Field exposure of *Pinus* heartwoods to subterranean termite damage (Isoptera: Rhinotermitidae, Mastotermitidae)

B.C. Peters[1,2] and C.J. Fitzgerald[1]

[1]Forestry Research, Agency for Food and Fibre Sciences, Department of Primary Industries,
PO Box 631, Indooroopilly, Queensland 4068, Australia
[2]Email: brenton.peters@dpi.qld.gov.au

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Summary

Four field trials were conducted to evaluate responses of the Australian subterranean termites *Coptotermes acinaciformis* (Froggatt) and *Mastotermes darwiniensis* Froggatt to untreated softwood timbers. The aim of the research was to determine whether the termite resistance of the heartwood of maritime pine (*Pinus pinaster* Aiton) and of the F_1 hybrid of slash pine (*P. elliottii* Englem. var. *elliottii* L. & D.) x Caribbean pine (*P. caribaea* Morelet var. *hondurensis* Barrett & Golfari) was equivalent to that of slash pine heartwood. Containers with test specimens of maritime pine heartwood and sapwood, and slash pine heartwood and sapwood, and F_1 hybrid heartwood and sapwood, together with feeder specimens of radiata pine (*P. radiata* D.Don) sapwood, were prepared. These containers were placed on concrete brick assemblies, in above-ground, weather-protected situations in areas of high termite hazard. The work with *C. acinaciformis* was conducted at Beerburrum, in south-eastern Queensland, Australia, and termite responses were determined by losses of mass over a period of 17 weeks. The work with *M. darwiniensis* was conducted at Townsville, northern Queensland, and termite responses were determined by losses of mass over a period of 47 weeks.

The ranking in susceptibility of the timbers is as follows:

maritime pine sapwood > slash pine sapwood > F_1 hybrid sapwood > slash pine heartwood = maritime pine heartwood = F_1 hybrid heartwood.

The heartwood of maritime pine and of the F_1 hybrid of slash x Caribbean pines is highly resistant to damage by the subterranean termites *C. acinaciformis* and *M. darwiniensis*, when used in Hazard Class 2 (H2) (that is, internally above-ground) situations. Accordingly, with respect to *C. acinaciformis* and *M. darwiniensis*, we recommend that limitations on the use of heartwood unpenetrated by preservative in H2 situations be removed from Australian Standards and State regulations for maritime pine and the hybrids of slash x Caribbean pines.

Keywords: heartwood; susceptibility; durability; insect pests; damage; test procedure; methodology; termites; Isoptera; *Coptotermes*; *Mastotermes*; *Pinus*; Australia

Introduction

In Australia, about 20 species of termite are of economic importance to timber-in-service in buildings (Watson 1990). *Coptotermes acinaciformis* (Froggatt) is widely distributed throughout mainland Australia, and is considered the most economically important because of the damage caused in so many parts of this country (Gay and Calaby 1970). The giant northern termite *Mastotermes darwiniensis* Froggatt, which generally occurs north of the Tropic of Capricorn, is by far the most destructive termite in Australia. The economic consequences of the higher risk in northern Australia are, of course, offset by the sparseness of the human population in this region (National Health and Medical Research Council 1992).

There is a need to protect property and the structural integrity of buildings against termite damage. The Building Code of Australia (BCA) (Australian Building Codes Board 1996) describes the major requirements for building to ensure structural integrity. The *Queensland Building Act 1975* (Building Act (Queensland) 1975) (and similar legislation in some other States) requires that buildings in Queensland be constructed in accordance with the provisions of the BCA. Western Australia does not have a specific State Act, and local government bases its requirements on the BCA.

The BCA specifies that all susceptible structural members of buildings must be protected from damage by subterranean termites. If the materials and construction comply with Australian Standard AS 3660.1 (2000), the requirements of the BCA and the *Queensland Building Act 1975* are satisfied. Clause 3.1.3 of the BCA specifies the building materials classified as termite-resistant and permitted for use as 'primary building elements' without the need for termite-management systems. These include steel, aluminium and other metals, concrete, masonry and fibre-reinforced cement. The timbers permitted for use are naturally resistant timbers, in accordance with Appendix A of AS 3660.1, and preservative-treated timber, in accordance with Appendix D of AS 3660.1. The latter Appendix then refers to allowable Hazard Classes as defined in Australian Standard AS 1604.1 (2000), and specifies that Hazard Class 2 (H2) protection (that is, internally above ground) is required for termite-susceptible timber.

Some species of timber are naturally durable and the heartwood is resistant to termite damage. Table F1 in Appendix F of AS 1604.1, ‘The Natural Durability of Commercial Timbers’, gives modified ‘Natural Durability Expectancy’ ratings. Natural durability ratings of timber are based on the in-ground performance of the outer heartwood, and the CSIRO Durability ratings of 1–4 have been used for many years. Table F2 (AS 1604.1), based on combined decay and termite-susceptibility ratings (Thornton *et al.* 1996), is headed ‘Natural Durability Classification — In-ground Natural Durability Ratings — For the Mature Outer Heartwood of Selected Species’. It includes a footnote that slash pine (*Pinus elliottii* Englem. var. *elliottii* L. & D.) and Caribbean pine (*Pinus caribaea* Morelet var. *hondurensis* Barrett & Golfari) used internally above ground and protected from the weather will exhibit a higher resistance to termites. With regard to the preservative treatment of timber, AS 1604 specifies the minimum retention of allowable preservatives required for each Hazard Class. As a result of work by Kennedy *et al.* (1994, 1996), limitations on heartwood unpenetrated by preservative in H2 situations have been removed from Australian Standards and State regulations for slash and Caribbean pines.

In this paper we present methods developed to assess the termite resistance of heartwood of two other *Pinus* species, so that they can also be considered for inclusion in the Standard with slash and Caribbean pines. The species are the Western Australian-grown maritime pine (*Pinus pinaster* Aiton) and the Queensland-grown F_1 hybrid of slash pine × Caribbean pine (‘F_1 hybrid’).

Materials and methods

Timber specimens

Four types of pine timber: maritime, F_1 hybrid, slash and radiata (*P. radiata* D.Don), were used in these trials. Test specimens, containing either heartwood or sapwood, were prepared. Due to variation in the heartwood width, the dimensions of some test specimens differed from our ideal.

The maritime pine (heartwood or sapwood) specimens (70 mm × 30 mm × 190 mm long, with the grain in the longitudinal direction) came from five trees, each providing two heartwood and two sapwood specimens. The specimens were considered representative of the species. The heartwood specimens had a bluish sapstain on some corners. The boundaries of the sapstain were marked on each specimen with a felt pen (Fig. 1). The F_1 hybrid (heartwood or sapwood) specimens (70 mm × 15 mm × 190 mm long, with the grain in the longitudinal direction) came from commercially available timber (‘studs’, 70 mm × 35 mm × 2400 mm).

Locally-grown lengths of slash pine timber were cut into heartwood specimens (30 mm × 15 mm × 190 mm long) or sapwood specimens (70 mm × 15 mm × 190 mm long). Radiata pine sapwood (‘studs’, 70 mm × 35 mm × 2400 mm) was cut into ‘feeder’ specimens (70 mm × 15 mm × 190 mm long).

The initial mass of each specimen was recorded. We estimated the oven-dry mass of each test specimen according to the procedures of Peters and Fitzgerald (1997, 1998), because Peters and Allen (1995) demonstrated enhanced termite damage on wood that had been oven dried at 105°C for 24 h.

Figure 1. The boundaries of sapstain on maritime pine heartwood blocks marked on each block with a felt pen

Field trials

Lenz *et al.* (1992) used a supply of susceptible timber below the soil surface to provide a food source and an environment conducive to sustained foraging by termites. Preston *et al.* (1985, 1986) placed test specimens on hollow concrete bricks laid on the ground in an area of high termite hazard. Peters and Fitzgerald (1997, 1998) successfully combined and modified these two methods. The result is a modification of Protocol H2.2 Lunch-box Technique (Australasian Wood Preservation Committee 1997). We used trenches (each 300 mm × 300 mm × 10 000 mm long) filled with slash pine off-cuts and backfilled with soil to encourage sustained foraging by termites (Fig. 2). Concrete brick assemblies (about 100 mm thick) were placed adjacent to and on top of each backfilled trench. Radiata pine stakes (20 mm × 35 mm × 150 mm long) were driven into the ground within the gaps in the bricks to provide access by termites from the ground to the test specimens (Fig. 3). Test specimens and feeder specimens were arranged in a single layer, separated from each other by corrugated cardboard (a single piece of cardboard woven between alternating test specimens and feeder specimens) in six-litre plastic food containers (‘test containers’, 90 mm deep × 210 mm wide × 310 mm long). Feeder specimens were similarly separated by corrugated cardboard in identical containers (‘control containers’). Test containers and control containers were inverted and placed on corrugated cardboard on the brick assemblies on each trench (Fig. 3). Each container was then covered with heavy-duty black plastic sheeting and secured with soil. Two trials (Trials 1 and 3) against *C. acinaciformis* were conducted at Beerburrum (26°58'S, 152°54'E), in south-eastern Queensland. Following exposure for 17 weeks, losses of mass of the exposed specimens were estimated. Two trials (Trials 2 and 4) against *M. darwiniensis* were conducted at Townsville (19°12'S, 146°38'E), northern Queensland. Following exposure for 47 weeks, losses of mass of the specimens were estimated.

Trial designs

For the two maritime pine trials (Trials 1 and 2), one specimen of each of four substrates was exposed in each of five test containers at each site. The substrates were: maritime pine heartwood,

Figure 2. Trenches were filled with slash pine off-cuts and backfilled with soil to encourage sustained foraging by termites at Beerburrum and Townsville

maritime pine sapwood, slash pine heartwood and slash pine sapwood. The four treatments were arranged randomly in four positions (positions 4, 6, 8 and 10) with nine radiata pine feeder blocks (positions 1–3, 5, 7, 9 and 11–13) (total 13) in each container. Two control containers, each containing 15 feeder specimens, were exposed at each site to monitor termite foraging vigour.

For the two F_1 hybrid trials (Trials 3 and 4), four substrates were exposed in each of nine test containers at each site. The substrates were: F_1 hybrid heartwood (four specimens), F_1 hybrid sapwood, slash pine heartwood and slash pine sapwood (seven specimens in total). These specimens were arranged randomly with eight feeder specimens in each test container.

Statistical analyses

Termite feeding responses were assessed for each specimen by estimating the mass of wood consumed. The estimated-mass-loss data for individual specimens were subjected to standard analyses of variance using StatSoft, Inc. (1995), to partition the variation between substrates, test containers and the interaction of these variables. Hereafter, we use the term ‘mass loss’ to refer to ‘estimated-mass loss’.

Results

At harvest, termites were active in all containers in all four trials.

Maritime pine: *C. acinaciformis* Trial 1

An analysis of variance was performed on the mass-loss data obtained from specimens within each test container, and the plot of residuals on fitted values indicated that a logarithmic transformation was necessary (Kolmogorov–Smirnov $D = 0.36$; $P < 0.05$). The second analysis indicated that differences between the test specimen effects were highly significant ($F_{3,12} = 152$; $P < 0.001$), but differences between the test container effects were not significant ($F_{4,12} = 0.7$; $P > 0.05$) (Table 1). Examination of

Figure 3. Concrete bricks were laid above the trench. Radiata pine feeder stakes were driven into gaps in the bricks to encourage movement of termites from the ground to the test specimens.

the maritime pine heartwood specimens revealed that most of the damage due to termites had occurred in the stained region marked on each specimen with a felt pen (Fig. 4).

A Kruskal–Wallis one-way analysis of variance by ranks test was performed on the mass-loss data for the feeder specimens from each test container and from each control container. The analysis

Figure 4. Damage caused by *C. acinaciformis* to maritime pine test specimens: heartwood (top row), sapwood (bottom row)

indicated that differences between container effects were not significant (H ($d.f.$ = 6; N = 75) = 12.1, P = 0.06). Mean mass loss for the feeder specimens was 41.6 g (SD = 18.1) — about 36% of the initial mass of the specimens.

Maritime pine: *M. darwiniensis* Trial 2

An analysis of variance was performed on the mass-loss data obtained from specimens within each test container; the plot of residuals on fitted values indicated that a logarithmic transformation was necessary (Kolmogorov–Smirnov $D = 0.17$; $P < 0.01$). The second analysis indicated that differences between the test specimen effects were highly significant ($F_{3,12} = 130.4$; $P < 0.001$), but differences between the test container effects were not significant ($F_{4,12}$ = 2.0; $P > 0.05$) (Table 1). Examination of the maritime pine heartwood specimens revealed that most damage due to termites had occurred in the stained region marked on each specimen with a felt pen (Fig. 5). In contrast to *C. acinaciformis* (Fig. 4), *M. darwiniensis* damaged both the early wood and the late wood, and appeared to initiate damage both on the sides and on the end-grain of the maritime pine sapwood test specimens.

A Kruskal–Wallis one-way analysis of variance by ranks test was performed on the mass-loss data for the feeder specimens from each test container and control container. The analysis indicated that differences between container effects were significant (H ($d.f.$ = 6; N = 75) = 28.8; P = 0.0001). Mean-mass loss for the feeder specimens in one control container was 26.9 g (SD = 4.8); the corresponding figure in the remaining containers was 17.5 g (SD = 6.7), about 18% of the initial mass of the specimens.

F_1 hybrid: *C. acinaciformis* Trial 3

An analysis of variance was performed on the mass-loss data obtained from specimens within each test container; the plot of residuals on fitted values indicated that the data were not normally distributed (Kolmogorov–Smirnov $D = 0.28$; $P < 0.01$), and needed a logarithmic transformation (Kolmogorov–Smirnov D = 0.058; P = n.s.). The second analysis indicated that differences between the test specimen effects were highly significant ($F_{6,48}$ = 26.3; $P < 0.001$), but differences between the test container effects were not significant ($F_{8,48} = 1.2$; $P > 0.05$) (Table 2). Examination of the F_1 hybrid and the slash pine heartwood specimens revealed little damage due to *C. acinaciformis* (Fig. 6).

A Kruskal–Wallis one-way analysis of variance by ranks test was performed on the mass-loss data for the feeder specimens from each test container. The analysis indicated that differences between container effects were not significant (H ($d.f.$ = 8; N = 72) = 9.30; P = 0.32). Mean-mass loss for the feeder specimens was 42.5 g (SD = 18.7); about 43% of the initial mass of the specimens.

F_1 hybrid: *M. darwiniensis* Trial 4

An analysis of variance was performed on the mass-loss data obtained from specimens within each test container; the plot of residuals on fitted values indicated that the data were not normally distributed (Kolmogorov–Smirnov $D = 0.32$; $P < 0.01$), and needed a logarithmic transformation (Kolmogorov–Smirnov D = 0.15; $P < 0.15$). The second analysis indicated that differences between the test specimen effects were highly significant ($F_{6,48}$ = 39.9; $P < 0.001$), and differences between the test container effects were highly significant ($F_{8,48}$ = 7.5; $P < 0.001$) (Table 2). Examination of the F_1 hybrid heartwood specimens revealed that most of the damage due to *M. darwiniensis* had occurred on the longitudinal edges of the specimens; little damage was evident on the faces of these specimens (Fig. 7).

Table 1. Mean[1] mass loss (g) by test specimens of maritime pine and slash pine caused by *C. acinaciformis* and *M. darwiniensis* at Beerburrum and Townsville, respectively

Pinus substrate	*C. acinaciformis*	*M. darwiniensis*
Maritime heartwood	11.4c	6.8b
Maritime sapwood	153.1a	86.8a
Slash heartwood	0.02d	0.7c
Slash sapwood	54.7b	2.7c

[1] Means of five replicate test specimens. Within columns, means followed by different letters are significantly different ($P < 0.05$).

Figure 5. Damage caused by *M. darwiniensis* to maritime pine test specimens: heartwood (top row), sapwood (bottom row)

Figure 6. Damage caused by *C. acinaciformis* to feeder specimens (top row) and test specimens (bottom row): F_1 hybrid heartwood (4 samples), F_1 hybrid sapwood, slash pine sapwood and the slash pine heartwood, left to right, respectively)

Table 2. Mean[1] mass loss (g) by test specimens of F_1 hybrid and slash pine caused by *C. acinaciformis* and *M. darwiniensis* at Beerburrum and Townsville, respectively

Pinus substrate	*C. acinaciformis*	*M. darwiniensis*
F_1 hybrid heartwood	0.02cd	1.4e
F_1 hybrid heartwood	0.4c	3.8d
F_1 hybrid heartwood	–0.1d	3.6d
F_1 hybrid heartwood	–0.6e	6.2c
F_1 hybrid sapwood	3.3b	18.1b
Slash heartwood	0.7c	1.7e
Slash sapwood	15.3a	36.5a

[1] Means of nine replicate test specimens. Within columns, means followed by different letters are significantly different ($P < 0.05$)

Figure 7. Damage caused by *M. darwiniensis* to feeder specimens (top row) and test specimens (bottom row): F_1 hybrid heartwood (4 samples), F_1 hybrid sapwood, slash pine sapwood and slash pine heartwood (left to right, respectively)

A Kruskal–Wallis one-way analysis of variance by ranks test was performed on the mass-loss data for the feeder specimens from each test container. Results from the analysis indicated that differences between container effects were significant (H ($d.f.$ = 8; N = 72) = 32.9, P = 0.0001). Mean-mass loss for the feeder specimens in test containers 7 and 9 was 90.9 g and 62.2 g, respectively. Mean-mass loss for the feeder specimens in the remaining containers was 43.3 g (SD = 4.4), about 44% of the initial mass of the specimens.

Discussion

Subterranean termites are discriminating feeders, often feeding on the less dense earlywood and leaving the harder latewood intact (Forschler 1998). In our trials, *C. acinaciformis* exhibited this typical feeding behaviour on the sapwood of the four timber types: maritime, F_1 hybrid, slash and radiata pines. *Mastotermes darwiniensis*, however, was less discriminating and damaged both the earlywood and the latewood, and appeared to initiate damage both on the sides and on the end-grain of the sapwood specimens. These data support earlier observations by Peters and Fitzgerald (1998) on the differences in feeding behaviour of these termites.

The bluish stain of coniferous timbers is due to fungi long known to occur exclusively in the sapwood (Cartwright and Findlay 1958). The stain aided in recognising the sapwood/heartwood boundary on test specimens. The presence of sapwood in coniferous test specimens, before exposure to termites, can be demonstrated using chemical tests (Australian/New Zealand Standard AS/NZS 1605 2000). The presence of sapwood on the maritime pine heartwood specimens was problematic and resulted in some mass loss due to termite feeding. The F_1 hybrid and slash pine heartwood specimens were of irregular dimensions to avoid the presence of sapwood.

Nevertheless, there was minor feeding by *M. darwiniensis* on these specimens. Ideally, the heartwood specimens of these three types of timber should have contained no sapwood and been of identical dimensions to avoid bias.

The losses of mass in the heartwood specimens of these three types of timber were consistently small compared with losses in the sapwood specimens, indicating high resistance of the heartwood specimens to termite damage. The negative losses of mass resulted from a combination of variation in estimating initial moisture content of the specimens, and sorption during field exposure. For preservative-treated test specimens, drying in a vacuum oven at 40°C and –95 kPa for five days to remove any residual solvents and volatiles prior to weighing is recommended (Australasian Wood Preservation Committee 1997). Creffield (1994) conditioned test specimens in a constant temperature room held at 32°C and 75% relative humidity for three weeks. After conditioning, test specimens were weighed to determine their initial mass. Spare, unexposed specimens were designated as conditioning controls and used to adjust losses of mass in test specimens exposed to termites. Gains in mass for highly resistant specimens were reported (Creffield 1994) and a qualitative scoring system (based on visible wood consumption) proposed, after the method of Beesley (1978). Where quantitative losses of mass are to be used, care and precision in determining initial moisture content of the test specimens is important.

The susceptibility of radiata pine sapwood to *Coptotermes* has been known for over 40 y (Gay 1957). In our trials, mass loss for the radiata pine feeder specimens varied from 36% to 43% for *C. acinaciformis* when exposed for 17 weeks and 18–44% (mean mass loss in one test container was 92%) for *M. darwiniensis* when exposed for 47 weeks. These data are similar to those recorded by Creffield (1994) for *C. acinaciformis* when exposed for 15 weeks. They are, however, generally much less than the 42–95% recorded by Creffield (1994) for *M. darwiniensis* when exposed for 15 weeks. Our *M. darwiniensis* trials were conducted during particularly dry weather in 2001/02. Lenz *et al.* (1992) noted that environmental factors, particularly soil moisture and temperature, greatly influence the level of termite foraging in the upper layers of the soil. Furthermore, even when termites have contacted the test specimens and the adjacent supply of bait wood is providing a suitable feeding site, the termites may abandon the site and retreat deeper into the ground once the top layers of soil dry out or become too wet or too warm. It is likely that *M. darwiniensis* was not foraging strongly in the test containers for much of the 47 weeks.

With regard to test duration, the question 'How long is long enough?' is fundamental, but largely unresolved. The Australasian Wood Preservation Committee (1997) requires test duration of at least 15 weeks. Creffield and Watson (2002) used a test duration determined by the time taken for the termites to consume the available susceptible substrate and retreat from the drum: 15 weeks for *M. darwiniensis* and 10 months for *C. acinaciformis.* At distant trial sites, like our Townsville site, it is difficult to know much of the foraging behaviour of the termites in the containers. Termatrac™ microwave technology for non-destructive detection of insect pests in timber may have application in monitoring termite activity at such trial sites in the future (Peters and Creffield 2002; Evans 2003). With balanced orthogonal trial designs, differences between containers in average mass loss probably reflect differences in termite feeding duration. The termite feeding pressure, indicated through our results from the two *M. darwiniensis* trials, was sufficient to say confidently that the trials were fair and the outcomes realistic. It is apparent, however, that minimum performance requirements of an adequate test should define minimal acceptable termite feeding on control or feeder specimens rather than merely test duration (see also Tsunoda and Nishimoto 1986).

At Beerburrum, *C. acinaciformis* feeding activity was sustained and more uniform between containers. In-test inspections of the containers indicated *C. acinaciformis* transported and deposited mud or moist soil around timber specimens. These termites appeared to regulate the microenvironment within the containers, resulting in significant termite feeding pressure. For natural durability performance-testing, these conditions produced a satisfactory test. The method is also suitable for H2 performance testing using mounds of *C. acinaciformis*. Creffield (1994) notes that for H2 performance testing of preservatives, the presence of mud or moist soil in contact with the test specimens can be detrimental. Its presence can provide another mechanism whereby mobile, diffusible preservatives can be depleted from treated test specimens and can provide conditions that are conducive to fungal decay. Fungal decay, however, is normally not a problem where there is significant termite feeding pressure.

The method is applicable as an H2 simulation and has several advantages in common with the method of Creffield (1994). In particular, the containers are portable and can be set up in the laboratory, and transported to the field and installed promptly with a minimum of effort. More importantly, the method utilises foraging termites in natural field populations; an advantage over the restricted numbers of orphaned termites usually used in laboratory bioassays.

Conclusions

The test methods provided an environment conducive to sustained significant termite feeding pressure. From this work we rank the termite susceptibility of the timbers as follows:

maritime pine sapwood > slash pine sapwood > F_1 hybrid sapwood > slash pine heartwood = maritime pine heartwood = F_1 hybrid heartwood.

We consider the heartwoods of maritime pine and the F_1 hybrid of slash x Caribbean pines to be highly resistant to damage by the subterranean termites *C. acinaciformis* and *M. darwiniensis* when used in H2 situations. Accordingly, with respect to *C. acinaciformis* and *M. darwiniensis*, we recommend that limitations on the use of unpenetrated heartwood in H2 situations be removed from Australian Standards and State regulations for maritime pine and the hybrids of slash x Caribbean pines.

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