J Wood Sci (2007) 53:76–79
DOI 10.1007/s10086-006-0817-0

NOTE

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Evaluation of the temperature and relative humidity preferences of the western dry-wood termite *Incisitermes minor* (Hagen) using acoustic emission (AE) monitoring

Received: February 10, 2006 / Accepted: May 10, 2006 / Published online: July 24, 2006

Abstract Twenty-four different combinations of six temperatures (15°, 20°, 25°, 30°, 35°, and 40°C) and four relative humidity (RH) (60%, 70%, 80%, and 90%) conditions were used for pseudergates of the western dry-wood termite *Incisitermes minor* (Hagen). The feeding activities of the termites were monitored by the detection of generated acoustic emission (AE) events from feeder wood blocks in a test chamber. Temperature and RH showed independent and interactive significant effects on the feeding activity of *I. minor*. The optimal temperature and RH conditions for the feeding activities were 35°C and 70%, respectively, and the optimal combinations were 35°C–70% and 35°C–80% with an exceptionally higher feeding activity at the combination condition of 30°C–70%.

Key words Temperature · Relative humidity · Feeding activity · *Incisitermes minor* (Hagen) · Acoustic emission

Introduction

Dry-wood termites differ from other termites in their ability to live within structural timbers or furniture inside buildings, feeding on wood with a low moisture content.[1] One of the dry-wood termite species categorized as a serious pest in the United States is the western dry-wood termite *Incisitermes minor* (Hagen).[2] *Incisitermes minor* is widespread along the coastal areas in the USA, as remarked by Jones,[3] and in Japan by Indrayani et al.[4] This species was reported to be much more tolerant of high temperatures and arid conditions than other termite species.[5–8]

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One of the most important environmental factors affecting wood consumption by termites is temperature.[9] Rudolph et al.[10] stated that dry-wood termites (Kalotermitidae) obtained their favorable relative humidity (RH) conditions indirectly via the available moisture from wood and metabolic process. Both temperature and humidity are likely to play important roles in the survival of termites and influence their feeding activities.[5,6,11–16]

Recently, considerable attention has been paid to methods of termite control using less or no chemicals. To prevent or at least decrease termite damage with the reduced use of chemicals, a nondestructive technique to detect termite attack is indispensable.[17,18] The feasibility of acoustic emission (AE) monitoring has been studied to detect the feeding activity of termites.[18–24] When wood is attacked by termites, microfractures occur, and as a result, elastic waves known as AEs are generated because strain energy, which is stored in the wood material, is released by termite feeding.[22,23]

In this study, we investigated the temperature and RH preference of *I. minor* by monitoring feeding activity, which was defined as generated AE events, from feeder wood blocks in a test chamber.

Materials and methods

Termites

Pseudergates of *Incisitermes minor* were collected from infested timbers in Yokohama, Kanagawa Prefecture, Japan, and used as test organisms. The termites were extracted from the timbers and kept in plastic containers with lids containing small wood blocks of Douglas fir (*Pseudotsuga menzietti* Franco) as both food source and harborage. The containers with the termites were kept in a termite culturing room of the Research Institute for Sustainable Humanosphere (RISH), Kyoto University, at 28° ± 2°C, >85% RH, in darkness for at least 1 week before testing to ensure that only healthy termites would be used in the experiment.

Test timber

Air-dried sapwood specimens of spruce (*Picea abies* Karst.) were used for the feeding tests. In our previous wood feeding preference study, spruce sapwood was the most preferred species among the ten wood species investigated.[25] A hole measuring 40 mm (depth) × 10 mm (diameter) was drilled in the center of each wood specimen [30 (R) × 30 (R) × 50 mm (L)] to accommodate the termites.

Test apparatus

Ten pseudergates of *I. minor* with no external evidence of wing buds or eyes were put into the hole of a test wood specimen, and the hole was then covered with a fine-mesh screen and tightened up by two stainless steel wires to allow similar environmental conditions inside and outside the specimen (Fig. 1). One wood specimen without pseudergates served as a control. A piezoelectric AE sensor with a resonant frequency of 150 kHz was attached to the top surface of the wood specimen using silicone grease and a rubber band (Fig. 1). The signal from the sensor was amplified by about 85 dB, filtered by a high-pass filter with a cutoff frequency of 50 kHz, and discriminated at a threshold voltage of 0.6 V with the AE apparatus (AE Detector 510; Maruwa Biochemical).

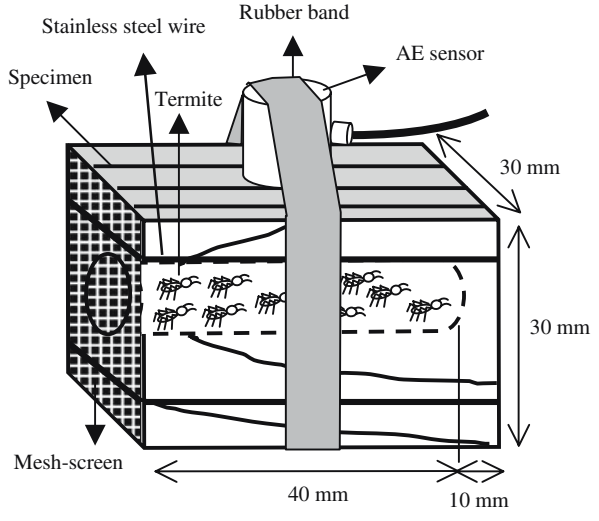

Fig. 1. Test apparatus for acoustic emission (AE) monitoring of the feeding activity of *Incisitermes minor*

The observation units were kept in a test chamber (Eyela KCL 1000; Tokyo Rikakikai, Tokyo, Japan) with variable temperature and RH, and the feeding activities were monitored by the detection of generated AE events for 12 h. Twenty-four different combinations of six temperatures (15°, 20°, 25°, 30°, 35°, and 40°C) and four RHs (60%, 70%, 80%, and 90%) were selected as test conditions. Three replicates were employed for each condition.

The effects of treatment parameters were analyzed by two-way 4 × 6 factorial analysis of variance (ANOVA) using Microsoft Excel (version 2003). The selection of the optimum condition for each treatment was analyzed by Tukey's test using SPSS program (version 13.0).

Results

The feeding activities of *Incisitermes minor* monitored by the AE events under various temperature and humidity combinations are summarized in Fig. 2. Results of ANOVA are shown in Table 1.

In general, the average number of AE events generated from the wood specimens steadily increased with temperature up to 35°C, regardless of RH with an exceptionally high value for the 30°C–70% RH condition (22 388.67 events/12 h). The results of two-way 4 × 6 factorial ANOVA indicated that temperature had an independent significant effect on the feeding activity of termites (ANOVA: $P < 0.01$). No significant difference was observed among temperatures of 25°, 30°, and 35°C at 60%, 70%, and 80% RH with an

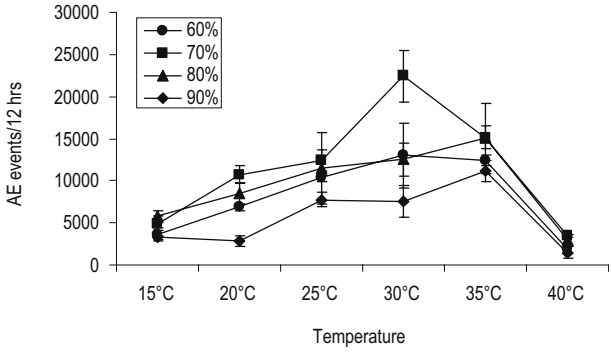

Fig. 2. Cumulative AE events for 12 h generated from wood specimens with *Incisitermes minor* pseudergates under various conditions of temperature and relative humidity. *Error bars* represent standard deviations

Table 1. Results of two-way 4 × 6 factorial analysis of variance for the acoustic emission events of feeding activities of *Incisitermes minor*

Sources of variation	Sum of squares	Degrees of freedom	Mean square	*F*	*P*
Temperature (*T*)	1 342 361 946	5	268 472 389.2	79.87	3.15E–22**
Humidity (RH)	322 953 251	3	107 651 083.5	32.03	1.26E–11**
T-RH interaction	213 571 937	15	14 238 129.16	4.24	5.5E–05**
Error	154 625 950	46	3 361 433.69		
Total	2 037 717 178	72			

** $P < 0.01$

exceptionally higher feeding activity for 30°C–70%, while at 90% RH a temperature of 35°C gave a stronger effect on the feeding activity of the termites than the other temperature conditions (Tukey's test: $P < 0.05$).

The results of the ANOVA indicated that RH had an independent significant effect on the feeding activity of termites (ANOVA: $P < 0.01$). Tukey's test showed that RH had a significant effect at 15°, 20°, and 40°C ($P < 0.05$), and no significant effect was seen at 25°, 30°, and 35°C; an exceptionally higher feeding activity occurred at 30°C–70%. The optimal RH was 70% but no significant difference was observed between RHs of 70% and 80% at temperatures of 15°, 20°, and 40°C (Tukey's test).

The combination of temperature and RH also significantly affected the feeding activity of the termites. The combinations of 35°C–70% and 35°C–80% resulted in the high average number of AE events of 15150.00 and 15017.67 events/12 h, respectively. Combinations of 30°C–90%, 25°C–90%, and 20°C–80% showed lower average numbers of AE events (7509.33, 7772.00, and 8491.33 events/12 h, respectively) than combinations of 30°C–60%, 30°C–80%, 35°C–60%, 25°C–70%, 25°C–80%, 35°C–90%, 20°C–70%, and 25°C–60% (13005.00, 12514.33, 12425.00, 12352.33, 11429.67, 11085.00, 10714.67, and 10320.33 events/12 h, respectively), but no significant difference was observed between these two groups (Tukey's test) (Fig. 2). The lowest feeding activity occurred in the combination of 40°C–90% with 1464.00 events/12 h on average; however, there was no significant difference in average AE events between this combination and the combinations of 40°C–60%, 20°C–90%, 40°C–80%, 15°C–90%, 40°C–70%, 15°C–60%, 15°C–70%, 15°C–80%, and 20°C–60%, (1862.00, 2854.33, 2960.67, 3266.00, 3441.00, 3670.67, 4927.67, 5743.67, and 6861.33 events/12 h, respectively) (Tukey's test).

At the end of the monitoring process, the survival rates of the termites at the temperatures of 15°, 20°, 25°, 30°, and 35°C were 100% regardless of the RH. However, a temperature of 40°C caused some of the pseudergates to become moribund.

Discussion

Our previous study showed that the most favorable conditions for the feeding activity of the Japanese dry-wood termite *Cryptotermes domesticus* (Haviland) were 35°C and 70% RH.[11] In the present investigation, 35°C was also the optimal temperature for *Incisitermes minor* (Fig. 2). According to the results of Nakayama et al.,[26] the optimal temperature for the Japanese pest subterranean termites *Coptotermes formosanus* Shiraki and *Reticulitermes speratus* (Kolbe) is 30°C. This may indicate a preference for higher temperatures in dry-wood termites when compared with subterranean termites that live in the same distribution area. The fact that the majority of *I. minor* attacks are found in the upper parts of houses (roofing materials)[4] seems to support this assumption. Cabrera and Rust[5] found the greatest amount of wood consumption at 26.7°C and 75% RH by *I. minor* after 34 weeks. The optimal temperatures for the feeding activity of the other dry-wood termite species were 25°–30°C for *Kalotermes flavicollis*,[16] 28.3°–29.1°C for *Cryptotermes brevis*,[14] 31.8°–32.2°C for *Cryptotermes dudleyi*,[14] and 29.7°C for *Cryptotermes havilandi*.[14]

The highest temperature (40°C) caused some of the pseudergates to become moribund, and their feeding activity decreased rapidly. However, the coolest temperature (15°C) did not kill the termites, but did reduce the feeding activity. These results were very consistent with the results of Cabrera and Rusts,[6] who stated that *I. minor* pseudergates move away from temperatures higher than 45°C and lower than 12°C. Previous studies showed that oxygen consumption by *K. flavicollis*[16] and *I. minor*[7] was increased at higher temperatures. Higher temperatures induced higher metabolic activity, but resulted in earlier death of the insect than lower temperatures.[7,16] Oxygen consumption is very low at lower temperatures, and feeding activity is reduced due to the decreased respiration and lower metabolic rate. In addition, the higher temperatures were reported to cause greater water loss rates than the lower temperatures.[5,27,28] Shelton and Appel[29] also stated that the lower basal metabolic rate of *I. minor* was caused by the high release of carbon dioxide (CO_2) at the higher temperatures. Our results clearly showed that the termite feeding activity steadily increased up to the optimal temperature, and then decreased rapidly.

The present results indicate that 70% and 80% RH generally resulted in higher numbers of AE events than 60% and 90% RH at temperatures of 15°, 20°, and 40°C, while at 25°, 30°, and 35°C, *I. minor* showed similar feeding activities at all RH conditions. RH seems to be more important at lower and higher temperature conditions (15°, 20°, and 40°C) than the RH at favorable temperature conditions (25°, 30°, and 35°C). From these results, it is suggested that RH had a slight effect on the feeding activity of *I. minor*. Similar results have also been reported by other researchers who worked with the dry-wood termite *C. dudleyi*.[15] It was reported that higher RH could be detrimental to *I. minor* because the exposure to excess moisture led to water poisoning of the termites,[5] and that lower RH caused cuticular water loss in *I. minor*.[5] The humidity preferences of other dry-wood species are 80.1%–82.5% for *C. brevis*, 83.6%–84.4% for *C. dudleyi*, 89.3% for *C. havilandi*, and 89.6% for *Cryptotermes naudei*.[1] In the case of subterranean termites distributed in Japan, the optimal humidity for the feeding activities of the workers are 90% RH and 70%–90% RH for *C. formosanus* and *R. speratus*, respectively.[29]

The results from the present study show that temperature has a strong effect on the feeding activities of *I. minor*, relating to its infestation manner. On the other hand, RH has a slight effect on the feeding activity. This information is essential for gaining a better understanding of the feeding behavior of the pest dry-wood termite *I. minor*, and may contribute to the improvement of termite control measures with less or no use of chemicals in the future.

Acknowledgments The authors are thankful to CATS Inc. for providing the test insects used in this study.

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