

# Uniform Size Particle Barrier: A Physical Exclusion Device Against Subterranean Termites (Isoptera: Rhinotermitidae)

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**ABSTRACT** Workers of the Formosan subterranean termite, *Coptotermes formosanus* Shiraki, and the eastern subterranean termite, *Reticulitermes flavipes* (Kollar), were tested for their abilities to penetrate barriers of ground coral particles 5 cm thick. Each barrier was composed of one of 13 particle sizes, ranging from 0.5 to 4.0 mm in diameter. *C. formosanus* penetrated the least through particles of 1.70-2.36 mm in size, and a wider size range of particles (1.00-2.36 mm) excluded penetration by *R. flavipes*. When several size ranges were uniformly mixed, the resultant barriers composed of particles in the 1.18-2.80 mm size range effectively prevented penetration by both termite species.

**KEY WORDS** Insecta, physical barrier, subterranean termite, preventative control

OVER ONE BILLION DOLLARS is spent annually to protect homes and repair damage from subterranean termites in the United States (Mauldin 1986). Current soil termiticide applications provide chemical barriers beneath structures to prevent invasion of soil-borne termites. Control is achieved when termites are killed by organophosphates or repelled by pyrethroids (Su et al. 1982). The purpose of this type of control is to exclude termites from structures.

Other studies have shown that similar results may be achieved by means other than chemicals. Ebeling & Pence (1957) first suggested an alternative control method when they discovered that sand particles ranging in size from 10 to 16 mesh (equivalent to particles 1.2-1.7 mm in diameter) were not penetrated by the western subterranean termite (*Reticulitermes hesperus* Banks) in a laboratory test. Their observation indicated that the particles were too large for termites to displace with their mandibles, yet were small enough so that termites could not maneuver between them. This physical control technique failed to attract attention during the 1950s because of the availability of inexpensive and effective soil termiticides such as chlordane and heptachlor.

During a routine termiticide evaluation, Tamashiro et al. (1987) rediscovered the finding of Ebeling & Pence (1957). Their results showed that the Formosan subterranean termite (*Coptotermes formosanus* Shiraki) did not penetrate sand barriers composed of particles 1.7-2.4 mm in diameter. A field study in Hawaii demonstrated that sand barriers of specified sizes that were used beneath structure foundations effectively prevented invasion by *C. formosanus* (Tamashiro et al. 1987).

Apparently, an effective particle size is dependent on the mandible and head capsule dimensions

of the target termite species. Three economically important subterranean termite species exist in Florida. These are the eastern subterranean termite, *Reticulitermes flavipes* (Kollar); the dark southern subterranean termite, *R. virginicus* (Banks); and the Formosan subterranean termite (Scheffrahn et al. 1988). Although the two *Reticulitermes* species are fairly similar in size, *C. formosanus* is generally larger than *Reticulitermes* species. Uniform size particle barriers that successfully prevent *C. formosanus* invasion may prove ineffective against *Reticulitermes* species.

The objectives of our study were to obtain the morphological measurements of *C. formosanus* and *R. flavipes*, to determine the sand particle size range required to prevent invasion by these two termite species, and to examine the relationship between body measurements of termites and their ability to penetrate barriers of various particle sizes. We also evaluated efficacy of mixed size barriers against both termite species.

## Materials and Methods

**Morphological Measurement.** Foragers of *C. formosanus* and *R. flavipes* were collected from field colonies using the method of Su & Scheffrahn (1986). Mean body weight of workers was determined for each colony and species by weighing five groups of 10 termites each. Twenty workers were selected at random from each colony/species combination and placed in 85% ethanol. The ethanol specimens were measured under a microscope (30×) to obtain means of body length (from mandible tip to the end of abdomen), abdomen width (the widest tergite), head length (from the tip of mandible to vertex), head width (maximum width),

**Table 1. Morphological measurements of worker termites collected from four colonies each of the Formosan subterranean termite (*C. formosanus*) and the eastern subterranean termite (*R. flavipes*)**

Colony	Mean $\pm$ SE <sup>a</sup>					
	Body wt (mg)	Body length (mm)	Abdomen width (mm)	Head length (mm)	Head width (mm)	Mandible length (mm)
<i>C. formosanus</i>						
2G	2.80 $\pm$ 0.08	3.89 $\pm$ 0.23	1.32 $\pm$ 0.08	1.44 $\pm$ 0.08	1.21 $\pm$ 0.08	0.42 $\pm$ 0.03
3G	3.05 $\pm$ 0.16	4.17 $\pm$ 0.25	1.28 $\pm$ 0.07	1.32 $\pm$ 0.30	1.17 $\pm$ 0.11	0.42 $\pm$ 0.04
HM	4.80 $\pm$ 0.03	4.61 $\pm$ 0.19	1.47 $\pm$ 0.11	1.59 $\pm$ 0.08	1.32 $\pm$ 0.08	0.49 $\pm$ 0.04
PS	5.40 $\pm$ 0.40	5.75 $\pm$ 0.68	1.69 $\pm$ 0.14	1.67 $\pm$ 0.09	1.44 $\pm$ 0.09	0.50 $\pm$ 0.08
Mean	4.01 $\pm$ 1.28	4.61 $\pm$ 0.82	1.44 $\pm$ 0.19	1.51 $\pm$ 0.16	1.29 $\pm$ 0.12	0.46 $\pm$ 0.04
<i>R. flavipes</i>						
DT	1.72 $\pm$ 0.04	3.39 $\pm$ 0.18	1.09 $\pm$ 0.10	1.16 $\pm$ 0.07	0.97 $\pm$ 0.03	0.34 $\pm$ 0.05
ET	1.93 $\pm$ 0.06	3.33 $\pm$ 0.19	1.10 $\pm$ 0.04	1.17 $\pm$ 0.11	1.02 $\pm$ 0.08	0.38 $\pm$ 0.04
AM	1.94 $\pm$ 0.04	3.44 $\pm$ 0.19	1.02 $\pm$ 0.04	1.13 $\pm$ 0.04	0.95 $\pm$ 0.04	0.34 $\pm$ 0.03
SW	1.99 $\pm$ 0.06	4.01 $\pm$ 0.30	1.25 $\pm$ 0.08	1.36 $\pm$ 0.08	1.17 $\pm$ 0.08	0.42 $\pm$ 0.04
Mean	1.90 $\pm$ 0.12	3.54 $\pm$ 0.31	1.11 $\pm$ 0.10	1.21 $\pm$ 0.10	1.03 $\pm$ 0.10	0.37 $\pm$ 0.04

<sup>a</sup> Body weights are means of five groups of 10 termites each; the other figures are means of 20 individuals.

and mandible length (separated from head; apical tooth to articulation).

**Particle Size Evaluation.** Sand and gravel of fossilized coral were obtained from garden suppliers. The gravel was sifted through a series of 13 sieves (corresponding to the Tyler screen scale of 5, 6, 7, 8, 9, 10, 12, 14, 16, 20, 24, 28, and 32 mesh) to obtain groups of uniform particle sizes. Thirteen sizes of particles ranging from 0.5 to 4.0 mm, and 12 sizes from 0.5 to 2.5 mm (excluding those larger than 5 mesh) in diameter were used for tests with *C. formosanus* and *R. flavipes*, respectively.

Barrier efficacy was evaluated in glass tube devices similar to those described by Su & Scheffrahn (1990). The glass tubes (1.3 cm I.D. by 15 cm high) contained 5-cm segments of moistened particles sandwiched between two sectors of 7% agar (one measuring 1 cm, the other 3 cm). Two wooden applicators and a piece of paper (1 by 5 cm) were placed into a 5-cm void outside the 3-cm sector of agar. The particles were tightly packed before use. Eighty termites (plus 5 soldiers for *C. formosanus* and 1 soldier for *R. flavipes*) were introduced into the 3-cm void at one end of the tube. Several pieces of paper were placed in the remaining 1-cm void at the opposite end. Both ends were closed with metal fixture caps.

The tubes were mounted vertically, with the void containing termites situated at the bottom. The experimental units were held at  $28 \pm 1^\circ\text{C}$ . Observations were made daily for up to 1 wk. Vertical distances of tunnels excavated by termites were recorded.

Termites collected from four colonies were tested for each species. The test was replicated three times for each species/colony combination. Particle size was the factor for evaluation. The maximum vertical distance penetrated was subjected to analysis of variance. Differences of distance among particle sizes were analyzed for each colony by a completely randomized design; those for each species were analyzed using a completely randomized

block design with colony origin as the blocking factor (SAS Institute 1987). Significant differences of penetration distance among particle size barriers were separated by Student-Newman-Keuls test at  $\alpha = 0.05$  (SAS Institute 1987). A regression analysis (polynomial) was used to estimate the relationship between particle size and distance penetrated by each termite species (SAS Institute 1987). Because the exact size of each soil particle used for the testing is unknown, the mean value of the sifted size range of each group was used as the independent variable and penetration distance was used as the dependent variable for the polynomial regression.

**Mixed Size Barrier.** Based on the results from the previous experiment, two mixed particle size ranges, 1.18–2.80 and 1.70–2.36 mm in diameter, were selected for evaluation against both termite species. The same procedures described above were used except that particles were sifted between the 7 and 14 mesh screens (resulting in particle sizes 1.18–2.80 mm in diameter), or the 8 and 10 mesh screens (1.70–2.36 mm). Tests were repeated three times for four colonies each of *C. formosanus* and *R. flavipes*. Results were compared with those of four uniform sizes within this size range, 1.18–2.36 mm (7–8 mesh, 8–9 mesh, 9–10 mesh, and 12–14 mesh). The maximum vertical distances penetrated by termites within a week of the experiment were subjected to the analysis of variance for each termite species using a completely randomized block design. Colony origin was used as the blocking factor. Significant differences among these six treatments were separated by Student-Newman-Keuls test at  $\alpha = 0.05$  (SAS Institute 1987).

## Results and Discussion

**Morphological Measurement.** Workers of *C. formosanus* were larger than *R. flavipes* (Table 1). Measurements of *C. formosanus* workers by Oshima (1919) were 4.50 mm in body length and 1.15

**Table 2.** Distance (cm) through uniform size particle barriers tunneled by *C. formosanus* and *R. flavipes* during a 1-wk period<sup>a</sup>

Particle size (mm)	Tyler screen scale (mesh)	Colony				Species mean
		2G	3G	HM	PS	
<i>C. formosanus</i>						
0.50–0.60	28–32	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
0.60–0.71	24–28	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
0.71–0.85	20–24	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
0.85–1.00	16–20	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
1.00–1.18	14–16	5.0 ± 0.0a	2.3 ± 0.3bc	5.0 ± 0.0a	5.0 ± 0.0a	4.3 ± 0.4ab
1.18–1.40	12–14	1.5 ± 0.3b	1.2 ± 0.4cd	1.5 ± 0.4b	1.7 ± 0.5b	1.5 ± 0.2cd
1.40–1.70	10–12	0.4 ± 0.1c	0.1 ± 0.1d	1.5 ± 0.3b	1.3 ± 0.4bc	0.8 ± 0.2de
1.70–2.00	9–10	0.2 ± 0.1c	0.5 ± 0.0cd	0.6 ± 0.1c	0.8 ± 0.2c	0.6 ± 0.1e
2.00–2.36	8–9	0.1 ± 0.1c	0.3 ± 0.2cd	0.4 ± 0.1c	0.6 ± 0.1c	0.4 ± 0.1e
2.36–2.80	7–8	0.5 ± 0.0c	1.0 ± 0.0cd	0.5 ± 0.1c	0.8 ± 0.2c	0.7 ± 0.1de
2.80–3.35	6–7	2.3 ± 0.8d	3.7 ± 1.3ab	0.9 ± 0.3c	1.0 ± 0.1bc	2.0 ± 0.5c
3.35–4.00	5–6	5.0 ± 0.0a	3.8 ± 1.2ab	5.0 ± 0.0a	1.0 ± 0.0bc	3.7 ± 0.6b
>4.00	<5	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
<i>R. flavipes</i>						
0.50–0.60	28–32	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a
0.60–0.71	24–28	4.7 ± 0.3a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	4.9 ± 0.1a
0.71–0.85	20–24	4.3 ± 0.7a	4.4 ± 0.6a	5.0 ± 0.0a	0.7 ± 0.3b	3.6 ± 0.5b
0.85–1.00	16–20	0.3 ± 0.2b	3.7 ± 1.3a	2.0 ± 1.0b	0.2 ± 0.1b	1.6 ± 0.6c
1.00–1.18	14–16	0.0 ± 0.0b	0.5 ± 0.3b	1.0 ± 0.3bc	0.1 ± 0.1b	0.4 ± 0.2d
1.18–1.40	12–14	0.0 ± 0.0b	0.1 ± 0.1b	0.1 ± 0.1c	0.0 ± 0.0b	0.0 ± 0.0d
1.40–1.70	10–12	0.1 ± 0.1b	0.0 ± 0.0b	0.1 ± 0.1c	0.2 ± 0.1b	0.1 ± 0.0d
1.70–2.00	9–10	0.1 ± 0.1b	0.3 ± 0.2b	0.2 ± 0.0c	0.5 ± 0.0b	0.3 ± 0.1d
2.00–2.36	8–9	0.8 ± 0.1b	0.5 ± 0.1b	0.4 ± 0.1c	0.7 ± 0.2b	0.6 ± 0.1de
2.36–2.80	7–8	1.2 ± 0.1b	1.3 ± 0.3b	1.0 ± 0.3bc	1.5 ± 0.3c	1.3 ± 0.1ce
2.80–3.35	6–7	2.0 ± 0.6c	4.5 ± 0.5a	2.2 ± 0.2b	2.3 ± 0.3d	2.8 ± 0.4f
3.35–4.00	5–6	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a	5.0 ± 0.0a

<sup>a</sup> Figures are means of three replicates for each colony, and 12 replicates for each species. Means followed by the same letter within a column are not significantly different ( $\alpha = 0.05$ ; Student–Newman–Keuls test [SAS Institute 1987]).

mm in head width. Our data ( $\bar{x} \pm SE$ ; body length, 4.61 ± 0.82 mm; head width, 1.29 ± 0.12 mm) agree fairly well with Oshima's (1919) original description. *C. formosanus* in Florida showed a wide range of body size. Larger individuals such as those collected from the PS colony were nearly twice the body weight of those collected from the 2G colony (5.40 versus 2.80 mg). *R. flavipes* workers were smaller and their body size was generally more uniform than *C. formosanus*.

**Particle Size Evaluation.** All of the workers of *C. formosanus* penetrated the entire 5 cm of barriers composed of the largest particle size, >4 mm in diameter (Table 2). Intercolonial variation in the ability of termites to penetrate the substrate was evident even within the same species (Table 2). The largest workers tested (colony PS) were also the most vigorous; only particles 2.00–2.36 mm in diameter stopped them from penetrating more than 0.6 cm. Gaps formed between particles of the second largest size (3.35–4.00 mm) were apparently too small for passage of the heads of PS workers (head 1.44 mm diameter).

One replicate of colony 3G advanced only 1.5 cm into the barrier of particle size range 3.35–4.00 mm, resulting in a smaller mean penetration distance. The lower vigor of this replicate may have been due to the inadvertent mishandling. Because mandibles of HM and PS were larger than those

workers from 2G and 3G (0.49–0.50 mm versus 0.42 mm), HM and PS workers were more capable of manipulating particles with diameters of 1.40–1.70 mm and penetrated deeper than workers of the 2G and 3G colonies (Table 2). Head widths of 2G and 3G workers, on the other hand, were smaller than those of HM and PS (Table 1). These smaller head widths of the 2G and 3G *C. formosanus* workers penetrated deeper into barriers of the third largest size (2.80–3.35 mm diameters) than their larger HM and PS counterparts (Table 2). Barriers composed of 1.70–2.80 mm (7–10 mesh) particles were most effective in preventing penetration by *C. formosanus*; these results agree with those of Tamashiro et al. (1987) for this termite species in Hawaii.

As expected from their smaller body size, *R. flavipes* were stopped by barriers with particle sizes smaller and equal to those effective against *C. formosanus*. Because of their relatively uniform body size, intercolonial variation in penetration ability for *R. flavipes* was less profound than for *C. formosanus*. Barriers consisting of 1.00–2.36 mm diameter particles (8–14 mesh) significantly reduced penetration of all four colonies of *R. flavipes* tested (Table 2). Our results coincide with effective particle sizes for the western subterranean termite, *R. hesperus* (1.2–1.7 mm) as reported by Ebeling & Pence (1957). Smith & Rust (1990) reported that

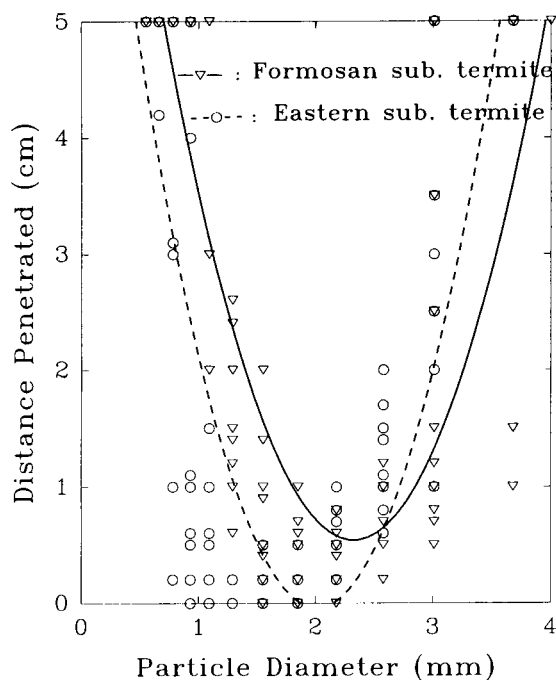


Fig. 1. Relationship between particle diameter (mm) and penetration distance through sand barriers by the Formosan subterranean termite (—▽—) and the eastern subterranean termite (---○---). Polynomial regression models were  $y = 1.69x^2 - 7.85x + 9.68$  ( $R^2 = 0.87$ ) for solid line, and  $y = 2.09x^2 - 8.43x + 8.45$  ( $R^2 = 0.84$ ) for broken line;  $y$ , distance (cm) penetrated;  $x$ , particle diameter (mm).

*R. hesperus* did not penetrate particles 0.85–2.36 mm in diameter (8–20 mesh). Our results also showed *R. flavipes* failed to penetrate barriers with 1.00–2.36 mm diameter particles (8–16 mesh), but advanced approximately 1.6 cm into the 0.85–1.00 mm particle (16–20 mesh) size barrier (Table 2).

The polynomial models describing termites' ability to penetrate the barriers in relation to the particle size were  $y = 1.69x^2 - 7.85x + 9.68$  ( $R^2 = 0.87$ ) and  $y = 2.09x^2 - 8.43x + 8.45$  ( $R^2 = 0.84$ ), for *C. formosanus* and *R. flavipes*, respectively (Fig. 1;  $x$ , particle diameter [mm];  $y$ , distance penetrated [cm]). According to the model derived for *C. formosanus*, a barrier composed of a single particle size of 2.32 mm diameter would allow the least penetration (0.57 cm). This agrees fairly well with the empirical data in Table 2 ( $0.4 \pm 0.1$  cm penetration at particle sizes of 2.00–2.36 mm). The polynomial model for *R. flavipes* indicates that particle sizes in the 1.92–2.12 mm diameter range would totally prevent penetration by *R. flavipes*. This prediction did not fully agree with the empirical data of no penetration at a particle size range of 1.18–1.40 mm (Table 2). The size ranges predicted by the models, however, generally fell into the size ranges that allowed significantly lower penetrations (1.00–2.36 mm) than other particle sizes (Table 2).

Table 3. Distance (cm) penetrated by *C. formosanus* and *R. flavipes* through particle barriers consisting of single size or mixed size particles

Barrier type	Particle size (mm)	Tyler screen scale (mesh)	Distance ( $\bar{x} \pm SE$ ) <sup>a</sup> (cm)	
			<i>C. formosanus</i>	<i>R. flavipes</i>
Uniform size	1.18–1.40	12–14	1.5 $\pm$ 0.2a	0.0 $\pm$ 0.0a
	1.70–2.00	9–10	0.6 $\pm$ 0.1b	0.3 $\pm$ 0.1ab
	2.00–2.36	8–9	0.4 $\pm$ 0.1b	0.6 $\pm$ 0.1b
	2.36–2.80	7–8	0.7 $\pm$ 0.1b	1.3 $\pm$ 0.1c
Mixed size	1.18–2.80	7–14	0.7 $\pm$ 0.1b	0.4 $\pm$ 0.1b
	1.70–2.36	8–10	0.3 $\pm$ 0.0b	0.3 $\pm$ 0.1ab

<sup>a</sup> Figures are means of 12 replicates (three replicates each for four colonies). Means followed by the same letter within a column are not significantly different ( $\alpha = 0.05$ ; Student–Newman–Keuls test [SAS Institute 1987]).

**Mixed Size Barrier.** Both particle sizes of 1.70–2.00 and 2.00–2.36 mm diameter (9–10 mesh and 8–9 mesh) provided effective barriers for penetration by both termite species (Table 2). As expected, when these two sizes were sifted together, the mixed size barriers of 1.70–2.36 mm (8–10 mesh) also effectively stopped advances by both *C. formosanus* and *R. flavipes* (Table 3). *C. formosanus* penetrated approximately 1.5 cm into barriers of particles with diameters of 1.18–1.40 mm, whereas no penetration was made by *R. flavipes*. Apparently mandibles of *C. formosanus* were larger and more capable of manipulating particles of this size range than those of *R. flavipes*. When barriers were composed of particles screened between 7 and 14 mesh (resulting in mixed sizes of 1.18–2.80 mm), penetration by *C. formosanus* was significantly reduced.

*R. flavipes* was more capable of penetrating into a barrier of particles 2.36–2.80 mm in diameter than *C. formosanus* because of their smaller head width (Table 3). When particles of 2.36–2.80-mm diameter were sifted together with other sizes (1.18–2.36 mm) to form mixed sizes (1.18–2.80 mm), penetration by *R. flavipes* was again significantly reduced. Our results suggest that a particle size range of 1.18–2.80 mm (7–14 mesh) can be effectively used to prevent penetration by either *C. formosanus* or *R. flavipes*. Use of wider size ranges of sand particles are more practical because they are easier to manufacture. Field tests with the suggested size ranges are currently being done to test the validity of laboratory data for colonies of these two subterranean termite species.

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