Urban Australian cities under termite attack

Barry Noller
National Research Centre for Environmental Toxicology, University of Queensland
Email: b.noller@uq.edu.au

Dale Gilbert
Department of Public Works
Email: dale.gilbert@publicworks.qld.gov.au

Ross Sadler
Qld Health Scientific Services
Email: Ross_Sadler@health.qld.gov.au

Rowan Truss
School of Engineering, University of Queensland
Email: r.truss@uq.edu.au

Myron Zalucki
School of Integrative Biology, University of Queensland
Email: m.zalucki@uq.edu.au

Des Connell
Griffith University
Email: d.connell@griffith.edu.au

Barry Chiswell
National Research Centre for Environmental Toxicology – The University of Queensland
39 Kessels Road Coopers Plains Qld 4108
Email : chiswell@uq.edu.au

Aaron Stewart
National Research Centre for Environmental Toxicology, University of Queensland
Email: a.d.stewart@uq.edu.au

Sharad Rajendran
School of Engineering – The University of Queensland St Lucia Qld 4072
Email : s.rajendran@minmet.uq.edu.au

Amanda Hasthorpe
National Research Centre for Environmental Toxicology, University of Queensland
Email: a.hasthorpe@uq.edu.au

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ABSTRACT

There is an emerging huge cost to buildings and other wooden structures from termite damage in urban Australia. Concerns about the environmental and public health consequences of the large quantity and frequent reapplication of termiticides (chemicals for the treatment of termites) in urban Australia has led stakeholders to identify a need to have appropriate information that reflects local conditions about their environmental and health effects. There are costs associated with the prevention and treatment of termite infestation in wooden structures. Reapplication of chemical barriers is required every 2 to 5 years depending on the products used and local conditions. Currently in urban Australia, we have been enjoying a period of overlap where older buildings are still being protected by the organochlorines while new structures are treated with organophosphates or pyrethroids. However, the effectiveness of the residual organochlorines is now reducing, and older houses may be at risk of termite infestation. The potential costs of re-treatment and repairs are likely to increase dramatically in the future as older slab-on-ground dwellings become susceptible due to the eventual breakdown of the organochlorine termiticides.

It is critical to identify information gaps between current acceptable industry practice for termite management in urban locations and public concerns. This may be achieved by recognising gaps in knowledge of each component of termite management, from termite ecology through to the present and future use of termiticides, and identifying these in terms of industry, public and client priorities. A review on aspects of environmental effects of currently used termiticides, along with a review of previous, current and future termiticides in the context of appropriate techniques for termite management and client priorities has identified several requirements including the following: (i) Further information on Australian termite biology, taxonomy, ecology and behaviour; (ii) Improved definition of the problem of termite infestation needs to be defined, locally and nationally; (iii) Identification of high-risk structures and building types, so that preventive measures can be taken in terms of design and construction; and (iv) Further education for homeowners, builders, designers, legislators and landscape designers in terms of practices in landscaping and design that inadvertently favour termites. Such approaches provide a pathway to deal with the “attack” by termites on buildings in urban Australia.

INTRODUCTION

Termites consume wood and cellulose in natural bush land and serve an important ecological function by converting dead trees into organic matter. Unfortunately in the urban environment, the wood in buildings and other structures such as wooden power poles and bridges is equally appealing to termites and infestation can cause considerable damage. During the 1999–2000 financial year, the Queensland Department of Housing spent $410,000 managing termite infestations in public housing. In the Ipswich, Woodridge and Capalaba areas in southeast Queensland, the estimated cost of repairs for termite damage ranged from $18,000 to $60,000 per property (Department of Public Works’ Built Environment Research Unit figures, September 2005). On average, termite infestations cost approximately $1500 in treatment, and repairs of $5000 for each building affected (Caulfield, 2002). It is estimated that 10% of Australian houses have had or will have termite infestations, with that figure rising to 65% in some areas – a resulting per annum cost of $4 billion (Caulfield, 2002). Management of termites, and eradication of exotic species is also costly – a campaign to eradicate West Indian dry wood termite *Cryptotermes brevis* (Walker) in Queensland is estimated to have cost $4.2 million by 1998 (Peters and Fitzgerald, 1998). Worldwide, damage caused by termites is estimated at U.S $22 billion per annum in terms of damage to wooden structures (Fage et al., 1988). Treatment and prevention of termite damage in Australian cities is therefore needed, and may give rise to unwanted side effects (Figure 1).

Until 1995, organochlorine termiticide treatments were used to create barriers to termites in Australia. These have since been replaced with other, less persistent, chemicals and physical barriers. As a consequence, chemical termiticides need to be reapplied on a regular basis, averaging every 3 to 5 years depending on local conditions. There is a relative lack of knowledge of the consequences of repeatedly using these replacement chemicals under Australian conditions (Boyd et al., 2003). In 2005, bifenthrin (FMC Australasia Pty Ltd) is the most commonly used termiticide in Australia followed by imidacloprid and fipronil. Chlorpyrifos (Dow Agricultural Products) has decreased in use because of concerns over toxicity and efficacy in alkaline soils (Boyd et al., 2003). Permethrin, alpha-cypermethrin are not currently used even though they remain registered for use in Australia by the National Registration Authority (NRA).

Thus a key problem is identified with respect to building and housing protection in Australian cities from termite attack. This attack is expected to increase due to the apparent decline in effectiveness of the organochlorines that were applied prior their use being banned.

Termite Ecology

Australia's termite fauna is diverse, represented by five families (Mastotermitidae, Termopsidae, Kalotermitidae, Rhinotermitidae and Termitidae) comprising 40 known genera and more than 266 described species. Termites play a key role in the nutrient cycles of tropical ecosystems (Whitford, 1991). Termites may be grouped as damp wood, dry wood or subterranean, depending on their habits. Damp wood termites live in rotten wood, particularly in logs or in damp sections of trees and are rarely considered to be of economic concern. Certain dry wood termites are of economic importance, with the exotic West Indian dry wood termite *C. brevis* identified as the most destructive species (Peters and Fitzgerald, 1998). Subterranean termites are those that require contact with the ground or moisture and they are responsible for damage to timber structures in buildings and in trees.

In Australia, the majority of pest termites are native (the exception is *C. brevis*) (Boyd et al., 2003). They are well adapted to local conditions and may be quite resistant to treatments. Relatively few Australian termites are considered to be pests of sound timber, with the most economically important being *Mastotermes darwiniensis* (Froggatt), *Coptotermes acinaciformis* (Froggatt), *Coptotermes frenchi* Hill, *Coptotermes raffrayi* Wasmann, *Coptotermes michaelseni* Silvestri, *Schedorhinotermes reticulatus* (Froggatt), *Schedorhinotermes seclusus* (Hill), *Schedorhinotermes intermedius* (Brauer), *Schedorhinotermes actuosus* Hill, *Heterotermes platycephalus* Froggatt, *Heterotermes paradoxus* (Froggatt), and *Nasutitermes exitiosus* (Hill) (Hill, 1942, Peters et al., 1996, Postle & Abbott, 1991).

Subterranean termites forage for food by means of covered runways (or galleries), which extend from the central nest to food sources above or below ground (up to 95m away) (Miller, 1993). Colonies consist of distinct castes, each performing a specialised task within the colony. Workers provide food for the colony, feed the other caste members and excavate galleries, while soldier termites defend the colony and tend to be equipped with mandibles or a proboscis (depending on the species) for defence. Reproductives are winged, and tend to swarm after summer rains to establish new colonies. On returning to the ground the reproductives shed their wings and search for food and moisture in the soil. After digging a chamber near a food source, the pair mate and a colony is begun. Supplemental reproductives can be formed in some species within 3 to 4 months after separation from the founding colony (Pawson & Gold, 1996), making it important not to fractionate the colony during management procedures.

Figure 1 Examples of termite damage. Photos courtesy of Amalgamated Pest Control.

HISTORICAL TERMITE MANAGEMENT IN AUSTRALIA

In Australia prior to 1962, arsenic dusting was the most common means of small-scale termite management. Nests were located and dusted directly with arsenic trioxide powder. Before 1995, subterranean termite management in Australia was based on the use of the highly persistent organochlorine insecticides (Peters & Fitzgerald, 1988), such as aldrin, dieldrin, chlordane and heptachlor (known collectively as cyclodienes, because of their particular chemical structure), which were well suited to slab-on-ground housing construction. Because of their chemical stability, they were extremely effective Australia-wide, and had no immediate adverse health effects at the levels of exposure arising from the approved use. Owing to environmental and public health concerns associated with their persistence in the environment and their tendency to accumulate in the fat of animals and humans, these chemicals were withdrawn from the market in 1995 and alternative strategies for termite management have been developed (Boyd et al., 2003).

Organochlorines used under slabs offered protection from termites for up to 30 years, and pre-treated wood for up to 10 years (Boyd et al., 2003). For some species organochlorine baits (Mirex) were used with success. The Northern Territory and Western Australia received an extension to use of organochlorines in the form of Mirex and Mirant baits for *M. darwiniensis* management only, until June 2003. These products were largely used for prevention of termite infestation of fruit trees in orchards.

Currently in Australia, we may be enjoying a period of overlap where older buildings are still being protected by the organochlorines while new structures have been treated variously with organophosphates (chlorpyrifos), pyrethroids (bifenthrin) and imidocloprid. Houses built before 1985 may still be protected to some extent by the organochlorine termiticides applied to the soil during construction. However, the effectiveness of the residual organochlorines will have been reducing over time (possibly up to 20 years although there is no reliable Australian data), and older houses may be at risk of termite infestation. The potential costs of re-treatment and repairs are likely to increase dramatically in the future as older slab-on-ground dwellings become susceptible due to the eventual failure of the organochlorine termiticides.

The success of the organochlorines over long periods of time has added to the popularity of slab-on-ground housing in Australia, buildings which are much more susceptible to infestation by termites than older style above-ground housing (Boyd et al., 2003). This means that the potential for termite damage is increased. The result of Australia’s previous reliance on the highly persistent organochlorines is that modern housing is quite susceptible to attack by termites, with termites entering buildings through weepholes, expansion joints, service ducts and cracks in brickwork which often extend several courses below ground. Simple alterations in building and property maintenance practices, such as providing exposed slab edges above ground and extending aprons of slab around slab-on-ground dwellings will allow termite incursions to be reduced and detected, providing that regular inspections take place.

Organophosphates and pyrethroids have since been offered as alternatives to the organochlorines (Boyd et al., 2003). These chemicals are effective against termites for a much shorter time (< 5 years), due to the shorter lifetimes of these chemicals which break down relatively quickly and therefore do not provide long-term protection. The need for more regular applications of the newer, less-persistent chemicals results in an increased chance that householders and the pest control operators will be more frequently exposed to the chemicals.

Persistence of Termiticides

Persistence describes the tendency of a chemical to survive in the environment without transformation or loss (Boyd et al., 2003). Persistence in soils is usually described by the half-life (the time taken for the chemical to degrade to half of the original concentration). Degradation of a termiticide may be by various routes, including microbial degradation (breakdown by micro organisms), chemical degradation (breakdown due to reactions with air, water and oxygen, or other chemicals the non-enzymatic pathway is very slow), and photo degradation (breakdown of pesticides by sunlight). The half-life may be established under different conditions, varying pH or soil type or in matrices other than soil (i.e. in water). The resultant values can therefore cover a large range and may only be of use as a comparative or relative description, and can vary greatly due to differences in soils, biota, climate and other factors. For this reason, soil half-life values should be interpreted with caution. It should also be noted that most half-life data represent breakdown of the parent compound and do not take into account biological effects of metabolites. Generally:

- Termiticides described as “persistent” have half-lives of >100 days
- Termiticides described as “moderately persistent” have half-lives of 30–100 days
- Termiticides described as “non-persistent” termiticides have half-lives of <30 days

The mobility of a termiticide in soil, air and water is influenced by its persistence and can be defined by parameters, including sorption, water solubility and vapour pressure.

Sorption is the attraction between a chemical and soil, vegetation, or other surfaces, but often simply refers to the binding of a chemical to soil particles. The sorption constant K_{oc} describes the potential to bind to soil particles, based on organic carbon content. Put simply, the higher the K_{oc} value, the greater the sorption (Table 1) (Bockting et al., (1993), Boyd et al., (2003), Laskowski (2000) & Sabljic et al., (1995)). Differences in termiticide formulations and soil types can influence sorption.

Termiticides may volatilise, with rates determined by the moisture content of the soil, and the pesticide’s vapour pressure, sorption and water solubility. Volatilisation from moist soil is described by the Henry’s Law Constant, calculated by the ratio of the vapour pressure of the chemical to its solubility in water, which characterises the tendency for a pesticide to move between the air and the soil water. The higher the Henry's law constant, the more likely it is that a pesticide will volatilise. Vapour pressure is the tendency of a chemical to volatilise – a termiticide with a vapour pressure of less than 1.0×10^{-8} mm Hg has a low tendency to volatilise, while those with vapour pressures of more than 1.0×10^{-3} mm Hg have a high tendency to volatilise. Solubility in water describes how much of a chemical will dissolve in water, usually measured at 20^{o}C or 25^{o}C. Termiticides with high solubility are more likely to be mobile in the soil, they are likely to leach to groundwater and be involved in runoff.

Current Chemical Termite Management in Australia

The withdrawal of the organochlorines as termiticides in Australia has by necessity encouraged the introduction and investigation of new products and methods for termite management (Boyd et al., 2003). Previously, because the organochlorines were so effective, there was apparently little commercial incentive to develop new chemicals or barrier controls. Chemical control can be divided broadly into preventative and curative measures. New buildings are treated with a chemical barrier beneath and surrounding their slabs. Where access to slabs is not practical for under-slab termiticide application, reticulation systems can be installed pre-construction, enabling repeated application of termiticides over time. Where a termite infestation has occurred, chemicals may be applied as spot treatments, sprays, baits or gases. There are termiticides registered for use in Australia as varying formulations of synthetic pyrethroids (e.g. permethrin and bifenthrin), organophosphates (chlorpyrifos), the chloronicotinyls (imidacloprid), arsenic trioxide (as a dust for spot treatments), and recently a phenyl pyrazole (fipronil), along with wood preservatives such as

Table 1 Reported Koc values of various termiticides in soil

Termiticides	Log K_{OC} (Range)	Reference
Synthetic Pyrethroids		
Bifenthrin	5.06 – 5.47	Laskowski (2000)
Deltamethrin	4.7 - 6.39	Laskowski (2000)
Cyfluthrin	4.7 – 5.09	Laskowski (2000)
Fenpropathrin	4.13 – 4.98	Laskowski (2000)
Permethrin	3.91 – 5.74	Bockting et al., (1993), Laskowski (2000)
Lambda-cyhalothrin	3.5 – 5.92	Laskowski (2000)
Cypermethrin	3.02 – 5-72	Laskowski (2000)
Other		
Chlorpyrifos	3.00 – 4.32	Bockting et al., (1993)
Fipronil	2.91	Boyd et al., (2003)
Imidacloprid	2.12 – 2.49	Boyd et al., (2003)
Organochlorines		
Mirex	6.00	Sabljic et al., (1995)
p-DDT	5.31	Sabljic et al., (1995)
Chlordane	5.15	Sabljic et al., (1995)
Aldrin	4.69	Sabljic et al., (1995)
Dieldrin	4.55	Sabljic et al., (1995)

boron, copper, fluorine and creosote that are also used alone or in combination to prevent termite attack.

Migration and Behaviour of Currently used Termiticides in Soils

Environmental variables are important, particularly in terms of transport, degradation and volatilisation of termiticides. Following application, termiticides can be lost from the original application site via lateral and vertical movement into surrounding soil and groundwater. It is possible that these chemicals will be transferred to local biota and animals.

The movement of termiticides through soil largely depends on the physical properties of individual chemical actives, the presence of water and biota and organic material, as well as the solvent/s that have been used in the pesticide formulation. Soil characteristics, pH and the presence of organic matter play major roles in determining the persistence and efficacy of chemicals. The half-life of a chemical in the soil will depend on a combination of these factors and will be influenced by the biota present. Sandy soils with low biota/low organic content and wet conditions generally result in increased transport, whereas those with high clay and organic content minimise chemical migration. The mineral content of the soil will influence degradation, by affecting adsorption rates or catalysing decomposition. Termiticides, in particular the organophosphates, can be lost from the soil through movement of volatiles into the air due to their significant vapour pressures at ambient temperatures associated with lower Henry’s Law constants. Soil properties – organic content, silt and clay content, pH and cation exchange capacity – are therefore important in affecting the bioavailability and dispersal of termiticides.

The Efficacy and Persistence of Currently used Termiticides

Australian evaluations of the organophosphates in soils suggest an effective life for chlorpyrifos of 7 to 12 years if covered, to as little as 4 years when exposed to the elements (Lenz et al., 1988), and less than 3 years in tropical Australia. A field study of leaching and degradation of pesticides (including chlorpyrifos, chlorthal dimethyl, fenamiphos, fenamiphos plus metabolites, linuron, metalaxyl, metribuzin, prometryne, propyzamide and simazine) in coastal sandy soils (pH 5.3) in Western Australia demonstrated that degradation rates vary widely between pesticides (Kookana et al., 1995). Murray et al. (2001) examined the stability of chlorpyrifos in six Australian soil types. Soil pH had no effect on the rate of degradation.

Testing of four soil types with six termiticide formulations indicate that soils have a significant influence on the efficacy of the chemicals (Forschler and Townsend, 1996). Of the termiticides tested (including chlorpyrifos, fenvalerate, cypermethrin and permethrin), all had concentrations lethal to termites that were at least seven times lower in sandy soils than in sandy loam or sandy clay loam (Forschler and Townsend, 1996).

A study of 6 termiticides (bifenthrin, chlorpyrifos, cypermethrin, fenvalerate, permethrin and isofenphos) applied to different soil types in Texas, USA, demonstrated significant differences in effectiveness (as measured by termite activity), bioavailability and residue (Gold et al., 1996). Barrier efficacy tests of a range of termiticides (Dursban, Equity, Dragnet, Prevail, Biflex, Pryfon, Demon, PP321 and Sumithion) in the USA indicate that while all formulations provide equal protection against *R. flavipes*, *C. formosanus* was able to tunnel deeper into sand treated with organophosphates than in sand treated with pyrethroids (Su et al., 1993). Acidic soils with low clay and organic content in Texas, USA, were found to be the most stable in terms of remaining bioavailability of pesticides, while alkaline soils with high clay content and organic compositions higher than 1% were least effective in retaining termiticide residuals over time (Gold et al., 1996).

Pyrethroids (bifenthrin, cypermethrin, lambda-cyhalothrin and permethrin) appear to provide longer protection than organophosphates (chlorpyrifos, fenitrothion and isofenphos). According to 5-year field trials in Florida, USA, against *R. flavipes* (Su et al., 1999), permethrin had the longest half-life (21.9 months) of the pesticides examined. Microencapsulated formulations generally result in longer persistence. In comparisons of different soil types treated with imidacloprid, pesticide effects on *R. flavipes* were greatest in sand and reduced in silty clay loam soils (Ramakrishnan et al., 2000). Little published Australian data are publicly available on the persistence and efficacy of other termiticides.

THE DEVELOPMENT OF ALTERNATIVE APPROACHES

History of Termite Barrier Technology Research

Traditionally termite prevention calls for the use of an insecticide treated soil barrier to restrict access to structural timber. The restriction of effective insecticides has led to development of alternative techniques. Much of the research into the specifics of termite foraging has sought to suppress populations with baits eg: (Chen & Henderson, 1996, Cornelius, 2003, Delaplane & LaFage, 1989, French, 1991, Polizzi & Forschlerp, 1999, Waller et al., 1990) The traditional concept of a barrier chemical treatment is being replaced by a attempt to maintain population control through the use of toxic baits. (French, 1994, Potter, 1997, Su, 2002). However other environmental and health conscious technologies are available and more are being developed. Barrier technology involving inert gravel (Granitegard), stainless steel mesh (Termimesh) and chemically impregnated polyethylene sheeting (Impasse) (Su et al., 2004) (Wege et al., 2003) are all available for protection of houses from termites.

The future of termite management in cities lies within an integrated approach that is able to take into account preventative and retrospective treatments for termites and that is not only effective, but is also economical, safe and environmentally friendly. Such treatments are likely to consist of physical and chemical barriers, used in combination with resistant or preserved wood or steel framing and according to the requirements of individual sites.

Integrated Barrier Approaches

An effective integrated approach needs to involve industry, government and consumer groups and combine treatment and prevention programs with education, monitoring and collating data together with research into new and better measures for termite management. There is a widely perceived need for improvements in building design in order to prevent or reduce termite infestation along with increased interest and demand for physical barrier systems. New building techniques and designs, along with novel barrier systems to reduce exposure to termites are warranted, and further research on termite foraging behaviour is required to facilitate the development of more effective bait and monitoring technology. The efficiencies of different termiticide formulations need investigating so that formulations to suit specialised purposes can be improved. Thus there are many areas in which different management techniques including approaches based on integrated pest management principles can be investigated.

Several requirements have been identified (Boyd et al., 2003):

- More information is required on Australian termite biology, taxonomy and ecology. Ideally, an understanding of the way in which termites forage, how they locate food sources, what specifically attracts and repels them, and the mode and speed of infestations need to be gained.

- The risks of termite infestation need to be evaluated, both locally and nationally so that susceptible or high-risk areas, structures and building types can be identified and preventive measures taken in terms of design and construction. Building regulations and designs need to be able to reduce or eliminate high-risk housing – and eliminate or reduce conditions that are attractive to termites and/or facilitate termite infestation.

- Further education is required for homeowners, builders, designers, legislators and landscape designers so that they can reduce the risk of infestation through the avoidance of practices in landscaping and design that inadvertently favour termites i.e. ensuring good under-floor ventilation, which discourages termite activity, not stacking timber or building up soil against or near buildings, reducing timber use where inspection for termites is difficult, and not building wooden in-ground structures (e.g. untreated timber retaining walls) close to houses.

- There needs to be a specific focus on the creation of alternative barriers for the range of wooden structures that need protection. The focus needs to take account of the current limitations of physical barriers and monitoring stations which may be avoided by termites and overcome the loss of activity associated with short-term response chemicals which have replaced the more hazardous organochlorine compounds. An innovative approach to barrier design is needed that seeks to incorporate the specific features of slow release chemicals, e.g. based on natural products which are more acceptable to the environment and public health.

- Since most termite-related damage to timber occurs from subterranean termites, preventative measures rely heavily on site housekeeping and the establishment of physical or chemical barriers to stop the termites getting into the premises or timber from the underlying soil.

> Once the termites have been found in wooden structures, a range of physical and chemical techniques are available to treat and eliminate (or control) the infestation. There is a need for a reliable long-term, maintenance-free method of preventing termite infestations that poses little or no risk to human or environmental health.

As a consequence research at the University of Queensland has commenced to look into the behaviour of termiticides, current and potential, in Australian soils and under Australian conditions. Open and collaborative communication between stakeholders needs to be maintained and widened so that the concerns of each group are addressed.

PHYSICAL RESISTANCE OF MATERIALS TO TERMITE ATTACK

Issues of Termite Attack

The large body of work describing biologically active repellent or attractive plant volatiles is in stark contrast to research investigating physical defences of plants (Sanson et al., 2001). What physical characteristics make a material difficult for termites to attack remains largely unanswered. Studies addressing the issue typically investigate the quality of hardness or general material type. It has been suggested that termites will only damage materials less hard than mandibles of termites (Potter, 1997), yet we are unaware of any quantification of termite mandibular hardness and contributing factors. Because mandibular hardness is associated with high concentration of zinc and

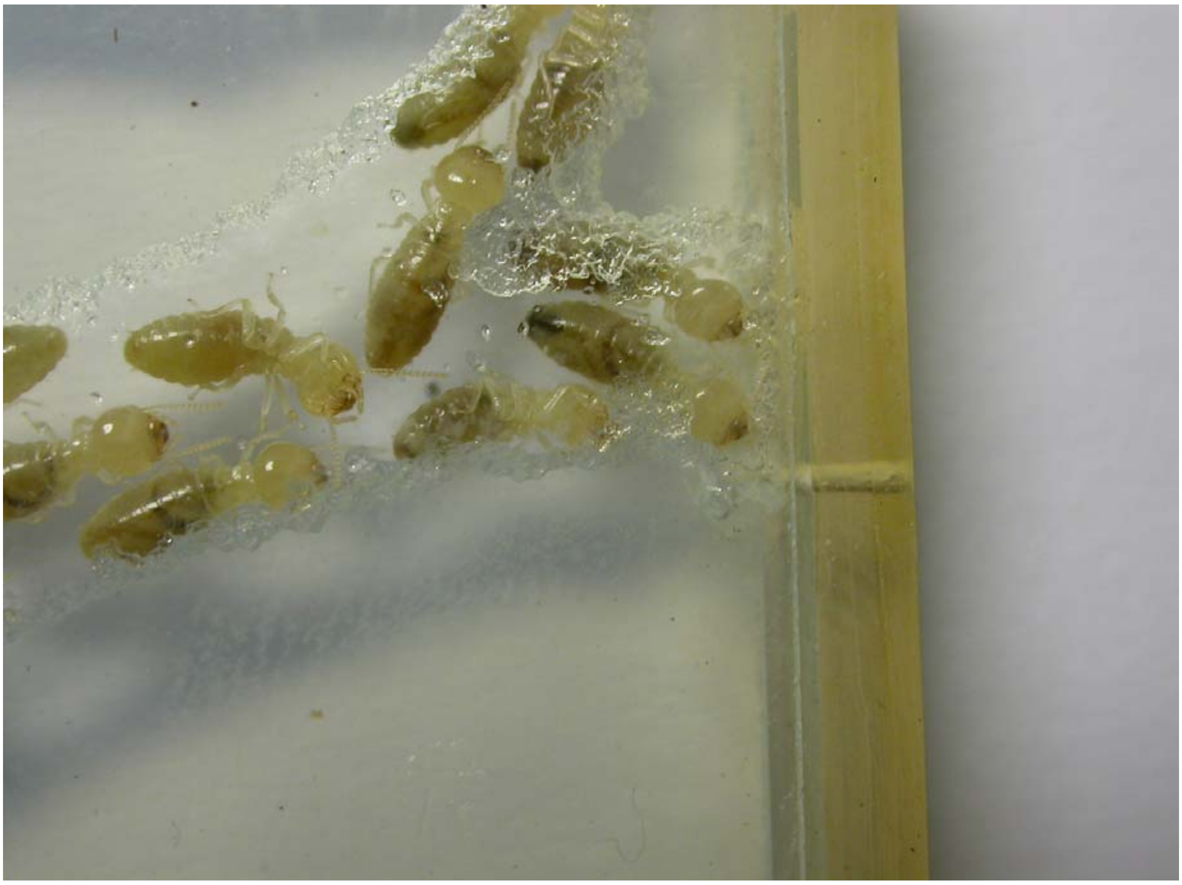

Figure 2 Experimental apparatus to study termite attack on a synthetic barrier material (photo by A. Stewart)

other metals nutrition may have an impact on the deposition of metals (Morgan et al., 2003). *Cornitermes cumulans cinereus* author mandibles were found to contain large quantities of manganese but not zinc (Fawke et al., 1997).

More understanding of the mechanics of micro-mechanics of mandibular action is needed to predict the resistance of synthetic materials is to be made. Deligne (1999) described a plane like carpenters tool on the mandible of workers and suggested a mechanism by which it is used. A scraping action would suggest that resistance to wear may be a critical material property. Although in some materials, wear resistance is related to hardness, in others, depending on the wear mechanism, issues of toughness and fatigue resistance are the critical parameters. Moreover, quantification of the magnitude and mode of force application by mandibular action is required to establish bench marks for material properties. The mechanical force applied by mandibles can be measured, as described for several Carabid beetles and a heliothine moth (Navon et al., 1992, Wheater & Evans, 1989). Using a similar methodology we have measured the mandibular closing force for several species of termites. The response of synthetic materials to surface forces of a magnitude exerted by termites is fundamental to understanding their mechanism of resistance to termite damage (Figure 2).

Synthetic Materials

Research into synthetics designed to protect timber should take into consideration the possibility that termites will be able to detect wood through the barrier, and consequently affect foraging behaviour. Early laboratory work that investigated the resistance of plastics to termite attack involved exposure of termites to test materials without any direct stimulus to attack, such as

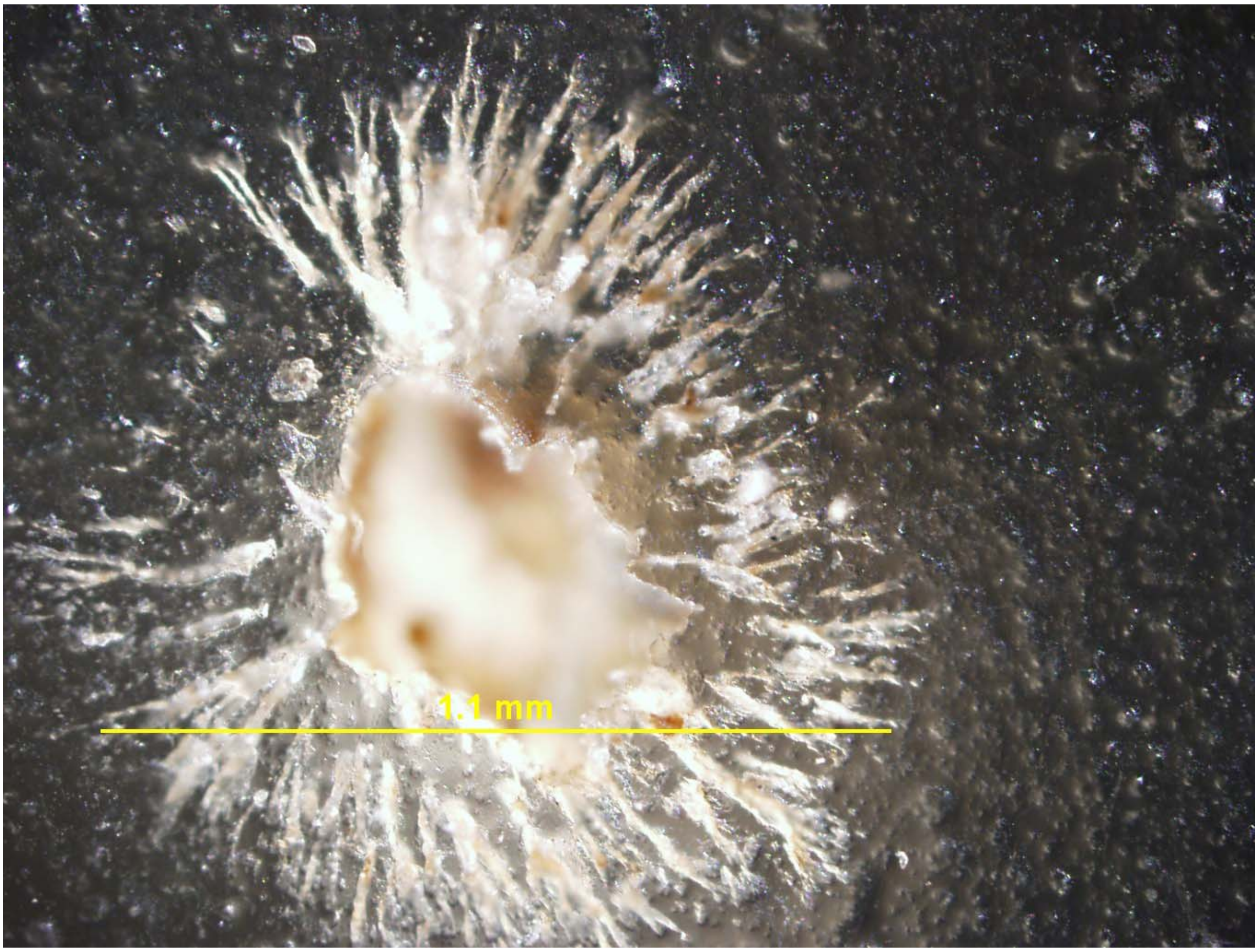

Figure 3 Termite damage to synthetic material without termiticide present (photo by A Stewart)

providing a barrier to a food source (Gay et al., 1955, Gay & Wetherly, 1969). Lenz (1994) examined the effect of food sourced on the other side of barrier in laboratory assays field trials, inevitably involving the presence of wood, (Nakamura et al., 1985). These studies on resistance of various materials are performance based and provide little idea of exactly how quickly termites can damage materials or what causes the apparent threshold of material toughness to stop damage. Damage to wood is commonly given as a volume or weight removed per termite weight per unit of time. This, however, hasn't been attempted for damage to synthetics (Figure 2).

It is generally agreed that a high degree of hardness is required to impart resistance to termite attack (Arkell et al., 1994, Nakamura et al., 1985). Unplasticised polyvinylchloride is hard enough to repel termites, consequently various UPVC products with a hardness of Shore D 70 or higher are used in Australia for protection via plumbing holes in the concrete slab (Ewart, 2001). Nakamura et al., (1985) found nylon with hardness greater than Shore D was 72 to impart resistance in a very thin layer < 0.3 mm thick. Sheets thicker than 0.33 mm are more resistant from edge chewing than thinner sheets.

The research currently being undertaken at the University of Queensland is approaching the problem of barrier resistance by seeking to understand how termites attack various synthetic materials via mandible action (Figure 3). This is different to studies undertaken to date and will lead to an ability to provide criteria for barrier material selection.

TERMITE REPELLENCE

Repellence is generally described as inability of termites to tunnel through treated substrate (Bläske & Hertel, 2001, Cornelius et al., 1995, Zhu et al., 2001) or as a tendency of termites to plug tunnels contacting undesirable substrates (Staples & Milner, 2000, Su et al., 1982), by aggregation, or lack of, on impregnated substrates (Sbeghen et al., 2002) and antifeedent properties of impregnated wood (Escoubas et al., 1995). All of these descriptions rely on a performance variable and the exact mechanism of repellence in not clear. Three types of insecticide have been described: those that repel immediately; those that kill quickly and the dying termites repel; and those that act slowly such that the termites don't die in situ (Su et al., 1982). The first two types would rate as repellent in soil penetration assays.

Various alternative compounds have the potential to repel termites if presented in a barrier system, the lower volume of chemical required in thin barrier technology may allow the use of previously prohibitively expensive or unstable compounds. Alternatives include Catnip oil (Peterson & Ems-Wilson, 2003), plant derived quinones (Ganapaty et al., 2004), semiochemicals extracted from ants (Cornelius & Grace, 1994), monoterpenoids (Cornelius et al., 1997), pathogenic fungi conidia (Staples & Milner, 2000), diterpenes (Lajide et al., 1995a), and extracts from seeds and fruits (Lajide et al., 1995b).

A variety of currently used insecticides have repellent properties including silaneophane, fenvalerate, bifenthrin, cypermethrin and permethrin all induce avoidance between 1 and 10 ppm (Su & Scheffrahn, 1990). Bifenthrin performed extremely well with *C.formosanus* at low concentrations; 1 ppm reducing tunnelling in adjacent soil 3 cm away from treated soil (48 hours) (Smith & Rust, 1990). However C. formosanus can tunnel through 10ppm if the thickness of the treated soil is 0.15cm (Su et al., 1995). The desired concentration of termiticide in thin synthetic barrier is ambiguous. Bifenthrin is repellent to termites, not unlike other parathyroids (Su et al., 1999). Soil was repellent at 1 % bifenthrin but the effect of repellence may have been through immobilisation of termites attempting to construct tunnels (Smith & Rust, 1990).

Laboratory response in terms of ability to tunnel into treated soils is generally a good reflection of results obtained from field populations, although threshold concentrations may be higher in the field in some cases, termites were more aggressive towards the treated soil in the laboratory. Interestingly the threshold of the repellent permethrin in the laboratory (1ppm) was much lower than what field populations (100ppm) could penetrate (Su et al., 1997). Soil from actual treatment sites has been used in assays (Su et al., 1993). Increased population density can increase the ability of termites to penetrate a substrate treated with an insecticide (Jones, 1990). Differing depths of soils impregnated with Dursban and other insecticides results in variation in termites ability to penetrate the barrier to the other side (Gahlgoff & Koehler, 2001, Su et al., 1995). This may not be the case in situations where the insecticide is more repellent.

THE FUTURE FOR AUSTRALIAN CITIES

The problems associated with termites in Australian cities are clearly identified and requiring innovative approaches. The identified large costs to buildings and other wooden structures from termite damage reveals that termites remain part of the urban environment of Australian cities following construction. The utilisation of less-persistent termiticides following the phase-out of organochlorines has created a less desirable situation of needing to reapply chemicals every few years to maintain barrier protection giving rise to environmental and public health consequences.

The future lies with well developed termite management strategies that incorporate the kind of research that will lead to alternative barriers giving protection of wooden structures against termite attack.

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