Above-ground durability of painted and unpainted Australian and imported timbers in an L-joint field test after 35 years

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Abstract

Field tests that assess timber durability above ground are essential for shaping construction Standards that guide building practices. This paper summarises the condition of timber specimens after 35 years in an above-ground L-joint field test under very high-decay-hazard conditions in Australia. Forty-one timbers representing 30 botanical species were tested, including a range of softwoods such as *Pinus radiata* sapwood, heartwood, and CCA-treated sapwood, and a range of hardwoods including eucalypts and other Australian native species. A selection of imported timbers including *Thuja plicata* and *Pseudotsuga menziesii* were also evaluated. Unpainted and painted L-joints were tested, and in the painted joints, the paint film around the joint had broken, allowing moisture to become trapped underneath.

The assessment of the samples confirmed that the broken paint coat commonly reduced durability, having this effect in 18 of the 41 timbers. The paint coat significantly increased the durability of four species, despite the moisture trapping. The broken paint coat had no significant effect for the remaining timbers. Results from this field test were used to update the Australian timber natural durability Standard, AS5604. A limitation of that Standard is that durability classifications apply for the whole of Australia, encompassing temperate climatic regions in the south to tropical climatic regions in the north. Future research on timber durability performance models that take climatic variables into account promise improved service life prediction capabilities.

1. Introduction

Decay in timber building elements above ground is primarily caused by the activity of fungi (Rayner and Boddy 1988). Decay fungi are unable to degrade timber that has a moisture content of less than 20%, as free water and adequate temperature enable enzymes and extracellular compounds to degrade the structural polymers of wood into assimilable substances required for fungal growth (Zabel and Morrell 1992). Environmental conditions and building design determine the availability of moisture and therefore influence the likelihood and progress of decay in timber building elements.

Natural durability is the inherent resistance of a timber species to biodeterioration by decay, termites, marine borer and lyctid borer for sapwood (Standards Australia 2022). Natural durability and protective treatments can prevent decay in the presence of conditions that are conducive to decay. In Australian Standard AS 5604:2022 Timber – Natural durability ratings, durability classifications are assigned according to a timber's performance both in contact with the ground and above ground when subject to periodic moderate wetting where ventilation and drainage are adequate. Of the four classes, species assigned to Durability Class 1 are most durable and species assigned to Durability Class 4 are least durable (Table 1). Durability classifications were based on field test data and expert opinion and represent a range of probable life expectancy values for each durability class (Table 1) (Standards Australia, 2022).

Table 1
Australian natural durability classification

Durability Class (DC)	Probable in-ground life expectancy (years)	Probable above-ground life expectancy (years)
1	Greater than 25	Greater than 40
2	15 to 25	15 to 40
3	5 to 15	7 to 15
4	0 to 5	0 to 7

Field tests are required to inform timber durability performance Standards such as AS 5604. Many test formats are used to evaluate timber durability above ground (Meyer 2016), and they vary in the degree to which they encourage decay. L-joints are a standard field test method in Australia, Europe, and the United States (AWPC 2015; EN 330 2015; AWPA 2016). L-joints consist of two lengths of timber connected using a mortise and tenon joint to form an L-shape. By design, L-joints are among the most conducive to decay (Highley 1995; Meyer 2016).

The L-joint field test reported in this paper was part of a study to evaluate timber durability performance above ground to inform timber durability Standards, such as AS5604. This paper reports findings from the largest array of L-joints, which were installed at the main site in south-east Queensland. Forty-one timbers representing 30 botanical species were installed at the main site to characterise their natural durability.

2. Materials and methods

2.1 L-joint test units

All timbers were represented by mature outer heartwood unless otherwise indicated (Table 3). L-joints were constructed using timber 35 x 35 mm in cross section, with a machined mortise and tenon joint. Each tenon member measured 300 mm in length while each mortise member measured 200 mm in length (Fig. 1). The 35 x 35 x 11 mm tenon component of each joint was assessed at each inspection time.

Half of the replicate samples for each species were painted using a conventional acrylic paint system. An acrylic primer was applied to the assembled L-joint test unit, followed by two coats of acrylic white paint. The distal 35 x 35 mm faces at the ends of the joint components were sealed with bitumastic tape to prevent the entry of moisture and microorganisms. The internal 35 x 35 mm surfaces of each joint were left as bare wood. Each joint was disassembled immediately after painting to break the paint film along the frame of the joint and therefore create a uniformly high decay hazard (Fig. 2). Painted L-joints were sanded, and acrylic white paint reapplied after 16 years.

L-joints were placed 800 mm above ground on exposure racks that were constructed using CCA-treated plywood and durable framing timbers. Spacers were fixed to the racks to support L-joints, preventing them from coming into direct contact with the plywood frame and to provide consistent spacing between each joint. The racks face north, and each rack was constructed such that L-joints placed on it are oriented 10° backward from vertical. Each rack had drain holes at the rear to prevent water pooling.

2.2 Field test location

L-joints were installed in subtropical southeast Queensland (Cause 1994), which presents a very high decay hazard (Francis and Norton 2006; MacKenzie et al. 2007; Wang et al. 2008). L-joints were originally installed at Beerburrum, situated 65 km north of Brisbane in Queensland, Australia in 1987 (-26.957141, 152.961085). The Beerburrum site was reclaimed in 2007, and L-joints were moved to Cleveland, situated 25 km east of Brisbane (-27.526137, 153.247547). At this location, L-joints were initially installed under a sparse canopy of eucalypt foliage, so that leaf litter intermittently reduced the ventilation around the L-joints. In 2017, partial site reclamation again necessitated that the L-joints be moved to an open area that had become available at the Cleveland site.

2.3 L-joint assessment

L-joints were assessed after 2, 3, 5, 7, 9, 11, 16, 19, 21, 30, 32 and 35 years (Cause 1994; Francis and Norton 2005; Francis and Norton 2006; Francis et al. 2007). During each inspection the 35 x 35 x 11 mm tenon component of each joint and the flanking end-grain was assessed by probing with an awl or small knife with a blunted end to determine the presence and extent of decay. Any decay identified was recorded according to a five-point scale that was a modified version of that proposed by Carey et al. (1981) (Cause 1994) (Table 2).

Table 2
L-joint assessment criteria (Cause 1994).

Decay score	Condition of the internal tenon joint portion and flanking end grain
4	Sound
3	Signs of slight surface decay (e.g. incipient decay)
2	Small areas of obvious decay (< 25% of surface area affected)
1	Extensive decay (> 25% of surface area affected)
0	Failed (decayed through the entire 11 mm tenon cross section)

2.4 Field test design

Three sources from throughout each timber's geographic range were sampled and equally represented in the test. Each timber was initially represented by 24 painted and 24 unpainted L-joints of mature outer heartwood unless otherwise indicated (Table 3). Painted or unpainted L-Joints from each of the three sources were randomised then eight from each source installed. One specimen from each source was removed after one and three years, so that by the fifth-year assessment 18 painted and 18 unpainted L-joints remained. Failed specimens were removed from the racks over time.

2.5 Data analysis

All data analyses were conducted using Genstat (2022). The time-series nature of the ratings data was considered by an analysis of variance of repeated measures (Rowell and Walters 1976), via the AREPMEASURES procedure. This forms a split-plot analysis of variance (split for time). Here the Greenhouse-Geisser epsilon estimates the degree of temporal autocorrelation and adjusts the probability levels for this. Failure for each L-joint was defined as a rating of zero. These binary values were analysed at each time point using a generalised linear model (McCullagh and Nelder 1989) with the binomial distribution and logit link.

Median time to failure was calculated for each timber via the usual method, of halfway between the time rated zero and the previous time which had rating > zero. However, this proved problematic for censored data (timbers that were still rated > zero after the last assessment). The standard statistical method for estimating likely censored values (Taylor 1973) was applied with the CENSOR procedure, however these tended to produce estimates that were biased downwards (i.e., notably close to the final year whereas the data-patterns indicated they should have been higher).

As an alternative, the probit generalised linear model (Finney 1971) was trialled, which fits a sigmoidal probit curve to survival rates over time. The zero failure-rates at time zero (i.e., all joints being rated as sound at the start of the trial) were included, and mean failure time was estimated for alternate failure percentages (typically 25, 50, 75 and higher). This method was adopted and applied with the PROBIT procedure. For each species, pairwise t-tests were used to test for significant differences in time to 50% failed (FT50) between the painted and unpainted treatments.

3. Results and discussion

In this study, failure (score 0, Table 2) was considered as the serviceability limit and time to failure of 50% of L-joints in a sample set was selected as the representative measure of a timber's durability. Constraints of the decay scoring system prevented any earlier score than failure being considered as a serviceability limit; a score of 1 may represent a good serviceability limit for low-durability L-joints in which decay progresses rapidly. For more durable timbers, however, decay commonly remains confined to the surface one or two millimetres without progressing deeper for long periods, so the effect of early decay may be exaggerated by using that score as a serviceability limit. Furthermore, a score of two can represent a pocket of decay in the end grain flanking the tenon part of a joint. Failure time was taken to be the assessment year that an L-joint was assessed to have failed. Considering condition time (the time between the assessment when a specimen failed and the assessment when sound wood remained (Thornton et al. 1983, Thornton 1994)) was considered too conservative due to the long periods between some assessments.

Different methods have been used by authors to calculate representative measures of timber durability performance in field tests. When considering data from Australian and imported timbers tested in-ground to determine their natural durability, Thornton et al. (1983) considered the serviceability limit to be mean time for stakes to have greater than half of the cross-sections lost to decay or termite attack. Later considerations of that test revised the serviceability limit to be the median time when stakes had lost greater than 60–75% of their cross-section to decay or termite attack (Cookson 2004; Johnson et al. 1996; Thornton et al. 1991). For above-ground tests, the European Standard L-joint method to measure the effectiveness of preservatives, requires mean ratings in addition to mean life (years) when all L-joints have failed (EN 330 2015). Mean decay ratings were reported for testing untreated L-joints (Clausen et al. 2006; Clausen and Lindner 2011) and decks (Laks et al. 2008) of naturally durable species. Cookson (2014) also reported mean ratings for accelerated above-ground field testing to evaluate wood preservatives and protection systems. Decay depths, which can be related to mean scores, have been presented when evaluating natural durability (Meyer-Veltrup et al. 2017). Results derived from mean scores were also reported for above ground tests (Preston et al. 2011; Zahora 2008). Median decay scores were presented for above ground natural durability field tests by Eslyn et al. (1985) and Highley (1995). Brischke et al. (2023) presented median scores and along with a range of other measures. Relative values comparing test species or treatments with low-durability reference species may aid comparison between tests and sites by reducing the effects of varying decay fungi virulence and site-specific climate-induced decay hazards (Brischke et al. 2023; Brischke et al. 2024; EN 350 2016).

In this study, the repeated measures ANOVA of scores gave a highly significant three-way (species by paint by time) interaction ($F = 9.28$; d.f. = 440, 15032; $P < 0.001$). Probit and median methods produced very similar estimates for species which all failed during the trial. However, for timber sample sets with reasonable proportions of L-joints remaining in the test after the last assessment, the extrapolated failure times from the probit analyses appeared more consistent with the observed data patterns. Probit analysis showed that the interaction between species, paint and time was highly significant (deviance ratio = 15.0; d.f. = 81, 920; $P < 0.001$). Predicted times to for 50% of L-joints to have failed (FT 50, probit fit) for unpainted and painted samples of each timber are presented in Table 3, along with predicted time to 25% of unpainted and painted L-joints of each timber to have failed (FT 25, probit fit). Where unpainted and painted L-joints had significantly different times to 50% failure, the greater value is indicated in bold font in Table 3.

Table 3

Time to 50% failed (probit fit) and associated 95% confidence interval (CI), time to 25% failed (probit fit), proportion of L-joints failed after 35 years and Australian Standard AS 5604 Durability Class for each timber in the L-joint field test.

Timber species	Trade name and details	Unpainted / Painted	FT50 Mean time to 50% failed (years)	Lower 95% CI (years)	Upper 95% CI (years)	FT25 Mean time to 25% failed (years)	Proportion failed after 35 years (%)	Above-ground Durability Class[a]
Softwoods								
Araucaria cunninghamii Aiton ex A.Cunn.	hoop pine, native forest heartwood[b]	U	7.0	5.5	8.4	3.7	100	4
		P	8.2	6.4	10.2	3.7	95	
Araucaria cunninghamii Aiton ex A.Cunn.	hoop pine, plantation heartwood[b]	U	**3.0**	2.6	3.5	2.8	100	4
		P	1.8	1.3	2.1	1.3	100	
Pinus caribaea Morelet	Caribbean pine heartwood[b]	U	9.8	6.0	13.0	2.7	100	4
		P	7.1	1.4	11.1	1.2	100	
Pinus elliottii Engelm.	slash pine heartwood[b]	U	8.0	5.0	10.5	1.7	89	4
		P	5.8	4.3	7.0	2.2	100	
Pinus radiata D.Don	radiata pine heartwood[b]	U	7.5	6.4	8.8	4.8	100	4
		P	4.3	0.0	7.1	0.0	94	
Pinus radiata D.Don	radiata pine sapwood[c]	U	**4.2**	3.7	4.8	3.4	100	4
		P	3	2.6	3.5	2.3	100	
Pinus radiata D.Don	H3 CCA-treated radiata pine sapwood[d]	U	50.0	-	-	42.7	6	-[d]
		P	-	-	-	-	0	

[a] AS 5604:2022 (Standards Australia, 2022)

[b] L-joints consisted of heartwood with small amounts of sapwood included in some cases

[c] L-joints consisted of sapwood with small amounts of heartwood included in some cases

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Softwoods								
Pseudotsuga menziesii (Mirb.) Franco	fast-grown Douglas fir heartwood[e]	U	**9.4**	7.9	10.9	5.4	100	4
		P	4.4	2.9	5.7	0.4	100	
Pseudotsuga menziesii (Mirb.) Franco	slow-grown Douglas fir heartwood[f]	U	**14.2**	12.9	15.8	10.8	100	4
		P	10.1	8.8	11.5	6.5	100	
Thuja plicata Lamb.	slow-grown western redcedar[f]	U	13.9	12.7	15.3	10.9	100	2
		P	**20.8**	18.4	23.6	12.8	89	
Callitris endlichrei (Parl.) F.M.Bailey	black cypress heartwood adjacent to sapwood[g]	U	**16.6**	15.0	18.5	12.5	100	n/a
		P	13.8	12.3	15.5	9.6	100	
Callitris endlichrei (Parl.) F.M.Bailey	black cypress sapwood adjacent to heartwood[g]	U	5.7	4.9	6.5	4.1	100	4
		P	5.8	4.8	6.8	3.4	100	
Callitris glaucophylla Joy Thomps. & L.A.S.Johnson	white cypress heartwood	U	33.2	31.7	35.6	30.5	67	1
		P	32.1	30.1	35.0	27.5	72	
Callitris glaucophylla	white cypress	U	20.8	18.8	23.0	15.1	94	n/a

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Softwoods								
Joy Thomps. & L.A.S.Johnson	heartwood adjacent to sapwood[g]							
		P	**25.2**	22.7	28.2	18.0	94	
Callitris glaucophylla Joy Thomps. & L.A.S.Johnson	white cypress sapwood adjacent to heartwood[g]	U	**4.8**	4.2	5.5	3.5	100	4
		P	2.7	1.7	3.4	1.3	100	
Hardwoods	**All heartwood**							
Backhousia bancroftii F.M.Bailey	Johnstone River hardwood	U	**43.6**	36.2	60.6	31.2	28	2
		P	16.1	14.1	18.3	9.6	100	
Caldcluvia australiensis (Schltr.) Hoogland	rose alder	U	**16.2**	14.6	18.0	11.8	100	3
		P	7	6.5	7.6	6.3	100	
Cardwellia sublimis F.Muell.	northern silky oak	U	10.9	9.8	12.2	8.1	100	3
		P	10.4	7.5	13.0	3.3	94	
Corymbia citriodora subsp. *variegata* (F.Muell.) *sensu* A.R.Bean & M.W.McDonald	spotted gum CCV	U	**43.3**	37.0	128.9	37.1	13	1
		P	30.1	27.3	34.0	23.1	56	
[a] AS 5604:2022 (Standards Australia, 2022)								
[b] L-joints consisted of heartwood with small amounts of sapwood included in some cases								
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Softwoods								
Corymbia citriodora subsp. *citriodora* (Hook.) K.D.Hill & L.A.S.Johnson (*sensu* A.R.Bean & M.W.McDonald)	spotted gum CCC	U	**50.0**	42.2	107.1	41.4	11	1
		P	37.8	32.6	47.4	27.1	39	
Corymbia henryi (S.T.Blake) K.D.Hill & L.A.S.Johnson	spotted gum CH[h]	U	**19.9**	18.1	22.0	14.8	94	1[h]
		P	14.8	13.3	16.5	10.6	100	
Dryobalanops spp.	kapur[i]	U	34.1	32.4	38.0	30.8	56	2
		P	30.8	28.6	33.7	25.6	61	
Eucalyptus deglupta Blume	kamarere[i]	U	**21.2**	18.6	24.2	12.2	83	3
		P	15.4	12.8	18.0	6.1	94	
Eucalyptus delegatensis R.T.Baker	alpine ash or Tasmanian oak	U	13.4	12.0	15.0	9.7	100	3
		P	13.9	12.0	15.9	7.6	100	
Eucalyptus drepanophylla F.Muell. ex Benth.	grey ironbark	U	**50.0**	-	-	42.7	6	1
		P	40.3	35.2	51.8	31.9	33	
Eucalyptus grandis W.Hill	rose gum	U	32.9	29.8	37.6	25.6	72	2

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Softwoods								
ex Maiden								
		P	33.8	30.5	39.0	26.3	50	
Eucalyptus obliqua L'Her.	messmate or Tasmanian oak	U	17.1	15.1	19.4	10.7	94	3
		P	**23.8**	21.1	27.3	14.7	78	
Eucalyptus pilularis Sm.	blackbutt outer heartwood	U	40.4	35.7	54.0	33.5	44	1
		P	43.4	37.2	70.4	36.2	22	
Eucalyptus pilularis Sm.	blackbutt inner heartwood	U	34.0	31.2	38.7	27.9	56	_ j
		P	37.3	33.7	45.1	30.9	44	
Eucalyptus pilularis Sm.	blackbutt regrowth outer heartwood	U	30.4	28.6	32.4	26.5	83	1
		P	**42**	36.6	68.9	35.6	33	
Eucalyptus regnans F.Muell.	mountain ash or Tasmanian oak	U	9.7	8.6	11.0	6.9	100	3
		P	6.7	3.4	9.1	0.9	94	
Eucalyptus resinifera Sm.	red mahogany	U	37.6	34.5	79.7	33.6	33	1
		P	33.8	31.8	39.6	30.6	58	
Eucalyptus saligna Sm.	Sydney blue gum	U	30.7	28.0	34.4	23.8	83	2
		P	**40**	34.2	51.5	29.3	44	

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Softwoods								
Eucalyptus tereticornis Sm.	forest red gum	U	38.5	35.0	56.5	33.8	28	1
		P	40.1	35.8	100.0	35.3	22	
Flindersia brayleyana F.Muell.	Queensland maple	U	**14.2**	12.6	16.0	9.6	100	3
		P	9.9	8.8	11.2	7.0	100	
Lophostemon confertus (R.Br.) Peter G.Wilson & J.T.Waterh.	brush box outer heartwood	U	**38.6**	33.1	49.2	27.6	44	2
		P	29.4	27.0	32.4	23.4	71	
Lophostemon confertus (R.Br.) Peter G.Wilson & J.T.Waterh.	brush box inner heartwood	U	**34.6**	28.5	47.5	28.1	42	-[j]
		P	15.9	13.8	18.3	10.7	100	
Neorites kevedianus L.S.Sm.	fish tail silky oak	U	**37.8**	34.9	99.4	34.3	28	-
		P	25.4	23.4	27.7	20.1	83	
Shorea sp.	light red meranti[i]	U	**11.4**	10.2	12.7	8.4	100	4
		P	5.1	4.5	5.9	4.0	100	
Shorea sp.	red balau[i]	U	**37.5**	34.3	48.3	32.6	29	-[i]
		P	29.5	26.4	33.7	21.0	56	
Syzygium wesa B.Hyland	white Eungella satinash	U	37.8	35.1	179.6	34.8	28	1

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[d] Copper Chromium Arsenic (CCA) Type C, 0.38% m/m (%Cu + %Cr + %As). Hazard class 3 (H3) refers to outside, above-ground exposure conditions where products are subject to moderate wetting and leaching. Typical H3 applications include weatherboard, fascia, window joinery and decking (Standards Australia, 2021). Protective-treated wood is not included in AS 5604:2022 (Standards Australia, 2022).

[e] Outer heartwood; fast-grown: growth rings ≤ 10 per 50 mm; juvenile wood excluded; imported from North America

[f] Outer heartwood; slow-grown: growth rings ≥ 20 per 50mm; juvenile wood excluded; imported from North America

[g] L-joints consisted of sapwood and heartwood (typically representing < 1/3 of cross section) that were assessed separately

[h] *Corymbia henryi* was only collected from one source location. AS 5604 notes that *C. henryi* cannot be confirmed to have the same rating as the group listing for spotted gum.

[i] Imported timber for which the number of source locations and heartwood position was unknown

[j] AS 5604 notes that inner heartwood generally has lower durability (Standards Australia, 2022)

3.1 Effect of broken paint coat

The effect of the broken paint coat varied between species (Table 3). For example, there was a significant reduction in durability for painted L-joints of the very highly durable DC 1 timber, grey ironbark (*Eucalyptus drepanophylla*) compared with unpainted L-joints, while conversely, painted slow-grown western redcedar (*Thuja plicata*) (DC 2) L-joints were significantly more durable than unpainted L-joints (Fig. 3 and Table 3). The broken paint coating did not significantly affect the durability of rose gum (*Eucalyptus grandis*) (DC 2) (Figs. 3 and 4). Further research is required to elucidate causes of these differences. Investigation of the effects of extractives properties including solubility, mobility and toxicity to key wood decay fungi may be beneficial, along with evaluation of timber permeability.

The broken paint coat significantly reduced durability for 18 of the 41 timbers, including the following softwoods: plantation hoop pine heartwood (*Araucaria cunninghamii*), plantation radiata pine (*Pinus radiata*) sapwood, fast- and slow-grown Douglas fir (*Pseudotsuga menziesii*) heartwood, and black cypress (*Callitris endlichrei*) heartwood adjacent to sapwood. Along with grey ironbark (*Eucalyptus drepanophylla*), other hardwood heartwoods for which the broken pain coat significantly reduced durability included: Johnstone River hardwood (*Backhousia bancroftii*), rose alder (*Caldcluvia australiensis*), spotted gum CCV (*Corymbia citriodora* subsp. *variegata*), spotted gum CCC (*Corymbia citriodora* subsp. *citriodora*), spotted gum CH (*Corymbia henryi*), kamarere (*Eucalyptus deglupta*), Queensland maple (*Flindersia brayleyana*), outer and inner brush box (*Lophostemon confertus*), fish tail silky oak (*Neorites kevedianus*), light red meranti (*Shorea* sp.) and red balau (*Shorea* sp.).

In addition to western redcedar (*Thuja plicata*), other timbers for which the broken paint coat significantly increased durability included messmate/Tasmanian oak (*Eucalyptus obliqua*) heartwood and Sydney blue gum (*Eucalyptus saligna*) heartwood. While the time to 50% failure was greater for painted inner and outer heartwood blackbutt (*Eucalyptus pilularis*) compared with unpainted L-joints, only painted regrowth outer heartwood L-joints were significantly more durable than their unpainted counterparts.

As was the case for rose gum (*Eucalyptus grandis*), the broken paint coat had no significant effect on heartwood durability of L-joints of the following species: native forest hoop pine (*Araucaria cunninghamii*), Caribbean pine (*Pinus caribaea*), slash pine (*Pinus elliottii*), radiata pine (*Pinus radiata*), northern silky oak (*Cardwellia sublimis*), kapur (*Dryobalanops* spp.), alpine ash/Tasmanian oak (*Eucalyptus delegatensis*), mountain ash/Tasmanian oak (*Eucalyptus regnans*), red mahogany (*Eucalyptus resinifera*), forest red gum (*Eucalyptus tereticornis*), and white Eungella satinash (*Syzygium wesa*).

In white cypress (*Callitris glaucophylla*) L-joints containing both heartwood and sapwood, the broken paint film affected the sapwood by significantly reducing durability and affected the heartwood by significantly increasing durability. There was, however, no significant difference between painted and unpainted L-joints that consisted of white cypress heartwood alone. The latter result should be considered as more reliable measure of heartwood durability, as the sizes of the heartwood portions in L-joints containing both heartwood and sapwood differed and was more difficult to assess. As suggested by Thornton et al. 1983, heartwood adjacent to sapwood failed more quickly for white cypress. For black cypress L-joints containing both heartwood and sapwood, the broken paint coat has no significant effect on sapwood durability, while heartwood durability was significantly reduced by the paint coat.

While a well-maintained paint coat can prevent checking, a broken paint film is known to increase time of wetness in durability test specimens, as water enters through the coating break and is slower to dry from under the intact coating (Militz and Bloom 2000; Brischke et al. 2017; Meyer-Veltrup et al. 2017). For commercially relevant species, knowledge of relevant properties such as wood porosity and the mobility and toxicity of extractives would further characterise durability and inform design optimisation. Too few L-joints of CCA-treated H3 radiata pine sapwood had decayed to allow analysis of the effect of the broken paint coat on L-joint durability. To prolong the service life of joinery at risk of water trapping, brush-on protective treatment of joint inner surfaces can be applied (Norton and Francis 2008).

3.2 Durability classifications

Direct comparison between the times to 50% failure (FT50) and probable above-ground life expectancies in the Australian natural durability Standard AS 5604 (Table 1) was undertaken to assess durability classifications. This was a conservative approach given the small size of the tenon component of L-joints that were assessed, the test design that created a moisture trap at the joint, the sub-tropical climatic conditions to which L-joints were exposed (Francis and Norton 2006; MacKenzie et al. 2007; Wang et al. 2008) and intermittent exposure to leaf litter from years 20 to 30, which encourages decay (Clausen and Lindner 2011).

The performance of many timbers was consistent with durability classifications (Table 3). For several timbers, the FT50 for unpainted L-joints exceeded the probable life expectancy for its durability classification, while the FT50 for painted L-joints was considerably shorter and within the probable life expectancy for its durability classification. This was the case for Johnstone River hardwood (*Backhousia bancroftii*), rose alder (*Caldcluvia australiensis*), kamarere (*Eucalyptus deglupta*) and light red meranti (*Shorea* sp.). The current durability classification was considered appropriate in these cases.

Data from the previous inspection of this test (32 years) were submitted to the Working Group on the revision of the Australian Standard AS 5604 Timber – Natural durability ratings. Several above-ground durability classifications were updated based on those recommendations (Standards Australia 2022): rose alder (*Caldcluvia australiensis*), northern silky oak (*Cardwellia sublimis*), kamarere (*Eucalyptus deglupta*) and Queensland maple (*Flindersia brayleyana* F.Muell.) are all now Durability Class DC 3 above ground after previously being unclassified; brush box (*Lophostemon confertus* R.Br.) is now classified as DC 2 above ground after previously being classified as DC 3; and white Eungella satinash (*Syzygium wesa*) is now classified as DC1 after previously being unclassified above ground. Additionally, it was noted in AS5604:2022 that *Corymbia henryi* cannot be confirmed to have the same rating as the group listing for spotted gum, a trade name shared with *Corymbia citriodora* subsp. *citriodora* and subsp. *variegata* and *Corymbia maculata*. The *C. henryi* trees in this study were only sourced from one location. Further discussion of the spotted gum species in this test is planned to be provided in a following manuscript, along with discussion of relative performance of other commercially relevant timbers, including Tasmanian oak species (*Eucalyptus delegatensis*, *E. obliqua* and *E. regnans*), the inner and outer heartwood brush box (*Lophostemon confertus*), and the inner, outer and regrowth outer heartwood of blackbutt (*Eucalyptus pilularis*).

While the red balau in this test performed consistently with expectations for Durability Class 2, the species represented were unclear. The rainforest species fish tail silky oak (*Neorites kevedianus*) performed consistently with a Durability Class 2 classification.

Radiata pine sapwood treated with Copper Chromium Arsenic (CCA) to the preservative retention and penetration suitable for above-ground applications subject to moderate wetting and leaching was very highly durable in this study. This is consistent with in-ground durability performance for this preservative (Cookson 2013; Van den Bulcke et al. 2014). Probable life expectancies are not provided in the Australian Standard for preservative-treated wood-based products (Standards Australia and Standards New Zealand 2021).

The need for Standards that reflect Australian conditions was demonstrated by the classification of Douglas fir (*Pseudotsuga menziesii*), which is rated as more durable in overseas standards than in AS 5604 (EN 350 2016; Scheffer and Morrell 1998; Standards Australia 2022). It is noteworthy, however, that slow-grown Douglas fir was significantly more durable than fast-grown Douglas fir in this study (Francis 2023).

A limitation of AS 5604 is that durability classifications apply for the whole of Australia, encompassing temperate climatic regions in the south to tropical climatic regions in the north. Timber durability performance models that build on the work of MacKenzie *et al*. (2007), Wang et al. (2008) and Leicester et al. (2009), which take climatic variables into account, promise improved service life prediction capabilities. To assist with this endeavour, data generated for a subset of the timbers included in the study reported in this paper that were also installed at other locations throughout eastern Australia will be valuable (Cause 1994; Francis and Norton 2005; Francis and Norton 2006).

4. Conclusions

Natural durability classifications for seven species in the Australian Standard AS 5604 Timber – Natural durability ratings were updated based on the results of this study. In addition, timber durability performance data provided confirmation of a range of durability classifications in AS 5604 that were initially based on expert opinion and in-ground field test results. The broken paint coat of painted L-joints and consequent water trapping significantly reduced the natural durability for almost half (18) of the timbers tested. The paint coat had a protective effect, despite being broken to trap moisture, for four species. The broken paint coat did not have a significant effect for remaining timbers. The field site for this study presented a very high decay hazard. Further research on timber durability modelling that takes climate variables into account would be beneficial.

Declarations

No conflict of interest exists in the submission of this manuscript for publication.

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Author contribution

LP Francis: writing original draft, data curation and interpretation of results.

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Figures

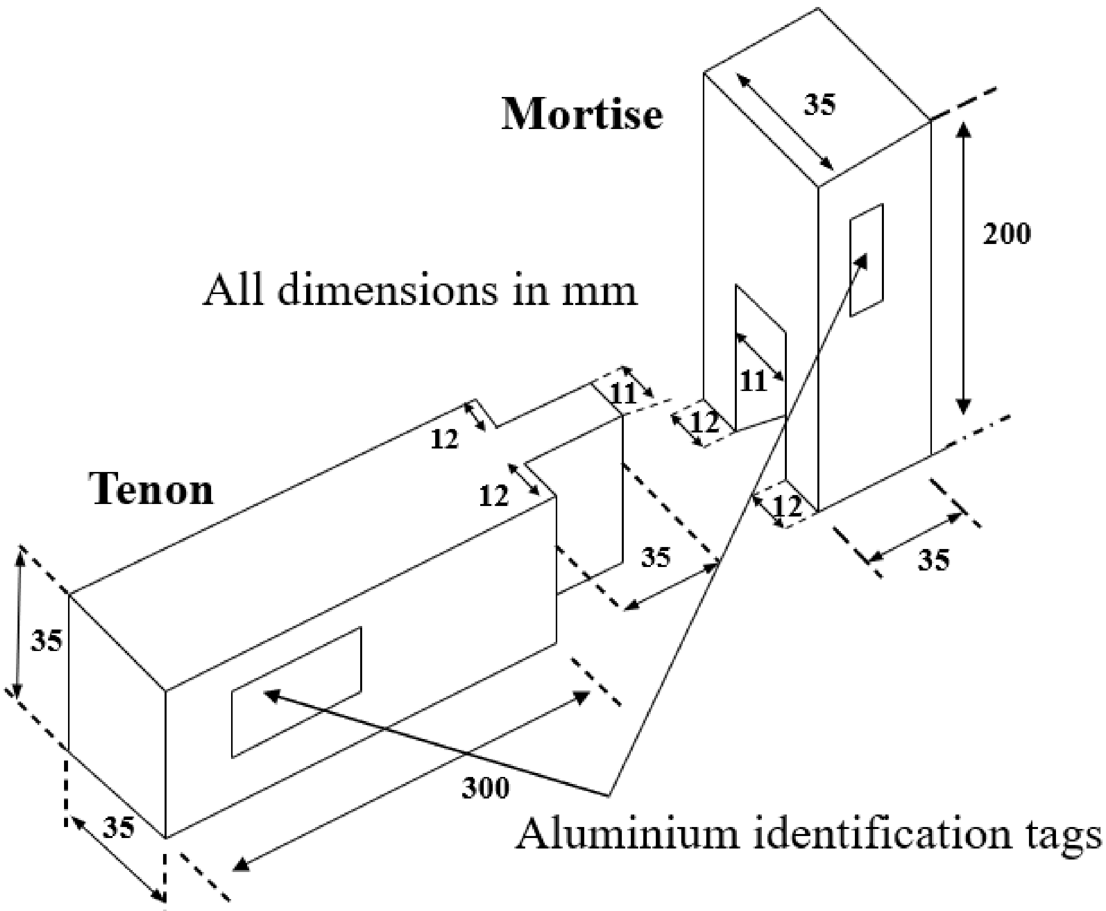

Figure 1

L-joint test unit dimensions

Figure 2

L-joints at Cleveland

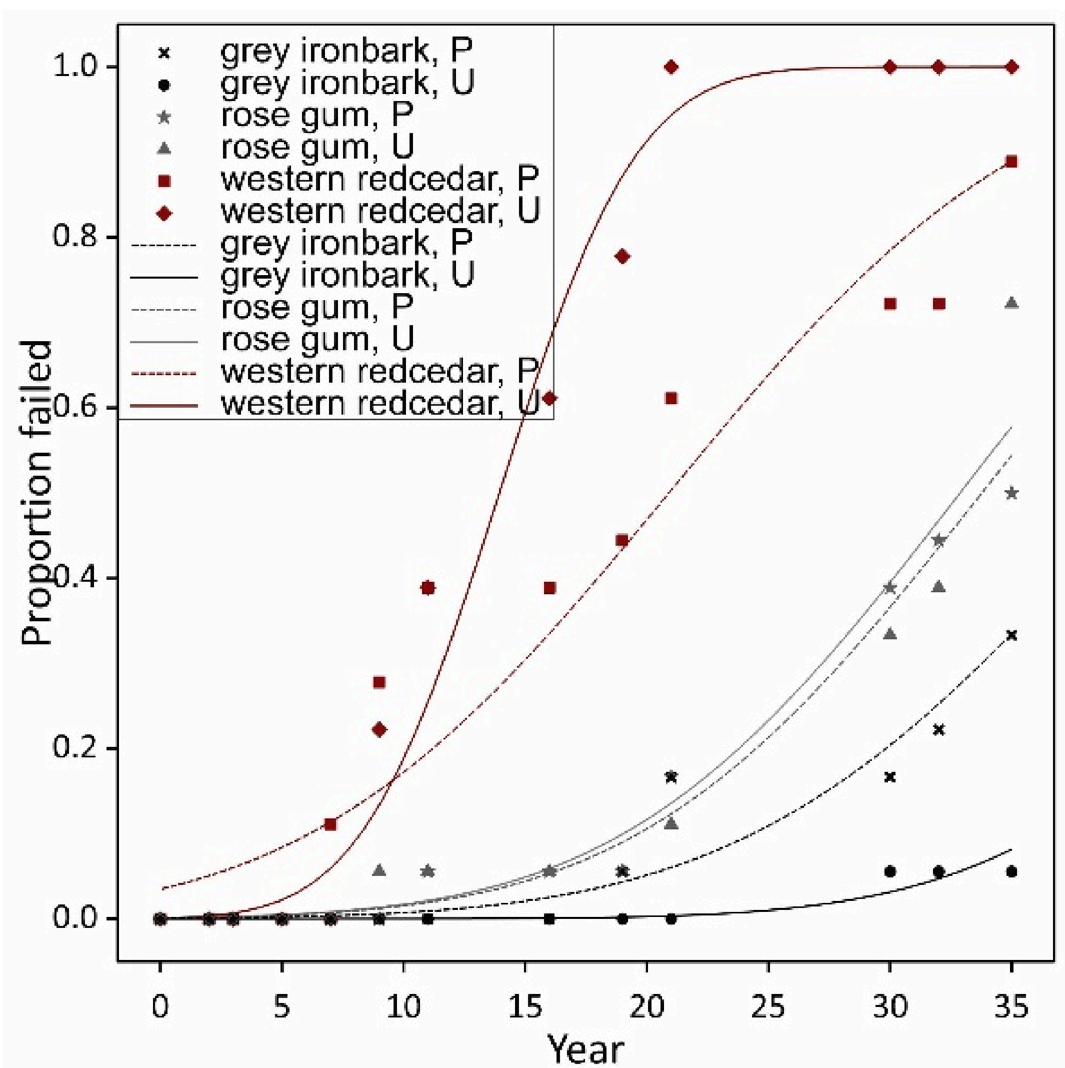

Figure 3

Different effects of a broken paint coat on durability (probit: times to proportion failed)

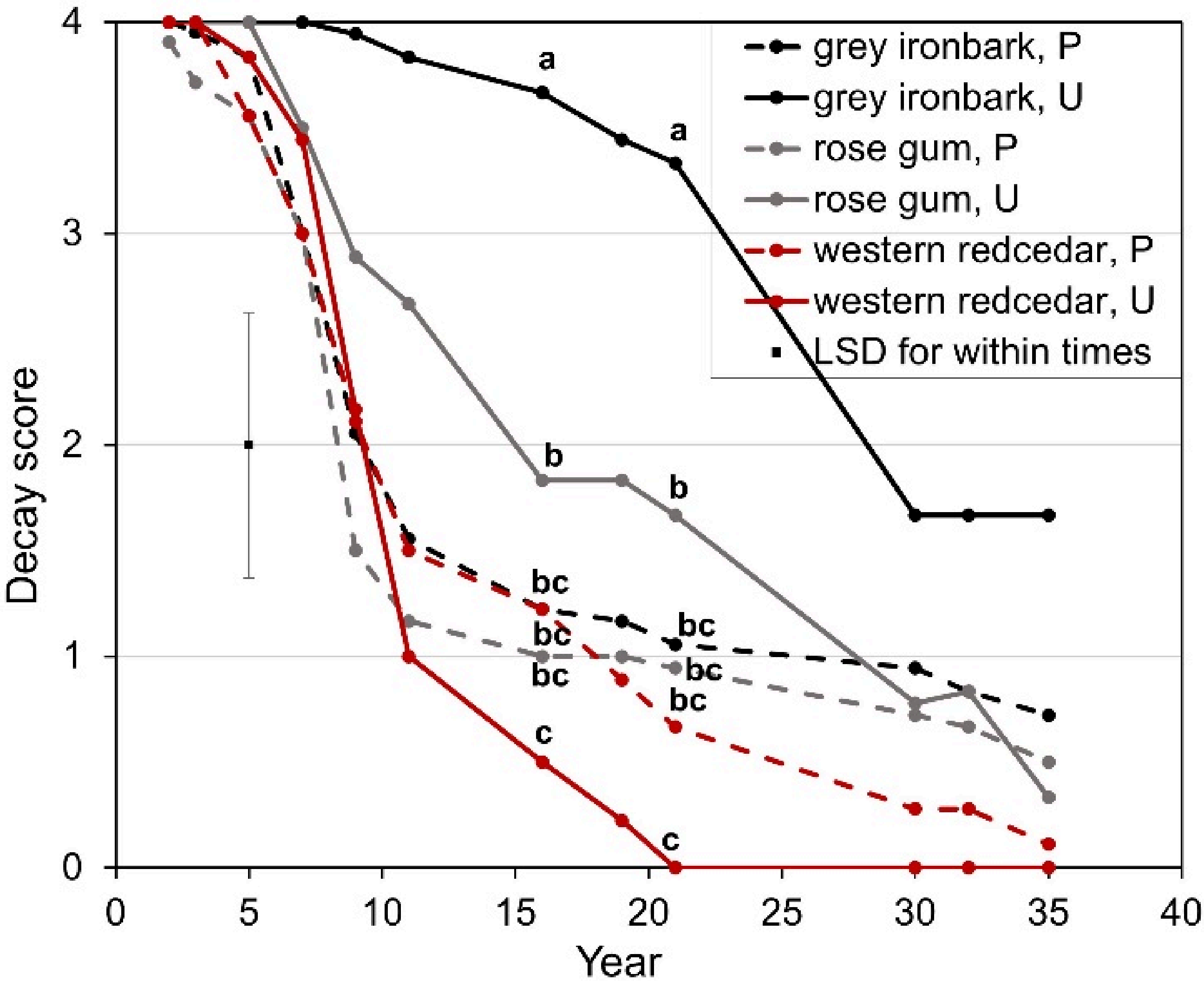

Figure 4

Different effects of a broken paint coat on durability (ANOVA: mean decay scores over time)