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Plate-type waveguides for detecting acoustic emissions generated by termite attacks

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Abstract To examine the feasibility of using plate-type waveguides for effective detection of acoustic emissions (AEs) from termite attacks in wood, AEs generated by breaking pencil leads or by termite attacks were detected using an AE sensor with a resonant frequency of 140kHz with steel plates of four different sizes and thickness and three AE sensors without them. The larger plates were associated with larger amplitudes of the artificial AEs. The amplitudes of AEs detected by an AE sensor with a steel plate larger than 30 × 30mm were greater than the average amplitude of the artificial AEs detected by three AE sensors. When detecting AEs generated by the feeding activity of workers, *Coptotermes formosanus* Shiraki, the cumulative AE events detected by the sensor with a steel plate were much larger than those of the three AE sensors without a plate. Because AE waves are attenuated much less in a steel plate than in wood, it is more effective to attach the AE sensor to wood with a steel plate rather than directly to the wood. These findings suggest that it is feasible to use an AE sensor with a plate-type waveguide for the nondestructive detection of termite attacks in wood.

Key words Acoustic emission (AE) monitoring · Termite attack · Plate-type waveguide · *Coptotermes formosanus* Shiraki

Introduction

Considerable attention has been given to methods to control termites using few if any chemicals. To reduce the use of chemicals, a nondestructive technique is needed that can detect a termite attack in wood as early as possible. When wood is attacked by termites, microfractures are generated in the wood by the feeding of workers. As a result, elastic waves, or acoustic emissions (AEs), are generated owing to the release of the strain energy stored in the wood.[1]

Fujii and coworkers[2–6] showed that AEs could be detected in wood specimens under termite attack, and the results obtained in their laboratory and field tests suggest that AE monitoring may be an effective nondestructive method for detecting the presence and activity of termites in wood, even if the attack is still in its incipient stage. They also observed the feeding behavior of termites using a microscope and CCD camera to better understand its relation to the generation of AEs.[7,8] They showed that the amplitudes of the AEs generated by termite attack depended on the type of feeding by the workers.

Lewis and coworkers[9,10] examined resonant frequencies for an AE sensor to determine one that was optimal for detecting AEs generated by termite attack. They also pointed out the need for a waveguide, such as a lag screw attached to the AE sensor that penetrated walls to reach the inner posts or studs, to detect effectively AEs generated inside the house walls. However, a needle- or screw-type waveguide that penetrates walls is disadvantageous in that it leaves a hole on the wall surface. To avoid this problem, a metal plate attached to the wood surface could be used as a waveguide to collect AEs effectively by enlarging the effective sensing area of the AE sensor. In this study, we examined the feasibility of using a steel plate as a waveguide for detecting AEs.

Materials and methods

Detection of artificial AEs using plate-type waveguides

Western hemlock (*Tsuga heterophylla* Sarg., moisture content 10.2%, specific gravity 0.51) wood was cut into a specimen of 1000mm long with a cross section of 105 × 105mm, and air-dried. Steel plates (15 × 15, 30 × 30, 45 ×

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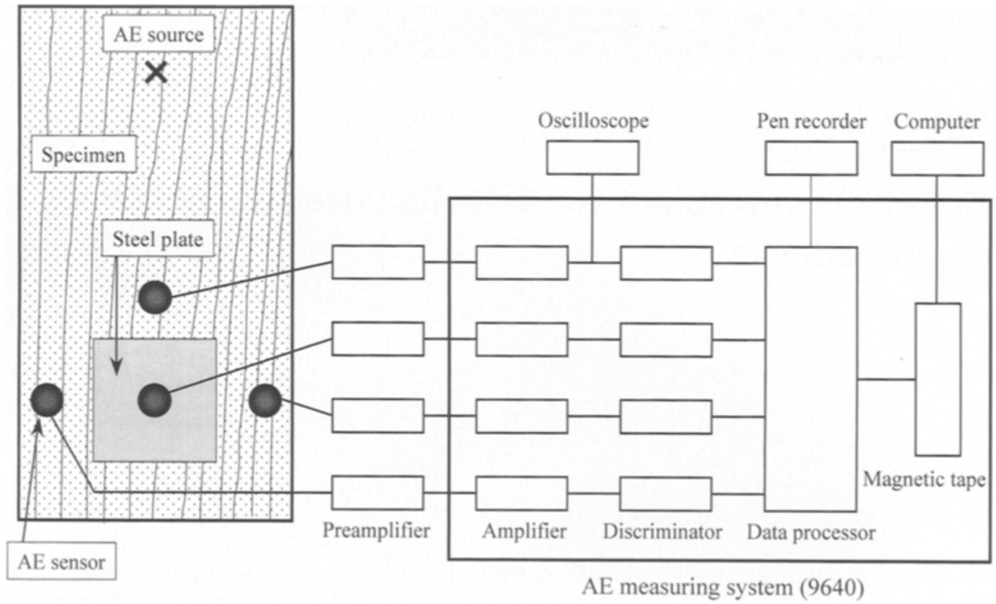

Fig. 1. Arrangement of acoustic emission (*AE*) sensors and AE measuring system

45, 60 × 60mm; 1, 2, 4, and 8mm thick) were attached to the surface of the specimen with silicone grease (Fig. 1). AEs were detected by four cylindrical piezoelectric transducers (22mm long, 8mm in diameter; 901U, NF Electric Instruments) with a fundamental resonant frequency of 140kHz. One of the sensors was attached to the plate with silicone grease at a pressure load of 2kgf to achieve close contact between the wood, the plate, and the sensor. The other three sensors were attached to the specimen around the steel plate with silicone grease and fixed with a rubber band. As the artificial AE source, a pencil lead (3mm diameter, B hardness) was broken 200mm away from the center of the steel plate. Using this artificial AE, a momentary release of load that exhibits a step function and includes the frequencies required for AE measurement can be obtained in a reproducible manner.[11,12] The elastic waves generated in the specimen and transmitted to the sensor were transformed into a voltage oscillation using an AE measuring system (9640, NF Electric Instruments). Signals from the sensors were amplified by 40dB and discriminated at a threshold voltage of 0.1V to be recognized as an AE event. The characteristic AE data (e.g., generation time, maximum amplitude, rise time of each AE event) were collected, recorded on magnetic tape, and postprocessed with a computer. Signals from the sensors and cumulative AE events were monitored by a digital oscilloscope and a pen recorder, respectively.

Use of a plate-type waveguide to detect AEs generated by termite attack

Western hemlock wood was cut into a specimen 500mm long with a cross section of 105 × 105mm and air-dried. A hole (10mm diameter, 30mm deep) was drilled at the center of the end surface of the specimen. A group of 100 worker and 10 soldier termites (*Coptotermes formosanus* Shiraki) that had been given only water for about 2 days was put into the hole, which was then sealed with a silicone plug. A steel plate (60 × 60mm, 4mm thick) was attached to the surface of the specimen with silicone grease. The distance from the center of the steel plate to the bottom of the hole was 200mm. AEs generated by the feeding activity of the termites were detected by the four sensors and measured under the same conditions as in the previous section, except that the signals from the sensors were amplified by 70dB and discriminated at a threshold voltage of 0.26V.

Results and discussion

Detection of artificial AEs using plate-type waveguides

Artificial AEs generated at 12 locations (numberd 1–12) on the surface of the specimen were detected by the four AE sensors (a–d) with or without a steel plate (Fig. 2). Figure 2 shows the average of 10 peak-to-peak amplitudes of the detected AEs generated by breaking pencil leads. For most cases, as the distance between the AE sensor and the artificial AE source increased, the average amplitudes detected decreased. Although the AE propagation distance between AE source 2 and sensor b is the same as that between 3 and d, the amplitude for the former source–sensor combination was larger than that for the latter one. In this case, as in others, the AE amplitude was influenced not only by the propagation distance but also by the propagation direction. This could be attributed to the facts that (1) AE waves are attenuated more when they propagate across the grain radially or tangentially than when they propagate longitudinally, and (2) AE waves are attenuated according to the number of annual rings through which they propagate. Although sensor c was located closer to the AE sources than sensor a, which was fixed to the steel plate, the AE ampli-

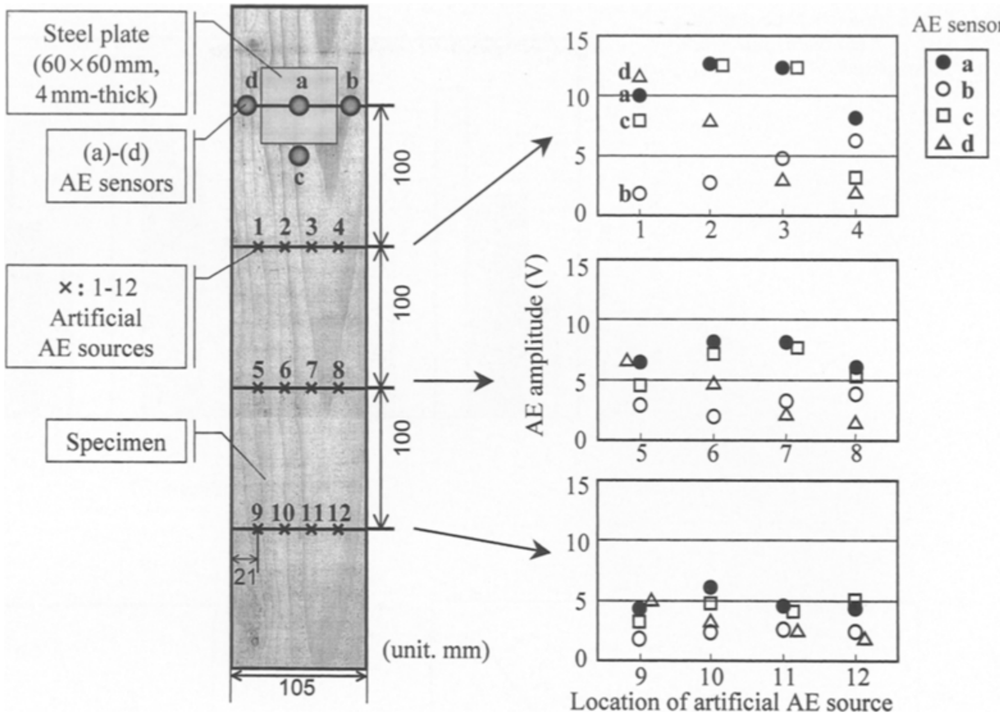

Fig. 2. Relations between the location of artificial AE sources and AE amplitudes

tudes by sensor a were as large as or larger than those detected by sensor c. One possible explanation for this result is that the AE wave detected at sensor c was also transmitted to the plate and detected again by sensor a after it propagated in the steel plate, which has less of a damping effect than wood. Another possibility is that the detection area of sensor a was increased by using the steel plate, which can detect AEs with large amplitudes propagating differently according to the anatomic features of wood. Although AE waves should be attenuated at the boundaries between the plate and the wood, and between the plate and the AE sensor, the above findings showed the feasibility of using a steel plate as a waveguide to detect AEs propagating in wood.

Figure 3 shows the relations between the AE amplitude detected by the sensors with and without a steel plate (60 × 60 mm, 4 mm thick) and the distance from the artificial AE source to the AE sensor. The AE amplitudes decreased exponentially as the distance increased. At distances of 100–500 mm, the AE amplitudes detected by the AE sensor with a steel plate were about two to three times larger than those without it. As the propagation distance increases, the distance that AEs must pass through the plate as a percentage of the total distance decreases, and the steel plate becomes less effective as a waveguide. At a distance of 800 mm, the amplitude of the AE detected by the sensor with a steel plate was almost the same as that detected by the other three sensors. Figure 4 shows the average amplitudes of artificial AEs detected by an AE sensor attached to 16 various steel plates as waveguides. It shows clearly that the larger the size of the plate the higher is the average amplitude, and that the thickness of the plate has no significant effect on the AE amplitude. The average amplitude of AEs detected by AE sensors attached directly to the wood was 4.42 V, which suggests that an AE sensor with a plate larger than 30 × 30 mm can detect AEs more effectively than a sensor without a plate.

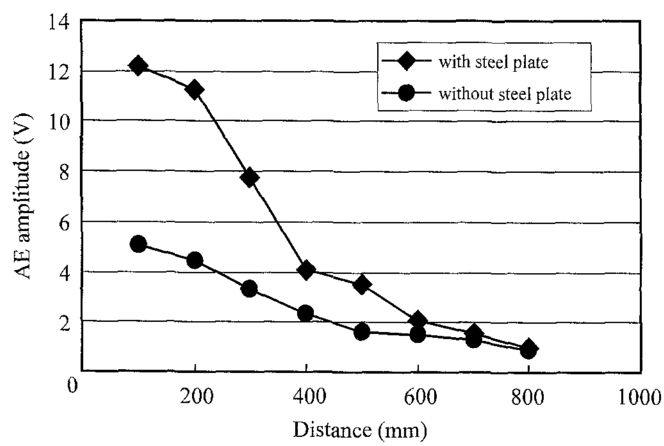

Fig. 3. Relation between the AE propagation distance and AE amplitude

Use of a plate-type waveguide to detect AEs generated by termite attack

Acoustic emission measurements were carried out on a wood specimen containing termites (Fig. 5). "Burst-type" AEs generated by termite attack were detected by the AE sensors with or without a steel plate, and the cumulative AE

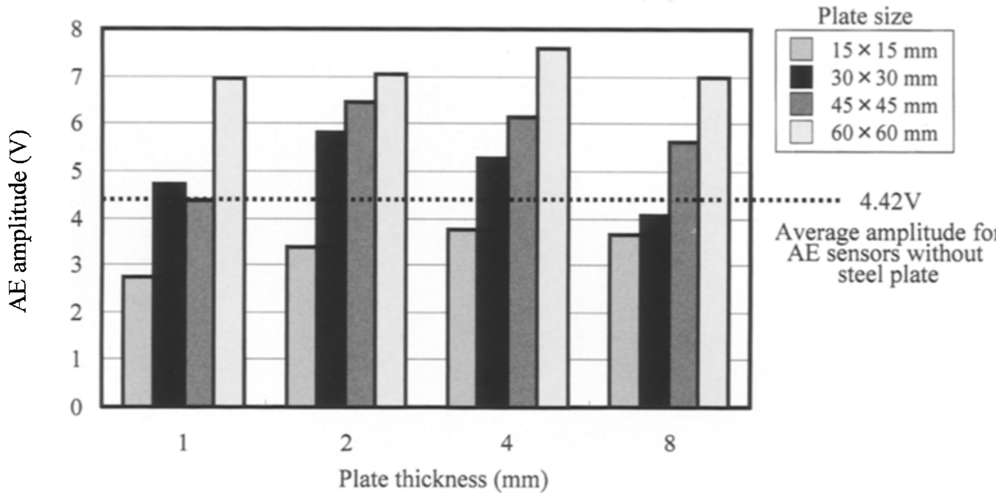

Fig. 4. Relations between thickness, size of steel plate, and average AE amplitude

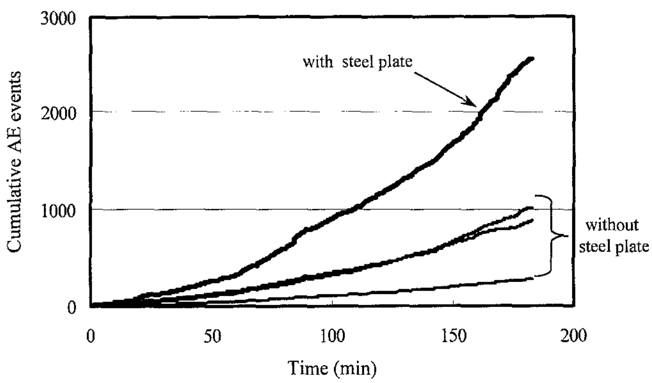

Fig. 5. Comparison of AEs detected with and without plate-type waveguide during the attack by termites

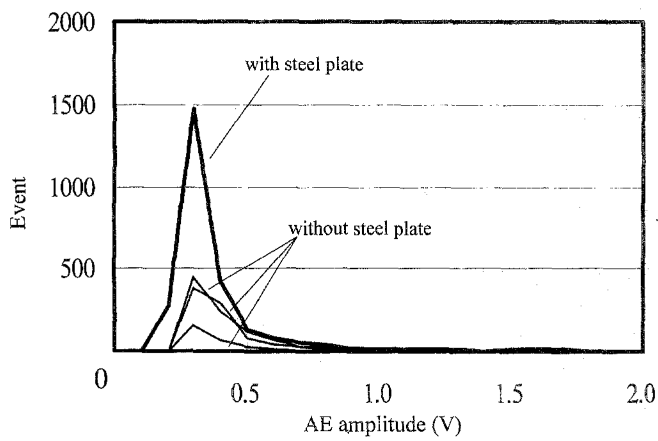

Fig. 6. Amplitude distribution of AEs detected with and without steel plate for termite attack

events increased with time. The AE sensor with a steel plate detected 2.5–10.0 times as many AE events as the AE sensors without a plate.

Figure 6 shows the amplitude distribution of the AEs detected over 180 min. The distribution had a peak near a threshold voltage of 0.26 V for both types of AE detection. In the AE sensor with a steel plate, the AE events detected by the AE sensor with a steel plate, especially near the threshold voltage, were larger than those detected without a plate. Using a steel plate that has less damping effect than wood increased the detection area of the AE sensor; and AEs that were attenuated while propagating in wood, and could not be detected by AE sensors without it, could now be detected. Therefore, it was considered that the AE events detected by AE sensors with a steel plate were larger than without it.

Conclusions

The ability of an AE sensor with a steel plate to detect AEs was greater than that of an AE sensor attached directly to the wood, in part because AE waves are attenuated less in steel plate than in wood. For detection of AEs generated by termite attack, the AE events detected by the AE sensor with a plate-type waveguide were about three times as large as those detected without a plate. To establish the usefulness of AE sensors using a plate-type waveguide for detecting termite attack in wood, it is necessary to confirm the present findings by carrying out AE detection films for other experimental conditions, such as structural members of wooden houses, and to study further the method of fixing large steel plates on wooden constructions.

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