Microwave irradiation of wood packing material to destroy the Asian longhorned beetle

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Abstract

The infestations of the Asian longhorned beetle (ALB) in New York and Chicago, discovered in 1996 and 1998, respectively, are believed to have originated with infested solid wood packing materials shipped to the United States from China. This insect poses a serious threat to urban trees and there is potential for vast devastation to commercial hardwood forests. Since 1998, the U.S. Department of Agriculture (USDA) has required that all wood packing materials originating in China be fumigated, heat treated, or treated with preservatives. To determine the feasibility of microwave irradiation as an alternative treatment, we performed laboratory experiments on 4- by 4- by 4-inch and 4- by 4- by 1-inch blocks of wood artificially infested with live ALB larvae and pupae with subsequent 2.45 GHz microwave energy irradiation. Temperature gradients generated both by conventional and microwave treatments were recorded. Experimental results for aspen, eastern white pine, red pine, and loblolly pine showed that temperature gradients were not consistent for short (< 3 min.) irradiation periods. However, all measurement points in the 4- by 4- by 4-inch green blocks reached 60°C within 0.5 to 5 minutes of irradiation, compared to 70 to 123 minutes with the conventional heat treatment; for the 4- by 4- by 1-inch green blocks, the times were 15 to 60 seconds with the microwave treatment versus 21 to 160 minutes with the conventional treatment. In China, both green and dry poplar blocks of the same dimensions were seeded with beetle larvae and pupae. Preliminary results showed that 30 seconds and 3 minutes of irradiation at 900 watts was lethal to larvae and pupae in green 4-by 4-by 1-inch and 4- by 4- by 4-inch poplar blocks, respectively. Only 5 seconds of irradiation was necessary to kill the larvae in dry wood. These preliminary results suggest that microwave treatment can eradicate Asian longhorned beetles in solid wood packing materials. Further trials with ALB-infested wood samples are planned to determine lethal microwave treatment protocols.

Many forests and street trees in China have been lost due to attack by the Asian longhorned beetle (*Anoplophora glabripennis* [Motsch.]) (ALB). "Members of the Biological Control Institute of the Chinese Academy of Agricultural Sciences (CAAS) consider ALB as one of the most serious forest pests in China," according to the USDA/APHIS Initial Pest Risk Assessment on Solid Wood Packing Material from China (USDA 1998b). In 1996, the first infestation of the ALB in the United States was identified in Brooklyn, New York (USDA

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*Forest Products Society Member.

Forest Prod. J. 53(1):46-52

Table 1. Measured MC and SG of processed wood samples compared with published values.[a]

Wood species	% MC (calculated)	SG (calculated)	% MC[b] (typical species avg.) heartwood/sapwood	SG[b] (typical species avg.)
Aspen	145	0.305	95/113	0.35 to 0.36
Eastern white pine	88.8	0.350		0.34
Red pine	46.4	0.374	32/134	0.41
Poplar (China)	73.5	0.400	NA	NA
Loblolly pine	125	0.430	33/110	0.47

[a] MC = moisture content; SG = specific gravity.
[b] FPL 1987.

1996). Since then residential infestations in Chicago, Du Page, and Summit, Illinois; and Brooklyn, Manhattan, and Amityville, New York have been identified (USDA Forest Service 1999, 2001a, 2001b). The beetle has been found in infested packing material in at least 26 warehouses in 14 states (USDA 2000b). Given this large geographical area, it is conceivable that the ALB may have been introduced into other U.S. sites yet to be discovered.

The ALB is known to attack poplar, willow, maple (including sugar, silver, and Norway), sycamore, elm, horsechestnut, boxelder, and other hardwood trees (USDA 2001, USDA Forest Service 2001c). As of January 2001, 6,608 infested trees have been cut down and destroyed to control the ALB threat in the United States (USDA Forest Service 2001a, 2001b). A recent report predicts that if the ALB were to spread to urban areas throughout the United States, the maximum national urban impact would be a loss of 35 percent of total canopy cover and a value loss of $669 billion (Nowak et al. 2001). This projection does not take into account that widespread ALB infestations in the United States could also adversely impact forest products, commercial fruit, maple syrup, nursery, and tourist industries (estimated at $41 billion in potential losses) (USDA 2001).

The ALB normally takes 1 year to complete its life cycle (USDA 2001). Adults may start to emerge from trees in June, but peak emergence is usually July (USDA 1996). Emergence generally ceases by October, but warm weather may prolong emergence. Upon emergence, females mate and begin a period of oviposition that lasts between 10 and) days. Female beetles chew a small depression through the bark where they oviposit a single egg. A female beetle can lay from 35 to 90 eggs during her lifetime (USDA 2001), but recent studies in the laboratory suggest fecundity may be even higher (Keena 2001). Eggs hatch in approximately 15 days. Young larvae tunnel beneath the bark feeding on the cambium and phloem tissue, and then move into the sapwood and heartwood as older larvae (Peng and Liu 1992). The larvae feed within the tree until early spring. Larvae pupate beginning in late May and early June. The adults chew an emergence hole ~1 cm in diameter. These exit holes are often how beetle infestations are detected. Newly emerged adults may disperse or oviposit on their natal host (USDA 2000a). It is unknown how long adult beetles live in the field. The feeding activity of the larvae disrupts the flow of water and nutrients, which weakens branches, and may eventually kill the tree (USDA 1998a).

Preventing additional ALBs from entering North America is of major importance. Consequently, the Solid Wood Packing Material from China Interim Rule was issued by the U.S. government in September 1998 (USDA 1998c). It states that "wooden packing material being shipped from China to the United States must be heat treated, fumigated or treated with preservatives prior to departure from China." Microwave energy may be a feasible alternative treatment. Microwave irradiation to control insect infestations has been reported for wood products (Burdette et al. 1975), for termites in wood (Lewis and Haverty 1996, Lewis et al. 2000), for stored-grain (Nelson 1996b, Tilton and Brower 1985), walnuts (Wilkin and Nelson 1987), and soil (Nelson 1996a). According to Lewis et al (2000), microwave irradiation has been available in California since 1989 for termite control. However, no previous research has been reported on microwave irradiation of wood infested with the ALB. In order to provide the Chinese pallet manufacturers with a reliable treatment alternative, our research sought to determine if microwave energy is a feasible method to treat solid wood packing materials containing wood-boring insects such as the ALB.

Materials and methods

Experimental wood sample preparations

The following four native U.S. wood species were chosen for the temperature gradient experiments because of their specific gravity (SG), moisture content (MC), and availability: aspen (*Populus tremuloides*), eastern white pine (*Pinus strobus*), red pine (*Pinus resinosa*), and loblolly pine (*Pinus taeda*). With the exception of loblolly pine, the wood species were locally harvested with logs bucked into 6-foot lengths for transport. Relatively small-diameter trees (≈10 in. diameter at breast height) were harvested to minimize processing requirements. Log ends were painted with Anchorseal™ wax coating (UC Coatings, Buffalo, New York) to control end-grain moisture loss and the log bolts were stored in an unheated warehouse until needed. Each log bolt was manually debarked with two surfaces processed on a wood jointer. A planer was then used to square and dress size the green material into surfaced-four-sides dimension 4 by 4 stock. Stock lengths were cut into two final sizes (4- by 4- by 4-in. +/- 1/8-in. tolerance or 4- by 4- by 1-in. +/- 1/16-in. tolerance) with a radial arm saw. These dimensions were chosen because typical pallets utilize approximately 1-inch-thick slats as well as 4-inch-thick stabilizers. Thickness is the most important parameter for this application since length can be adjusted for by the design of the microwave chamber. Finished cubes and the 4- by 4- by 1-inch material samples were then

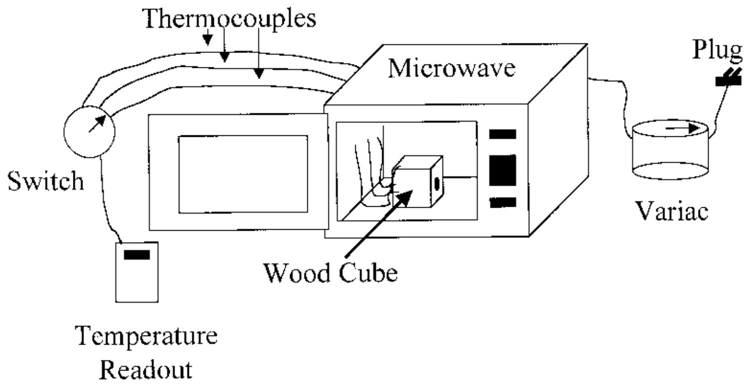

Figure 1. — Configuration of the microwave set-up used for irradiation of Asian longhorned beetles in wood blocks.

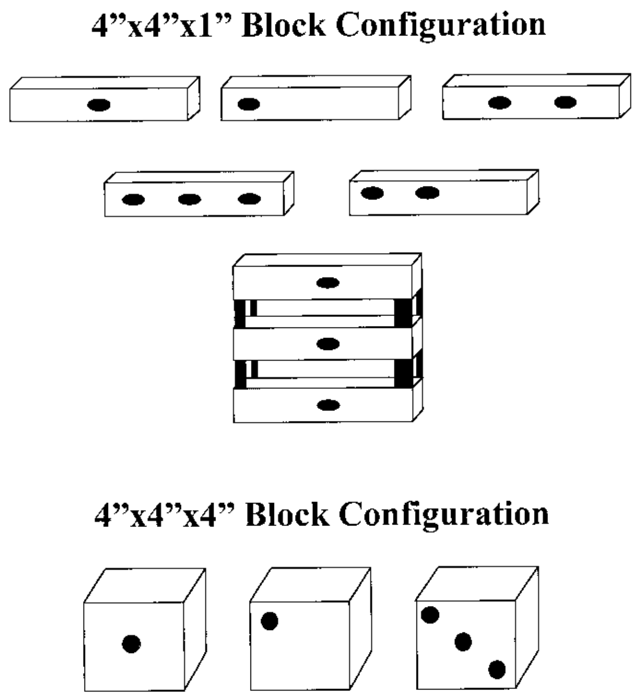

Figure 2. — The hole configurations used in the 4- by 4- by 4-inch and 4- by 4- by 1-inch wood blocks in which live Asian longhorned beetle larvae were experimentally irradiated with microwave energy.

Table 2. — Time measurements to reach 60° C for microwave irradiation versus conventional thermal exposure.

Wood type	Time to reach 60°C	
	Conventional	Microwave
4- by 4- by 4-in. block (green)		
Aspen	123 min.	2 to 5 min.
Loblolly pine	123 min.	1.5 to 5 min.
Eastern white pine	76 to 117 min.	2 to 2.5 min.
Red pine	70 to 73 min.	0.5 to 1 min.
4- by 4- by 1-in. block (green)		
Aspen	45 to 86 min.	15 to 60 sec.
Loblolly pine	69 to 160 min.	30 to 45 sec.
Eastern white pine	39 to 48 min.	15 to 30 sec.
Red pine	21 to 28 min.	15 to 30 sec.

meter (model #HI1501: 0.1 to 100 mW/cm^2 at 2450 MHz) was used to test the microwave set-up for radiation leaks. The simple boiling water test as described for the U.S. experiments showed an acceptable temperature reading of 98°C.

Nine different wood/hole configurations were used in these experiments (**Fig. 2**). Holes for each larva or pupa were drilled on one side of the wood block (approximately 1/2 in. in diameter and slightly less than 2 in. deep). For most experiments, a hole (~1/4 in. in diameter and slightly less than 2 in. deep) was drilled for the thermocouple wires on the opposite face. Only a thin wall of wood then separated the larva/pupa and the thermocouple tip. This set-up allowed a fairly accurate measurement of temperatures experienced by the larva/pupa throughout the experiment. One larva or pupa was placed in each hole and a wood plug was used to cover the hole. The wood block was then placed in the center of the microwave oven and the thermocouple wires were positioned in the appropriate holes.

Once the insect was irradiated, it was visually checked for movement and dehydration. If the larva was dehydrated and not moving despite repeated prodding, it was considered dead. Otherwise, it was placed on filter paper dampened with water in the bottom of a plastic petri dish. The filter paper was checked daily for frass production, a physiological parameter of live versus dead. If no frass was produced in 24 hours, then the larva was either dead (no movement with prodding) or deemed non-viable. All pupae were placed on damp filter paper in petri dishes and visually inspected daily. If a pupa was not moving and dehydrated or had changed color, it was deemed dead.

Results

Temperature gradient studies

Temperature gradients for the conventional drying oven experiments with green samples were as expected for all wood species. The surface temperature increased rapidly to near the air temperature, whereas the off-center hole was always hotter than the center hole until equilibrium was reached. Due to time constraints, the conventional trials were halted once the center reached 60°C. The temperature gradient results for the micro-

Table 4. — Irradiation of Asian longhorned beetle larvae and pupae in 4- by 4- by 4-inch green poplar blocks.

Time irradiated	% of maximum power (900W)	Status of larvae or pupae	No. of replicates under the same conditions
1 larva in center or in off-center holes			
3 minutes	100	Dead[a]	5 center, 5 off-center
3 minutes	95	Dead[a]	5 center, 5 off-center
5 minutes	90	Dead[a]	1 center
3.5 minutes	100	Dead[a]	5 center
3 larvae in one block			
3 minutes	100	Dead	1 rep, 3 larvae
1 pupa in center hole			
3 minutes	95	Dead	3
3 minutes	100	Dead	2
1 pupa in off-center hole			
3 minutes	100	Dead	1
3 pupae in one block			
3 minutes	95	Dead	1

[a] One of the larvae in this rep died within 48 hours post-irradiation, the remaining larvae died immediately.

Table 5. — Irradiation of Asian longhorned beetle larvae in dry poplar blocks.

Time irradiated	% of maximum power (900W)	Status of larvae or pupae	No. of replicates under the same conditions
4- by 4- by 4-in. block			
1 larva in center hole			
30 seconds	100	Dead	1
15 seconds	100	Dead	1
5 seconds	100	Dead	2
4- by 4- by 4-in. block			
1 larva in center hole			
30 seconds	80	Dead	5
5 seconds	80	Dead	5

power died. However, 1 of the 5 larvae placed in off-center holes was still moving its head after being subjected to these conditions. No frass was produced by this larva in 24 hours. With 3-1/2 minutes of irradiation at 100 percent power, 1 of 5 larvae was also moving its head; however, within 48 hours it was dead. Given the injuries sustained by these two living larvae, even if they survived the microwave treatment, most likely they would not be capable of further development and would eventually die. All experiments using pupae (both center and off-center holes) subjected to irradiation for 3 minutes at 95 and 100 percent of power were lethal.

Larvae placed in dry wood (**Table 5**) 'ied more quickly and under less severe conditions than in the moist wood experiments. Larvae placed in center holes of 4- by 4- by 1-inch blocks died in 5 seconds at 80 percent power. Larvae placed in the center hole of 4- by 4- by 4-inch blocks were killed in 5 seconds at 100 percent power. MC could be one reason for these observations. Unpublished dielectric studies on these five wood types conducted at Pennsylvania State University showed that transmission of microwaves at 10-GHz frequencies through the dry wood is much greater than through the green wood. If, as expected, this trend holds true for 2.45-GHz frequencies, microwave interaction with the water in the wood may potentially shield the larvae and pupae. Eventually the temperature surrounding the insect in the wood will reach lethal levels, and/or a lethal dose of the microwaves may reach and interact with the insect itself.

Conclusion

The ALB poses a significant threat to U.S. urban and forest resources. Our preliminary findings indicate that ALB larvae and pupae in 4-inch or thinner poplar can be eradicated with relatively low levels of microwave irradiation of both moist and dry wood. Due to the small number of larvae irradiated, additional trials are being conducted in order to determine parameters for effective treatment. Temperature profiles for the five wood species studied were not predictable in the microwave field. Variation in MC, density, defects, or other parameters on the local level could be contributing factors. However, power and time appear to be sufficient parameters for lethal microwave treatment of poplar. As a method to control the geographic movement of the ALB, microwave energy may prove to be a feasible commercial process as an alternative to fumigation, heat, or preservative treatments.

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