L.J COOKSON

DETERMINING THE NATURAL DURABILITY OF EUCALYPTS IN AUSTRALIA

Abstract
There is wide variation in heartwood natural durability between eucalypt species, which is mostly governed by polyphenol composition. Polyphenols can degrade (polymerise) with age in the inner heartwood of trees which reduces natural durability. In young eucalypt trees, timber density can be a useful predictor of natural durability within a species, but it is less useful when trees are at least 30-50 years old. The development of standards for natural durability is discussed, along with the trials that influenced the assignment of durability classes for each timber species when exposed in-ground, above-ground, and against lyctine beetles, termites and marine borers. Accelerated test methods for determining natural durability are also discussed.

1. EXTRACTIVES

The natural durability of eucalypts is caused by extractives, and a wide range of compounds are involved (Da Costa et al., 1962; Da Costa, 1975). Back in the 1950-60s, Rudman published numerous papers to show that the majority of the compounds responsible for decay resistance in eucalypts were polyphenols (tannins). These compounds were soluble in methanol, often aided by weak alkali. In contrast, the compounds responsible for termite resistance were ether soluble (Rudman, 1964).

Many of the important extractives are coloured, so that in some non-eucalypt species a deeper colour equates to increasing natural durability (Gierlinger et al., 2004; Bhat et al., 2005; Kokutse et al., 2006). Within the eucalypts there is also a trend between species where pale coloured eucalypts such as the generic ‘Victorian ash’ or ‘Tasmanian oak’ (*Eucalyptus regnans*, *E. delegatensis* and *E. obliqua*) have low durability while the red and deep brown coloured eucalypts (e.g. *E. tricarpa*, *E. bosistoana*) have high natural durability. However, Rudman (1964) found that within a species such as *E. marginata* and *E. diversicolor* there were too many exceptions for colour to be a useful indicator of natural durability. The problem appeared to be that while increasing polymerisation of polyphenols could give a deeper colour, that polymerisation also made those extractives less fungitoxic (Rudman, 1964).

2. SAPWOOD

The sapwood of all species is non-durable, and in pale coloured eucalypts it can be difficult to delineate the sapwood/heartwood boundary. The pH of heartwood is lower than sapwood, so its location can be determined using an indicator such as methyl orange (dissolve 0.1g methyl orange in 100 ml of 80% ethanol, lasts for years. Brush on fresh surface in the sapwood to heartwood direction) (Zosars and Kennedy, 1994). In larger trees, the sapwood of some eucalypts such as *Corymbia maculata* is thick, at 25-35 mm, while for others such as *E. pilularis* it is thin at 7-15 mm. While the heartwoods of both have similar natural durability, the same diameter post of *C. maculata* will obviously not last as long as *E. pilularis* if untreated simply because of the difference in sapwood thickness. The untreated sapwood of many eucalypts is also susceptible to lyctine beetles (powder post beetles) which can turn the sapwood into powder usually within 5-10 years. Lyctine susceptibilities are provided in AS 5604: 2005, with some further information for a few species provided by Cookson et al. (2009).

The sapwood of most timber species can be treated, and while a thick sapwood band is preferable from a treatment perspective (and radiata pine is a favourite of the treatment industry), some eucalypt sapwoods treat better than others. So for example, spotted gum and blackbutt poles and piles are usually treated in the same charge, and in a marine trial treated blackbutt poles performed better against marine borers than spotted gum piles, even though they had much thinner sapwood bands (Cookson, 2007).

If eucalypts are being grown for vineyard post production, then as well as natural durability, the propensity for splitting should be examined. Eucalypts posts would usually be air dried (not kiln dried) under hessian to slow drying rates and reduce splitting, and in a recent study species with excessive splitting under such a regime were *E. globulus*, *E. pilularis*, and *E. dunnii*, while those with low levels of splitting were *E. grandis*, *E. cladocalyx* and *C. maculata* (McCarthy et al., 2005; Mollah et al., 2006). Splitting could be another factor to look at in tree breeding. Also, the propensity to split can change as trees get older, so that for example *E. grandis* poles have an increased tendency to split compared to posts.

Due to the high proportion of sapwood, and the immaturity of the heartwood, vineyard posts of even naturally durable species need to be treated to ensure long term durability. An example of what can go wrong was with Australian native cypress pine (*Callitris glaucophylla*), which has durable heartwood (Johnson et al., 2006). Young trees were cut to produce vineyard posts, and because the sapwood is unusual in that it is difficult to treat, they were sold untreated. There were many court cases involving vineyard owners and post suppliers when the posts fell down after only 4-6 years of service. An alternative would be to grow older trees that can then have the sapwood removed, as long as there is still enough timber to make a post. Also, the remaining heartwood should have natural durability more similar to that found in mature trees, which is where tree breeding and selection can help.

3. HEARTWOOD

The most durable region in eucalypts is the outer heartwood of butt logs. Inner heartwood is usually less durable, and Rudman (1964) described the inner heartwood as being the inner one-third of the whole of the heartwood. There are two reasons for the lower durability. One is that eucalypts typically produce juvenile heartwood during their first 8-12 years at least (Nelson and Heather, 1972; Wilkes, 1984), and in this heartwood lower amounts of extractives are formed (Rudman, 1964). This inner core or pith is often degraded in older trees leading to ‘piping’ after it has been decayed and eaten by termites. They often become important hollows for native animals as well (Adkins, 2006). The second reason for lower durability of inner heartwood is that the polyphenols produced in mature heartwood gradually alter, which due to age shows up first in the inner heartwood. One theory by Rudman (1964) was that oxidation of polyphenols released acetic acid which then increased polymerisation of the remainder of the polyphenols, making them less durable.

Wood density tends to give a good indication of natural durability, especially when comparing between hardwood species (Chafe, 1989). Within eucalypt species, a correlation between density and durability appears to apply for trees of less than around 25 years of age (Cookson and McCarthy, 2013), but for older trees clear evidence of a correlation is lacking (Rudman, 1964; Johnson et al., 1996; Cookson and McCarthy, 2013). Bush et al. (2011) found good correlation for eight year old *E. cladocalyx* trees where those with higher basic density and higher methanol extractive contents were less susceptible to decay.

Producing durable heartwood has a number of advantages, such as being a natural material that is less likely to cause environmental problems. Another advantage from a preservative treatment perspective is that most heartwood cannot be properly treated, unlike sapwood. If the heartwood is non-durable then the percentage of heartwood in a treated piece of timber needs to be restricted, especially under the Australian standard specifications although this is not policed adequately. Therefore, if the heartwood is already durable, more of it can be included within treated products. For example, slash pine has an advantage over radiata pine in meeting H2 treatment requirements in Australia, as its heartwood is termite resistant so does not require penetration, only the sapwood. Whereas radiata pine does require heartwood penetration, which is almost impossible to achieve in most cases, so that treatments either do not meet specification (other than for the newer H2F treatments) or the percentage of heartwood must be limited.

A long term exposure trial that ran for over 33 years has shown that properly CCA-treated (perfectly treated) radiata pine sapwood performs better than all naturally durable timbers of similar size (Cookson, 2004). However, a problem for treated timber as mentioned above can be the impenetrability of heartwood, so that in practice CCA-treated pine sleepers in Australia can contain more than half of their section as heartwood, and may therefore fail after 5-15 years. New, naturally durable eucalypt sleepers last longer.

4. STANDARDS

Before 2003 in Australia, only in-ground natural durability ratings were provided, along with lyctine borer sapwood susceptibilities. AS 5604:2003 was a new standard, where all information for natural durability was assembled into the one document. It also introduced information on termite resistance under H2 conditions (house framing) and above ground decay durability, while the 2005 revision added marine borer ratings as well. During the 1950s, the in-ground ratings were based upon the experience of foresters, lab testing and a limited amount of field testing. In 1968-69 an in-ground trial of 77 timber species was installed at five sites around Australia to verify these ratings (Thornton et al., 1983). The stakes were 450 x 50 x 50 mm outer heartwood specimens, and at each site there were 10 replicates with two obtained from each of five different trees. The trees were sourced from several regions where the species grew naturally. The last and final inspection was after 33-36 years (Cookson, 2004), and most of the ratings already in place were validated, with only a few changes needed in the 2005 revision.

For the above-ground decay ratings, most information came from Queensland Forest Service where 39 timber species were tested, mostly Queensland species (Cause, 1993; Francis and Norton, 2005). The test specimens were L-joints placed at 11 different sites, and even though the specimens were 35 x 35 mm square it was the tenon which was 11 mm thick that was inspected and rated. It is generally known that timbers above-ground will last much longer than in-ground, often at least twice as long. Much of this information was synthesised into the TimberLife Educational Software Program, which can be found at the Wood Solutions website. [1] More recently, a nine-year flat panel test of six eucalypt species was conducted and some adjustments to ratings made (Cookson and McCarthy, 2013), although these have yet to be incorporated into a revision of the standard. The H3 decay field test is the slowest wood durability test, and recently a series of H3 methods were compared in Australia and New Zealand, and tests faster than the two mentioned above include the ground proximity test, deck test, and the embedded test (Cookson et al., 2014).

For H2 termite resistance, most of that information came from experience, coupled with a few rules such as Class 1 timbers (in-ground) would also be termite resistant, while Class 4 timbers would be non-resistant. There were some field tests as well, such as for pine species (Kennedy et al., 1996; Peters and Fitzgerald, 2004). The

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[1] Wood Solutions TimberLife program, https://www.woodsolutions.com.au/Articles/Resources/TimberLife-Educational-Software-Program

tests needed are usually of only 6-12 months duration. A more recent trial showed that termite resistance in eucalypts applies mainly to areas where the termite species *Mastotermes darwiniensis* is lacking, as after one year in an H2 field test, five out of six 'resistant' timbers were virtually destroyed (82-97% wood volume lost), with river red gum being the only exception. In comparison, in a trial of the same timber species against *Coptotermes acinaciformis* the mass losses were restricted to 9-29% wood volume (McCarthy et al., 2009). Although not examined, the results would probably be influenced by how much baitwood is included in the test, as it does for boron-treated wood (Peters and Fitzgerald, 2006). New Zealand does not have any native economically important termite species, although there have been some introductions from Australia of *C. acinaciformis* over the years in imported sleepers and poles (Pearson and Bennett, 2008).

The marine borer durability ratings produced in the AS 5604: 2005 revision arose mainly from a sea trial of 25 timbers at three ports (Cookson and Scown, 2008), an aquaria trial (Cookson, 1996) and experience. Also, any timber not tested but listed Class 4 in-ground, as well as Class 3 timbers also non-resistant to termites, were assumed to be non-durable against marine borers.

5. ACCELERATED TESTING

When testing new timbers for natural durability, it is important to include the mature heartwood of a range of yardstick timbers with known ratings, so that the novel timber species or breeding stock can be placed into proper context. In Australia where there is reduced support for wood durability research, the different yardstick 'trees' could be obtained by buying timber from different timber yards or from different timber packs within the same timber yard. The trials needed to prove natural durability would mostly be similar to those listed for wood preservatives in the AWPC protocols available on the TPAA website.

Still to be resolved, is whether naturally durable timbers placed in laboratory decay tests or termite H2 field tests should first be artificially weathered (leaching, vacuum oven drying) as is done for preservative treated wood. Some preservatives are dissolved in organic solvents, which need to be removed before testing within enclosed containers, while naturally durable timbers are less likely to be detrimental to the testing organisms involved. Conversely, weathering would be a way of obtaining accelerated results, or better comparative results, as the naturally durable timbers will have lost fractions that would be easily lost in service in any case. It can be difficult to separate Class 1-3 timbers in short term fungal bioassays, if not artificially weathered. Table 1 shows the results from a recent soil-block fungal bioassay after 12 weeks incubation, where several mature and naturally durable heartwood timbers had decay above the 3% threshold used to indicate significant decay. Whereas, in an agar tray bioassay of fencing components where there was no artificial weathering, there was no decay of untreated messmate heartwood after 16 weeks incubation (Cookson et al., 2002), suggesting that comparisons in durability bioassays would be even more difficult without weathering. Note however, that agar bioassays are also usually less severe than soil substrate bioassays (need to do a direct comparison of weathered and unweathered blocks).

In tree breeding research, the initial priority is to select those trees that show the best traits for natural durability. The 'formal' tests needed for proving natural durability in comparison to species with established ratings should occur at later stages in the forestry breeding program after genotypes have already been selected and trees are grown with sufficient mature heartwood for testing. For timber samples produced by core-boring into young trees, often with hundreds of individual trees involved, a bioassay similar to that shown in Table 1 could be considered. Perhaps, the artificial weathering steps is not needed, especially if the heartwood is juvenile. Another option would be an in-ground or in-soil 'AFS' test (e.g. Cookson et al., 2000), where the heartwood cores are tested as mini-stakes. Such tests should give results in 6-18 months if conducted in the wet tropics, or within bins of fresh soil housed within an incubation room at 25-28^{o}C. Normally, in-ground stakes are inspected by removing each one, and probing them with a knife to determine the depths of decay. Another option would be simply to 'nudge' each stake without removing it from the ground, and seeing if it breaks under a constant force. Some post trials are inspected by a moderate push against post tops (Lebow et al., 2014), or a 50lb 'pull test' against the tops of the posts (Freeman et al., 2005).

Table 1. Percentage mean mass losses (standard deviations) of six replicate blocks 20 x 20 x 10 mm and H3 weathered (leached then vacuum oven dried) after 12 weeks of exposure to decay fungi.

Timber	Fungus				
	Brown rots				White rot
	Fomitopsis lilacinogilva	*Coniophora olivacea*	*Gloeophyllum abietinum*	*Oligoporus placenta*	*Perenniporia tephropora*
Radiata pine sap	52.9 (8.8)	45.1 (7.7)	61.5 (6.9)	59.5 (10.9)	36.5 (7.3)
Messmate heart	38.0 (2.7)	33.4 (5.1)	33.3 (7.4)	1.8 (2.8)	49.6 (4.5)
Merbau heart	1.4 (0.9)	0.4 (0.1)	0.9 (0.7)	0.3 (0.1)	18.5 (8.9)
Spotted gum heart	12.8 (10.2)	12.4 (14.1)	5.7 (7.7)	1.4 (2.0)	17.4 (20.9)
Jarrah heart	10.8 (3.4)	10.3 (4.2)	1.9 (1.6)	0.4 (0.5)	7.5 (5.1)
H3 CCA P. radiata pine 0.41% m/m TAE	0.6 (0.2)	0.2 (0.1)	0.3 (0.2)	6.2 (4.4)	0.6 (0.3)

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7. AFFILIATIONS

LJ Cookson Consulting, Warrandyte, Victoria, Australia.
laurie@ljcookson.com