TERMITE RESISTANT CONSTRUCTION AND BUILDING MATERIALS

J. K. GRACE AND J. R. YATES
Department of Entomology, University of Hawaii at Manoa, Honolulu, HI 96822 USA

Abstract - Prevention of termite attack is preferable to remedial control. This can be accomplished through good architectural design, use of termite-resistant building materials, installation of physical or chemical barriers to prevent subterranean termite penetration, and possibly also installation of termite bait/monitoring stations. We review current developments and trends in each of these areas contributing to the construction of termite resistant buildings, particularly with respect to control of the Formosan subterranean termite.
Key words - *Coptotermes*, wood protection

INTRODUCTION

Subterranean (Rhinotermitidae) and drywood (Kalotermitidae) termites are severe problems in structures worldwide. Prevention of termite attack is preferable to remedial control, due to the structural damage that will inevitably occur prior to discovery and control of an active termite infestation. Prevention includes: 1) Proper architectural design, including the elimination of any wood-to-soil contact, avoidance of construction details that may trap water within the structure, and efforts to ensure that portions of the structure most prone to termite infestation can be readily inspected. 2) The use of termite-resistant building materials, such as preservative-treated or naturally-resistant timbers, or non-cellulosic building products. 3) Installation of either physical or chemical barriers beneath and around the perimeter of the structure to prevent penetration by foraging subterranean termites. 4) Possible installation of a network of bait/monitoring stations within or around the structure.

Termite-resistant building materials and physical barriers to termite penetration have gained in importance as a result of the discontinuance in most of the world of the long-lasting cyclodiene soil insecticides, and increasing environmental concerns over possible ill effects from applications of large quantities of liquid insecticides for termite control. In this paper, we review some of the current developments and trends in each of the above four areas, particularly with respect to control of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, in Hawaii. *Coptotermes formosanus* is an important pest in many tropical and subtropical regions of the world (Wang and Grace, 1999). This termite was introduced to Honolulu, in the late 1800s and is responsible for over US$ 100 million in costs of treatment and damage repairs each year in Hawaii (Tamashiro *et al.,* 1990).

Good architectural design

Good design practices involve (1) avoiding any contacts between wood and the soil, (2) keeping structural wood dry and controlling moisture conditions beneath and around the structure, and (3) ensuring that portions of the structure that are prone to insect attack can be readily inspected. (Amburgey, 1988; Yates *et al.,* 1997, 1999). Architectural strategies and details for controlling moisture have been described by Dost and Botsai (1990), Verkerk (1990) and the Wood Protection Council (1993).

Homes in Hawaii and other tropical areas used to consist of simple, uninsulated construction, in which one side of the wall was covered with wood siding, but the interior framing (or one side of an interior wall) was left exposed. This single-wall construction permitted ready inspection of the wall framing for signs of insect attack, and air movement around the framing served to inhibit termite activity. Modern construction techniques, however, require finished interior walls, or double-wall construction, in which the wooden framing is covered with wood paneling, plaster, or gypsum board. Subterranean termites frequently infiltrate these inaccessible wall voids and go unnoticed until severe damage to has occurred.

In order to facilitate inspection of these wall voids, a removable plastic (polyvinylchloride) baseboard (skirting) system has been developed and marketed successfully in Hawaii. This Snap-On Baseboard System (P.I.M. Development Inc., Kaneohe, HI) literally snaps onto the interior wall covering three inches above the floor with clips and can be easily removed for inspection purposes. The idea for this simple, yet practical, invention came from the inventor's personal experiences with termite damages in his home (Z. Watson, personal communication).

All too frequently, architects and builders incorporate design details on the basis of appearance and low cost without regard to without regard to the need to prevent termite attack on the structure. The reluctance of architects to include access panels in the walls adjacent to bathtub and other plumbing penetrations through the concrete foundation slabs, despite that fact that this is the generally the first point of access for subterranean termites, is one example of this problem. A second serious problems in Hawaii is the extensive use of hollow concrete masonry units (CMU, also known as hollow tiles, or concrete blocks) in retaining walls, perimeter building foundation walls, and as supports for pier posts below the structure. This is a simple and cost-effective construction technique. However, it is extremely difficult to completely fill the hollows within these prefabricated blocks with concrete without shrinkage cracks occurring that termite can penetrate. When these blocks are used as basement walls or as retaining walls in hillside construction, Formosan subterranean termites readily penetrate the mortar joints between the blocks, as well as tunneling through the center voids. Yet despite the extensive termite damages in Hawaii that have clearly resulted from the use of these hollow tiles, the construction industry has successfully blocked all attempts to eliminate installation of CMU below soil grade and to require the use of poured concrete foundations in such situations. This simple, but somewhat more costly from the contractors' point of view, change in construction practices would save numerous buildings from later termite attack. Rather than correct this poor design, various approaches have been developed to retrofit termite-resistant wire mesh, particle barriers, or other physical barriers to CMU walls in order to eliminate termite tunneling through these masonry units. Certainly, these methods are innovative and can provide protection, but they are also rather laborious and more costly to the consumer than the alternative of approving the initial structural design.

Durable building materials

The use of steel framing in residential building construction has increased in the Hawaiian islands and in the United States in general in the past several years. However, the higher cost of steel and the need for specialized installation procedures still limit its use. From an environmental standpoint, the energy costs associated with steel production certainly greatly exceed those associated with production of wood-based building materials.

With respect to residential construction using wood framing, Hawaii is fairly unique among the states in requiring the use of preservative-treated wood for all structural wood members throughout the structure. More typically in North America, where termites are not typically as serious a problem as in Hawaii, only the wood framing closest to the ground (such as the sill plate and the substructure wall framing) must be preservative treated. Naturally-resistant woods may be used in lieu of preservative treatment, but in Hawaii these woods must currently be approved on a case-by-case basis.

Douglas-fir, *Pseudotsuga menziesii* (Mirb.) Franco, imported from the western North America is the timber species most commonly used for construction in Hawaii. Unfortunately, the occluded pores in the heartwood of this species make it difficult to achieve adequate depth of penetration with waterborne preservatives such as the commonly-used chromated copper arsenate (CCA). Although CCA at retentions as low as 0.5 kg/m^2 has been shown to be effective at preventing all but minor termite grazing on more readily treated pine species (Grace, 1998), the thin outer shell of preservative-treated wood in a refractory species such as Douglas-fir is frequently not sufficient to prevent termites from penetrating and destroying the untreated interior wood (Wilcox, 1984).

Ammoniacal preservative formulations (e.g., ammoniacal copper zinc arsenate or ACZA) (Tamashiro *et al.,* 1988; Grace and Yamamoto, 1994a) and diffusible preservatives (e.g., disodium octaborate tetrahydrate or DOT) (Grace and Yamamoto, 1994b; Grace *et al.,* 1992, 1995; Tsunoda *et al.,* 1998) achieve greater penetration in Douglas-fir lumber, and thus can provide more consistent protection from termite attack. However, these preservatives also have their limitations. ACZA-treated lumber is unattractive in appearance due to its dark color and the use of incising, and DOT-treatments are leachable when exposed to rainfall and may require very different concentrations for different termite species (Su *et al.,* 1994). Clearly, at present the best approach to using preservative-treated wood in construction is a "prescription" approach, in different treatments are prescribed for different uses in the structure. However, promotion of such an approach will require a concerted educational effort, since contractors and architects view the logistics of specifying multiple types of wood treatment as impractical.

Naturally durable woods offer an alternative to preservative-treatments. For example, redwood (*Sequoia sempervirens*) heartwood has long been known to be more resistant to termite and decay than other softwoods commonly used in North American construction (Su and Tamashiro, 1986). Yellow cypress, also known as Alaska cedar (*Chamaecyparis nootkatensis*) heartwood was recently found to be more durable than redwood (Grace and Yamamoto, 1994). However, it is critical to note with these and other durable tree species that only the heartwood, and sometimes the bark (Delate and Grace, 1995, Grace, 1997), that contains extractives conveying durability. In comparison, the sapwood (outer wood) of almost all trees is completely susceptible to termite attack. Although yellow cypress heartwood is quite durable, recent laboratory tests demonstrated that the sapwood was readily attacked (J.K. Grace and A. Byrnes, unpublished). Thus, it is essential to specify heartwood lumber when purchasing durable woods, and to minimize any sapwood content in that lumber.

Declining sugar cane and pineapple cultivation in Hawaii have recently made fairly large blocks of land available for potential forestry use. *Eucalyptus* spp. have been of interest, since many are relatively fast-growing trees and useful both for lumber and engineered wood products. Unfortunately, the faster-growing species *E. deglupta* and *E. robusta* are lacking in termite resistance in comparison to the durability of the slower-growing *E. microcorys* (Grace *et al.,* 1996). On a small scale, however, *E. microcorys* may prove to be a valuable plantation species in Hawaii.

Recent studies of termite-resistant woods for plantation growth in Malaysia identified several feasible candidates, including *Azadirachta excelsa* (Sentang) (Grace *et al.,* 1999). This is a relative of the neem tree, *A. indica*, which is known for insecticidal activity and has termite-repellent compounds in its bark (Delate and Grace 1995). This Malaysian study, however, also illustrated the differential susceptibilities of two different *Coptotermes* species to some of these durable woods, and the variation in durability among trees harvested in different locations. Laotian and Burmese teak, for example were found to be much less susceptible to termite attack than samples of Malaysian teak (Grace and Yamamoto 1994; Grace *et al.,* 1999), possibly due to differences in extractive content among stands of different ages. Recently, the Indonesian hardwood *Shorea laevis* (Bangkirai) was also found to be extremely durable (J.K Grace and C.H.M. Tome, unpublished), but the durability of this same species from other parts of Southeast Asia still relies more on anecdote than documentation at this point.

One approach to deal with the individual and regional variability in extractive content found among naturally durable tree species is to identify the chemicals involved and possibly apply them as natural wood preservatives. However, despite academic demonstrations of the technical feasibility of this approach (Carter and de Camargo, 1983; Laks *et al.,* 1988) it has not yet proven commercially viable due to the complexity of the natural compounds and the associated costs. If the issue of cost could be overcome, other plant compounds (Cornelius *et al.,* 1997) and even termiticidal chemicals produced by other insects (Cornelius *et al.,* 1995) might also be viable natural preservatives.

Engineered wood products, from wafer board to oriented strand board (OSB), are attractive building materials from the point of view of efficient utilization of wood resources and the ability to design uniform and consistent products for specific end uses. However, incorporation of non-wood materials in such products does not, in and of itself, increase their durability and termite-resistance. Plastic/wood composite lumber may still be subject to fungal decay (Morris and Cooper, 1998), and even cement/wood composites will be "tasted" by Formosan subterranean termites (J.K. Grace, unpublished). In this latter case, however, termite feeding was limited to a few large embedded wood wafers to which they were able to obtain access from the edge of the composite board, and was negligible from a structural standpoint. Agricultural fibers are sometimes represented as termite-resistant, but various boards made from sugar cane fiber (bagasse) were readily attacked by termites (Grace, 1996, and unpublished).

Where engineered wood products offer an advantage over solid wood in terms of treatment to impart termite resistance is in the ability to either "pre-treat" the wood fibers prior to manufacturer, or to incorporate a preservative directly into the board. Zinc borate has been successfully incorporated into waferboard, and has been shown to perform better against termites than waferboards treated with the much more soluble sodium borate due to the greater leachability of the latter compound (Laks and Manning, 1995). Recently, a novel approach to using naturally durable woods in composite products was demonstrated by Morris *et al.* (1999), who found that western white spruce bark, essentially a waste product, could be used to manufacture composite boards with a high degree of both decay and termite resistance.

Barriers to subterranean termites

An elevated concrete building foundation alone, even when coupled with a naturally durable wood post or sill plate upon it, does constitute an effective barrier to termite attack on the structure. In a study replicating Japanese building construction, *C. formosanus* was observed tunneling over concrete post supports, and over and through both Japanese cypress (*Chamaecyparis obtusa*) and Hiba arborvitae (*Thujopsis dolabrata*) floor posts to reach the susceptible wood above (Grace, 1999b). The exception to this rule would be an uncracked concrete slab foundation, or one in which no cracks exceeded the smallest width of the termites' bodies. Lenz *et al.* (1997) reported that the Australian termite *Coptotermes acinaciformis* could penetrate cracks as small as 1.5 mm in width, and Ewart *et al.* (1991) found that mature workers of *C. formosanus* could penetrate circular holes as small as 1.4 mm in diameter. Thus, in order to function as a physical barrier to termites, a concrete slab must be uncracked and not subject to degradation by the termites, and any planned cracks (cold joints) or plumbing penetrations through the slab must be protected by additional physical or insecticidal barrier treatments.

Soil insecticide applications represent the most widely accepted method of creating a barrier to termite penetration. Even under tropical environmental conditions, where heat and moisture promote insecticide degradation, the cyclodiene soil insecticides, such as chlordane and aldrin, could provide over 25 years of structural protection (Grace *et al.,* 1993b). However, these materials are no longer available for use by the pest control industry in most parts of the world, and their replacements require more frequent reapplication. Despite the standing requirement for registration of termiticides by the United States Environmental Protection Agency (EPA) that they demonstrate 5 years of efficacy, none of the currently available formulations are able to consistently achieve this in Hawaii (Grace *et al.,* 1993a, and unpublished).

Two interesting recent trends are apparent in the development and marketing of soil termiticides (Grace, 1999a). The first is the application of smaller amounts (greater dilutions) of more biologically active pyrethroid insecticides. Cost, as well as environmental concerns, is also a contributing factor in this trend, since the newer insecticides tend to be more expensive to produce than first-generation insecticides. There is danger in this trend as well, since smaller quantities of insecticide can generally be expected to degrade more rapidly than greater concentrations, down to levels that will no longer prevent termite penetration. For this reason, termite researchers commonly recommend that soil insecticides always be applied at the highest label rate. Undoubtedly, the fact that chlordane and aldrin were applied at relatively high rates (1% or greater solutions), as well as the stability of these molecules in the environment, contributed to their successful use. With increasing chemical costs and environmental concerns, we no longer have as large a safety factor in termite control, and retreatments will have to occur at shorter intervals.

Along with the trend towards use of smaller quantities of more biologically active pyrethroid insecticides, which are quite repellent to termites, has come a second, and almost opposite, trend towards the use of non-repellent and slow-acting compounds. The use of slow-acting compounds as termiticides, which create a treatment "zone" (in the words of one manufacturer) but not necessarily a "barrier," is a significantly different approach to termite control. These insecticides are not necessarily chemically similar, but share the common characteristic that they do not repel or rapidly kill approaching termites, but rather act to disorient them and slowly kill them as they tunnel into and through the treated soil. It is still not clear whether these types of termiticides protect the structure by killing a sufficient number of termites in the vicinity of the treated zone that the area essentially becomes repellent to other termites, or actually kill so many termites that the colony is either reduced to a very low level or dies out altogether.

Physical barriers to termites offer an alternative to chemical barriers with the promise of more permanent efficacy, barring installation errors or damage to the barrier from construction activities, earth movement, etc. Although the concept of particle barriers was pioneered by Ebeling and Pence (1957), it was brought to fruition by the commercial development of the Basaltic Termite Barrier (Ameron Hawaii, Honolulu) in Hawaii (Tamashiro *et al.,* 1987, 1991), and was extended internationally by development of the similar gravel product Granitgard (Granitgard Pty. Ltd., Victoria) in Australia. Both of these are crushed rock (gravel), screened to a specific size that prevents subterranean termite penetration. The gravel particles are too large for the insects to grip in their mandibles and move, but pack too tightly together for them to tunnel between the particles. In Hawaii, the Basaltic Termite Barrier was adopted into the Uniform Building Code of the City and County of Honolulu in 1989 as an alternative to preconstruction chemical soil treatments.

As listed by Yates *et al.* (1999), many other researchers have since made significant contributions to the development of particle barriers from different materials or sized to accommodate different termite species. However, despite interest in using particle barriers in many regions, there are three limitations that have still not been overcome: (1) only very hard rock or sand is appropriate and this is not found in all regions, (2) the costs of shipping gravel or sand from one area to another are very high, and (3) the correct size of particles must be determined for each individual termite species, and (4) no method has yet been developed to use gravel barriers in areas where more than one subterranean termite species is a problem and each requires a different particle size, although efforts to develop such a method in Australia are reportedly advanced and quite promising (D.M. Ewart, personal communication). In addition, installation can be difficult. Unstable or not fully compacted soil, rough or irregular surfaces at the edges of the particle barrier, and protection from contamination or mixing with adjacent soil, sand, etc., are issues that must be addressed

In large part, research and extension needs with particle barriers have moved beyond entomological concerns into the realms of architecture and engineering. In both Hawaii and Australia, the respective manufacturers of these products have made available architectural drawings and design details to ensure correct installation of the barriers, and Yates *et al.* (1999) have described problems with and solutions to installation of the Basaltic Termite Barrier that may serve as a guide architects, builders, and building officials in other regions as well.

Another approach to physical barriers has been the development and successful commercialization of a stainless steel mesh, Termi-Mesh (Termi-Mesh Australia Pty. Ltd.). This is a marine grade 316 stainless steel mesh with an aperture size of 0.66 mm by 0.45 mm, and is effective in excluding both *C. formosanus* (Grace *et al.,* 1996a) and *Coptotermes acinaciformis* (Froggatt) (Lenz and Runko, 1994). Two one-year field tests were performed with this product in Hawaii, with results indicating that termites cannot penetrate the mesh but that care must be taken in installation to prevent them from circumventing the barrier (Grace *et al.,* 1996a, and unpublished). In one of 10 experimental units in each of these field tests, a corner of the mesh that had been sealed to pre-formed concrete block (hollow tile, or concrete masonry units) pealed away slightly from the porous concrete. In one case, termites were able to enter the test unit through this separation crack, and in the second case they were not able to do so within the duration of the field test. Although these small-scale concrete block test units are certainly not fully representative of true construction conditions, these results do indicate that great care must be taken to seal the edges of the wire mesh, if it is not embedded directly into the concrete. The manufacturer addresses this issue by training and licensing only specific contractors to install Termi-Mesh, and by offering a performance warranty. In 1995, the Termi-Mesh system was accepted into Hawaii's Uniform Building Codes as a stand alone pretreatment for new construction.

Termite baits and monitoring systems

Installation of bait/monitoring stations as part of termite resistant construction is a controversial concept. In Hawaii (Grace *et al.,* 1996b; Yates *et al.,* 1999) and elsewhere, termite baits (particularly the Sentricon System, DowAgrosciences, with which we currently have the most experience) have proven to be an effective method of remedial control, particularly for the Formosan subterranean termite. However, installation of monitoring stations, or actual baits, as a preventative measure in new construction is more questionable, since the possibility always exists that foraging termites will not intercept the bait or station as they tunnel towards the structure. Certainly, the safest approach, given the costly damages that might otherwise occur, is to employ all available technologies: proper design, durable building materials, a chemical or physical barrier, and baits. In reconstruction of historic buildings in New Orleans, Louisiana, for example, placement of "permanent" bait / monitoring stations at various locations in the concrete floor was one part of the repair efforts.

Good architectural design and the use of termite-resistant building materials should never be compromised. In addition to prevention of subterranean termite damage, these elements of good construction help to prevent both drywood termite infestation and fungal decay. However, the risks in installing bait/monitoring stations in place of chemical or physical barrier may be more appropriately considered on a case-by-case basis. The difficulty of obtaining thorough coverage with soil insecticides, and their relatively limited lifetime under tropical conditions are leading an increasing number of builders and homeowners in Hawaii to consider this alternative.

It is essential, though, that monitoring stations not simply be placed in the soil and forgotten. The only protection for the structure lies in a rigorous inspection program, not only of the stations themselves, but also of the yard and structure for any evidence of termite activity. Periodic replacement and placement of additional monitoring stations around the structure will also increase monitoring capabilities and help to avoid carelessness on the part of the inspectors due to the routine nature of the monitoring activity, as well as mitigating any problems of station contamination from homeowner applications of insecticides for house or yard insect control (ants, fleas, plant pests, etc.). Basically, if baits and monitoring stations are to be used for preventative purposes, which does not appear unreasonable, than the risks must be compensated for by an aggressive inspection and maintenance program.

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REFERENCES CITED

Amburgey, T.L. 1988. Wood inhabiting fungi. A new look at wood protection: a collection of presentations from the Wood Protection Council's Conference, Arlington Virginia, 11-13 October 1988. National Institute of Building Sciences, Washington, D.C. Pp. 71-75.

Dost, W.A., and E.E. Botsai. 1990. Wood: detailing for performance. GRDA Publications, Mill Valley, Calif.

Carter, F.L., and C.R.R. de Camargo. 1983. Testing antitermitic properties of Brazilian woods and their extracts. Wood and Fiber Science 15: 350-357.

Cornelius, M.L., J.K. Grace, P.W. Ford, B.S. and Davidson. 1995. Toxicity and repellency of semiochemicals extracted from a dolichoderine ant (Hymenoptera: Formicidae) to the Formosan subterranean termite (Isoptera: Rhinotermitidae). Environmental Entomology 24: 1263-1269.

Cornelius, M.L., J.K. Grace, and J.R. Yates . 1997. Toxicity of monoterpenoids and other natural products to the Formosan subterranean termite. Journal of Economic Entomology 90: 320-325.

Ebeling, W. and R.J. Pence. 1957. Relation of particle size to the penetration of subterranean termites through barriers of sand or cinders. Journal of Economic Entomology 50: 690-692.

Ewart, D.M., M. Tamashiro, J.K. Grace, and R.H. Ebesu. 1991. Minimum foraging aperture and particle barriers for excluding the Formosan subterranean termite. Unpublished poster presentation, Annual Meeting of the Entomological Society of America, Reno, Nevada, USA.

Grace, J.K. 1996. Susceptibility of compressed bagasse fiber to termite attack. Forest Products Journal 46(9): 76-78.

Grace, J.K. 1997. Influence of tree extractives on foraging preferences of the termite *Reticulitermes flavipes* (Isoptera: Rhinotermitidae). Sociobiology 30: 35-42.

Grace, J.K. 1997. Review of recent research on the use of borates for termite prevention. Proceedings of the 2nd International Conference on Wood Protection With Diffusible Preservatives and Pesticides. Forest Products Society, Madison, WI. Pp. 85-92.

Grace, J.K. 1998. Resistance of pine treated with chromated copper arsenate to the Formosan subterranean termite. Forest Products Journal 48(3): 79-82

Grace, J.K. 1999a. Recent trends in termiticides in the USA. Shiroari 115: 13-17 (in Japanese).

Grace, J.K. 1999b. Termite penetration of construction elements. Shiroari 115: 18-23 (in Japanese).

Grace, J.K. and R.T. Yamamoto. 1993. Diatomaceous earth is not a barrier to Formosan subterranean termites. Sociobiology 23: 25-30.

Grace, J.K. and R.T. Yamamoto. 1994a. Natural resistance of Alaska-cedar, redwood, and teak to Formosan subterranean termites. Forest Products Journal 44(3): 41-45.

Grace, J.K., and R.T. Yamamoto. 1994b. Repeated exposure of borate-treated Douglas-fir lumber to Formosan subterranean termites in an accelerated field test. Forest Products Journal 44(1): 65-67.

Grace, J.K., D.M. Ewart, and C.H.M. Tome. 1996. Termite resistance of wood species grown in Hawaii. Forest Products Journal 46(10): 57-60.

Grace, J.K., C.H.M. Tome, T.G. Shelton, R.J. Oshiro, and J.R. Yates III. 1996. Baiting studies and considerations with *Coptotermes formosanus* (Isoptera: Rhinotermitidae) in Hawaii. Sociobiology 28: 511-520.

Grace, J.K., K. Tsunoda, T. Byrne, and P.I. Morris. 1995. Field evaluation of borate-treated lumber under conditions of high termite hazard. Wood Preservation in the '90s and Beyond. Forest Products Society Proceedings No. 7308. Pp. 240.

Grace, J.K., A.H.H. Wong, and C.H.M. Tome. 1999. Termite resistance of Malaysian and exotic woods with potential for plantation growth. Forest Products Journal. In press.

Grace, J.K., R.T. Yamamoto, and M. Tamashiro. 1992. Resistance of borate treated Douglas-fir to the Formosan subterranean termite. Forest Products Journal 42(2): 61-65.

Grace, J.K., J.R. Yates, and M. Tamashiro. 1993a. Testing soil insecticides in paradise. Pest Control 61(7): 60-61.

Grace, J.K., J.R. Yates, M. Tamashiro, and R.T. Yamamoto. 1993b. Persistence of organochlorine insecticides for Formosan subterranean termite (Isoptera: Rhinotermitidae) control in Hawaii. Journal of Economic Entomology 86: 761-766.

Grace, J.K., J.R. Yates III, C.H.M. Tome, and R.J. Oshiro. 1996. Termite-resistant construction: use of a stainless steel mesh to exclude *Coptotermes formosanus* (Isoptera: Rhinotermitidae). Sociobiology 28: 365-372.

Laks, P.E. and M.J. Manning. 1995. Preservation of wood composites with zinc borate. International Research Group on Wood Preservation. Stockholm, Sweden. Document No. IRG/WP/95-30074. 12 pp.

Laks, P.E., L.J. Putnam, and M.S. Pruner. 1988. Natural products in wood preservation. Proceedings of the Canadian Wood Preservation Association 9: 105-123.

Lenz, M., and S. Runko. 1994. Protection of buildings, other structures and materials in ground contact from attack by subterranean termites (Isoptera) with a physical barrier - a fine mesh of high grade stainless steel. Sociobiology 24: 1-16.

Lenz, M., B. Schafer, S. Runko, and L. Glossop. 1997. The concrete slab as part of a termite barrier system: response of Australian subterranean termites to cracks of different width in concrete. Sociobiology 30: 103-118.

Morris, P.I. and P. Cooper. 1998. Recycled plastic/wood composite lumber attacked by fungi. Forest Products Journal 48(1): 86-88.

Morris, P.I., J.K. Grace, and G.E. Troughton. 1999. Preliminary indications of the natural durability of spruce bark board. International Research Group on Wood Preservation. Stockholm, Sweden. In Press.

Su, N.-Y., M. Tokoro, and R.H. Scheffrahn. 1994. Estimating oral toxicity of slow-acting toxicants against subterranean termites (Isoptera: Rhinotermitidae). Journal of Economic Entomology 87: 398-401.

Tamashiro, M., J.R. Yates, and R.H. Ebesu. 1987. The Formosan termite: Hawaii's most damaging insect. Hawaii Architect 16(12):12-14, 40.

Tamashiro, M., J.R. Yates, R.T. Yamamoto, and R.H. Ebesu. 1991. Tunneling behavior of the Formosan subterranean termite and basalt barriers. Sociobiology 19: 163-170.

Tsunoda, K., A. Adachi, T. Yoshimura, T. Byrne, P.I. Morris, and J.K. Grace. 1998. Resistance of borate-treated lumber to subterranean termites in the field. International Research Group on Wood Preservation, Stockholm, Sweden. IRG Document No. IRG/WP 98-10255. 5 pp.

Verkerk, R. 1990. Building out termites. Pluto Press Australia Ltd., Leichhardt, New South Wales.

Wang, J., and J.K. Grace, J.K. 1999. Current status of *Coptotermes wasmann* (Isoptera: Rhinotermitidae) in China, Japan, Australia and the American Pacific. Sociobiology 33: 295-305.

Wilcox, W.W. 1984. Observations on structural use of treated wood in Hawaii. Forest Products Journal 34: 39-42.

Wood Protection Council. 1993. Wood protection guidelines: protecting wood from decay fungi and termites. National Institute of Building Sciences, Washington, D.C.

Yates, J.R. III, J.K. Grace, and J.N. Reinhardt. 1999. Installation guidelines for the Basaltic Termite Barrier: a particle barrier to Formosan subterranean termites. Sociobiology. In press.

Yates, J.R. III, J.K. Grace, and M. Tamashiro. 1997. The Formosan subterranean termite: a review of new management methods in Hawaii. Proceedings of 1997 FAOPMA Convention (J. Chan, ed.). Hong Kong Pest Control Association. Pp. 59-68.

Yates, J.R. III, J.K. Grace, and M. Tamashiro. 1999. New technology for managing the Formosan subterranean termite. Household & Structural Pests No. 3. College of Tropical Agric. & Human Resources, Univ. of Hawaii at Manoa. 4 pp.