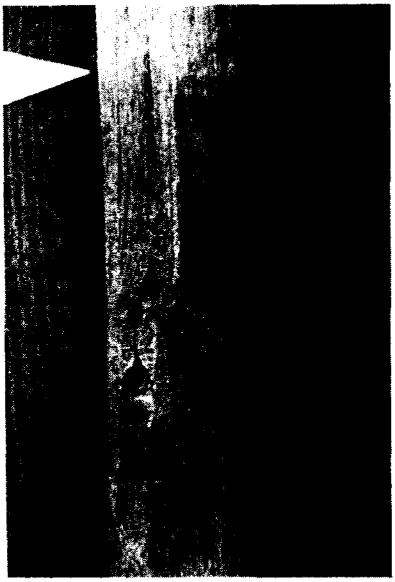


Fig. 4. Darkened surface of an unsleeved CCA-treated pole below the (arrowed) ground line after removal of the adherent biofilm.

ground line (Fig. 7(a)). Closer examination of the sub-soil surfaces of these poles showed longitudinal fissures; these poles were different from the CCA-treated poles in having larger fissures 2 mm deep, which were macroscopically visible (Fig. 7(b)) at the surface and were evidence of the onset of basidiomycete decay. Microscopical examination of these surfaces (Fig. 8(a)) confirmed the presence of transverse fissures typical of the cross-hatched appearance of wood decayed by basidiomycetes.

The fungal mycelium of the adherent biofilm was extremely widespread on the sub-soil surfaces of these poles, and, like that observed on the CCA-treated poles, was associated with the many fissures in these wood surfaces. Examination of surfaces that had ruptured showed that the hyphae penetrated to depths of at least 1 mm below the surface of the wood–soil interface (Fig. 8(b)).

In contrast to the sleeves that had been removed from untreated poles, those taken from creosote-treated poles were uncolonised by fungi at their wood–sleeve interfaces.

DISCUSSION

The results presented here lead to the conclusion that the application of the sleeves prevented failure of untreated *E. grandis* poles for 26 weeks under flood-irrigation conditions in a sub-tropical environment. Secondly, although the untreated sleeved poles were colonised by white-rot fungi at the end of the exposure period, no termite attack had occurred in these poles. Thirdly, microbiological colonisation of treated poles had been prevented. The application of the sleeves constituted a successful preventative measure against decay under the test conditions, and such application may well provide a method that would successfully prevent premature failure of treated poles in soil-contact, particularly under less aggressive conditions than those used here.

Although the present work was not designed to explain premature failure of treated poles in soil-contact, careful consideration was given to the factors affecting the growth of microorganisms in terrestrial ecosystems (Alexander, 1977). It was essential to take account of the microorganisms (Stanier *et al.*, 1989) that were already present (albeit dormantly) in the soil, on the surface of the poles and on the sleeves before their application.

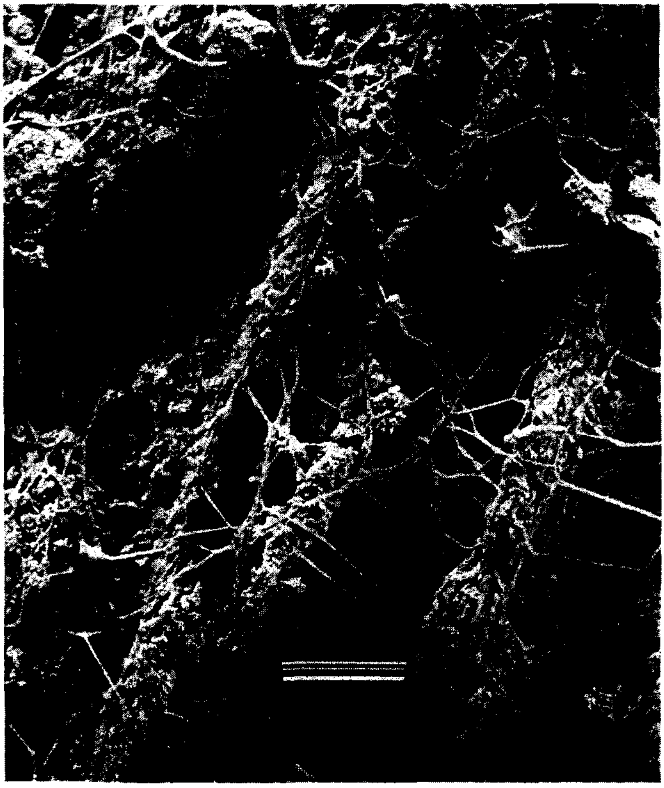


Fig. 5. Fungal hyphae on the surface of an unsleeved CCA-treated pole at the wood–soil interface. Scale bar = 40 μm.

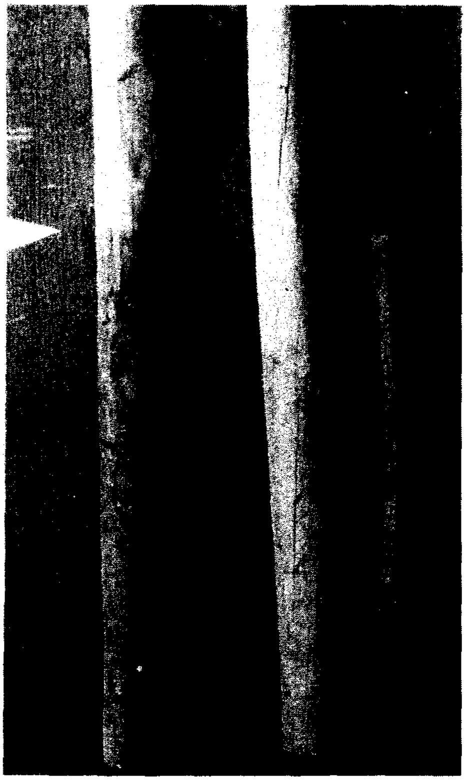
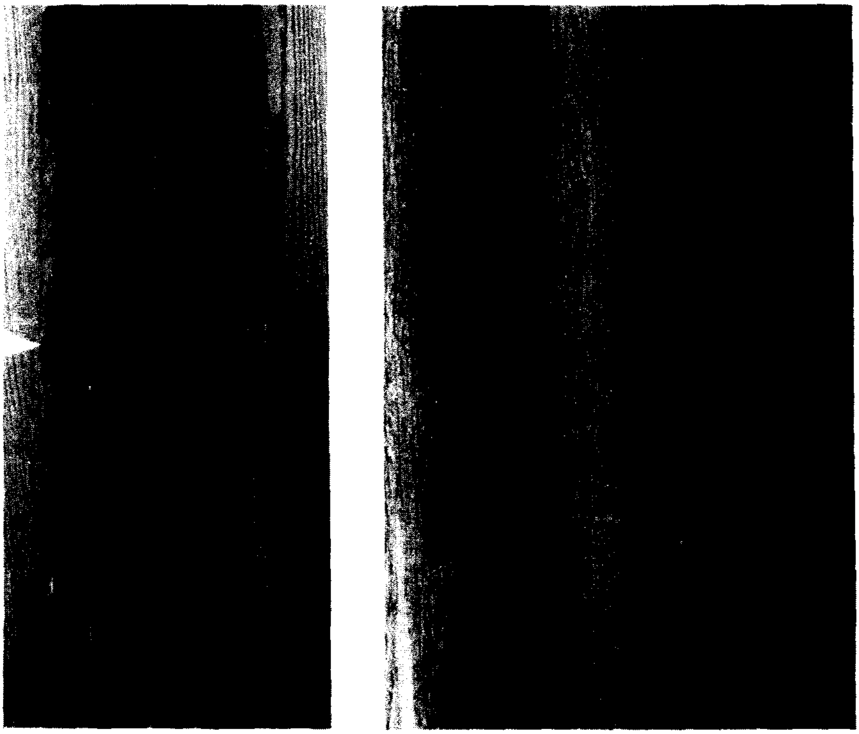


Fig. 6. Uncolonised surface of a CCA-treated pole (right) after removal of the sleeve, contrasted with the darkened surface below the (arrowed) ground line of an unsleeved pole (left).

These organisms only require the combination of environmental conditions appropriate for growth in order to cause biotransformation of biodegradable materials in their environment. Usually the nutritional status of an environmental niche is growth-limiting, and the ecosystem may be considered to be in dynamic equilibrium (Atlas & Bartha, 1987). However, the addition of wood to an ecosystem such as soil disturbs this equilibrium and alters the nutritional status to favour the growth of, *inter alia*, cellulolytic and ligninolytic basidiomycetes. These fungi consequently utilise cellulose and lignin in the wood until toxic catabolites become inhibitory, or another essential nutrient, such as nitrogen (Merrill & Cowling, 1966), is depleted.

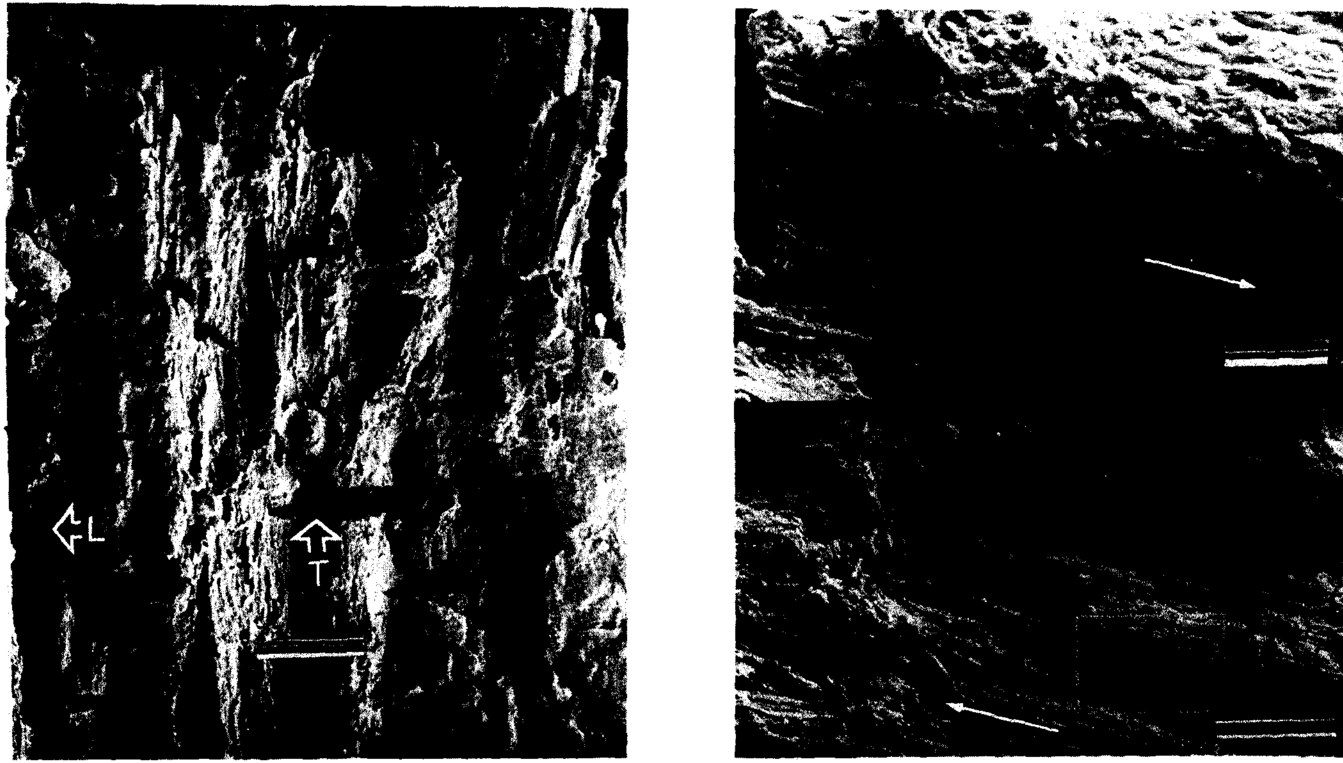
Water availability, or water activity (A_w), is usually too low for microbial growth at the evaporative surfaces of the soil ground line. Therefore, pole failure does not occur at this level, but can occur below the ground line, where A_w is higher. Similarly, oxygen tension, or more precisely



(a) (b)

Fig. 7. Creosote-treated poles showing the appearance above and below the ground line (arrowed) of (a) unsleeved (left and second left) and sleeved poles after removal of sleeves (right and second right). Surface examination (b) showed widespread longitudinal fissures suggestive of incipient decay on the soil-contact surface of each unsleeved pole (left), which contrasted markedly with the intact appearance of the pole surfaces that had been sleeved (right).

redox potential (Eh), also acts as a growth-limiting factor. The effect of Eh will be limiting for aerobic growth of basidiomycetes in deep soil where A_w may not be limiting. However, at a level in the soil profile that will depend on the soil type, the downwardly-increasing A_w gradient and the upwardly-increasing Eh gradient may overlap over a range in which they are both optimal for fungal growth. It is at such points below the ground line that premature failure of wooden poles usually occurs, as was observed in the present work. For example, the exposed lower ends of the untreated sleeved poles were neither decayed by fungi nor attacked by termites, presumably because the Eh was too low for proliferation of these oxidative organisms. Similarly, it was concluded that the wood above the ground line had remained sound because its A_w was also too low.



(a)

(b)

Fig. 8. Microscopical appearance of the sub-soil surface of an unsleeved creosote-treated pole showing (a) longitudinal (L) and transverse (T) fissures typical of basidiomycete decay (scale bar = 100 μm), and (b) aerial and substrate fungal hyphae (arrowed) on and below the surface (upper scale bar = 9 μm; lower scale bar = 100 μm).

The white-rot fungi at the interface between the untreated pole surface and the sleeve must have arisen from spores that germinated on these surfaces when the poles became moist in the soil, from rainwater which percolated down the wood–sleeve interfaces, or as ground-water drawn upwards by capillarity at the interface, or by wick action (Levy, 1968) in the wood. No evidence of fungal colonisation was seen on treated poles at wood–sleeve interfaces, presumably because the preservatives inhibited spore germination in these zones.

While the colonisation of the above zones in untreated sleeved poles was evident, the poles had remained intact, whereas their unsleeved counterparts had been mineralised. However, depending on species, the carbon–nitrogen ratios of woods range from 200:1 to 500:1 (Allison *et al.*, 1963), so that nitrogen is a growth-limiting factor in wood decay (Merrill & Cowling, 1966). Fungi overcome nitrogen deficiency of wood in soil by translocating this element into the wood from the surrounding soil (King & Waite, 1979). The sleeves described here must have prevented such translocation at the exact point in the soil profile where all the other conditions for wood decay were optimal. Therefore, it was concluded that it had been nutritionally impossible for fungi within sleeves to sustain their decay activities sufficiently to cause pole failure during these tests. In addition, the sleeves would have prevented fungi at sleeve–soil interfaces from gaining direct access to the wood to degrade it from bases in the soil. Furthermore, indirect penetration of the wood by foraging hyphae of soil fungi via the ends of the sleeves was not possible since, for reasons discussed above, conditions for growth were not suitable in those regions. Therefore, it can be concluded that it had been impossible for fungi outside sleeves to attack the poles because the physical barrier, in conjunction with adverse growth conditions at its ends, had prevented colonisation.

Another reason for not sealing the lower transverse ends of the sleeves was that open-ended sleeves precluded internal accumulation of rainwater; accumulated water inside end-sealed sleeves would soon become anaerobic owing to respiration of aerobes and subsequent fermentation of facultative anaerobes. Lowered Eh would make that microniche suitable for growth of recently discovered obligately anaerobic bacteria (Rogers & Baecker, 1991) which can degrade wood (Rogers *et al.*, 1992). These bacteria produce xylanases in wood (Baecker & Rogers, 1991) and enhance delignification of such wood at low Eh (Shelver *et al.*, 1991*a*). Such events may well have led to the extensive bacterial colonisation of CCA-treated vineyard poles which recently suffered premature failure in New Zealand (Singh & Butcher, 1989). In contrast, the open-ended sleeves probably permitted the upper sections of the poles to act as evaporative wicks (Levy, 1968) which drew water from the depths of the soil profile.

Such water would contain traces of dissolved oxygen sufficient to maintain the Eh above the upper limit for growth of obligate anaerobes, but below the level for the oxidative metabolism of basidiomycetes. The advanced effects of these major agents of wood decay were probably excluded from the ecosystem when sleeves were applied.

Because of the high replacement costs of failed poles (Murira, 1988), the method could give considerable financial benefits. The author does not agree with arguments that preventative solutions to premature failure centre on the application of increased retentions of biocides in wood destined for service in the environment. The present work suggests that it is possible that sleeves may permit use of lower retentions of preservatives in wood destined for service in ground contact, although effective thresholds would have to be determined by standard methodology.

In keeping with the above philosophy, certain authorities, such as the Swedish National Chemicals Inspectorate, assert that, if possible, an environmentally unacceptable chemical shall be substituted with a less dangerous one (Erlandsson *et al.*, 1992). Although CCA is considered permanent after fixation in wood, the copper and arsenic therein have been shown to leach out in both soil (King *et al.*, 1989) and sea (Shelver *et al.*, 1991*b*). The potential environmental benefits of sleeving poles in soil might include decreased contamination of soil and run-off of preservative, as was indicated by the appearances of the creosote-treated poles after exposure. In view of the search for alternative formulations (Schnippenkoetter *et al.*, 1988), it may be possible that sleeves would permit use of environmentally preferable preservatives previously considered to lack efficacy in wood exposed to soil.

The polymeric composition of sleeves could be formulated to produce material to last for predetermined periods. In such cases, the service lives of poles could be extended by that of the sleeves, thus conserving wood. Sleeves including dry-film biocides may also prevent fungal growth at wood–sleeve interfaces. Future work will therefore investigate the potential of sleeves to reduce preservative leach-rates, the use of lowered preservative retentions in sleeved poles and the performance of novel sleeve formulations designed specifically to inhibit fungal growth at wood–sleeve interfaces.

ACKNOWLEDGEMENTS

This work was conducted to substantiate provisional patent claims. The co-operation of Mr R. Farren, F. A. R. Timbers, Pietermaritzburg, in declassifying these results is acknowledged.

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