Detection of Wetwood in Green Red Oak Lumber by Ultrasound and Gas Chromatography-Mass Spectrometry Analysis

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ABSTRACT

Ultrasound-based scanning systems have recently been commercialized to evaluate both green and dried lumber. These systems have been used to identify bacterial infection called wetwood in red oak lumber with good results. Previously, bacterial infection has been verified by the use of scanning electron microscopes or by visual inspection of the lumber after drying.

The purpose of the research described in this report was to investigate the relationship between ultrasound scans of green red oak lumber and the use of gas chromatography-mass spectrometry (CC-MS) to identify wetwood. Green Pennsylvania red oak lumber was evaluated on an ultrasound test bed system manufactured by Perceptron, Inc. This inspection provided complete sampling of the ultrasound waveform so that both time and energy-based signal processing were completed. Samples were obtained from the lumber ends and evaluated using CC-MS for the presence of resorcinol, pyrogallol and gallic acid in methanol extracts which are indicative of wetwood.

A useful relationship was identified between the relative level of wetwood and the energy-based ultrasound parameter. The strongest relationship was evident for those samples having high or medium levels of wetwood as classified by CC-MS evaluation.

INTRODUCTION

Bacterial infection, often called wetwood, is an abnormal condition of wood and causes substantial downgrade during lumber drying unless conservative drying schedules are used. The problem is especially significant with red and white oak lumber. This is important because approximately fifty percent of the United States (US.) hardwood lumber production is oak. It is estimated that from the 11-13.5 million board feet annual U.S. hardwood lumber production, wetwood related drying defects can claim up to 500 million board feet at a cost of $25 million (Murdoch 1992).

Wetwood is a condition of wood that is caused by anaerobic bacteria entering the lower bole or roots through injuries (Ward et al. 1972, Ward and Pong 1980, Ward and Zeikus 1980). This bacterial infection weakens the basic wood structure through breakdown of the middle lamella. Therefore, lumber containing wetwood is prone to drying stress related defects of splits, honeycomb, surface checks, collapse and ring shake (Ward and Pong 1980).

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Substantial research efforts have focused on using ultrasound inspection techniques to identify wetwood in green lumber. United States Forest Service (USFS) researchers found that there was a strong relationship between the speed-of-sound transmission and the presence of wetwood in red oak lumber (Ross et al. 1992, Verkasalo et al. 1993, Fuller et al. 1994, Ross et al. 1994, Fuller et al. 1995, Ross et al. 1995). The presence of wetwood in these studies was confirmed through visual inspection (wetwood lumber has a strong vinegar odor and is often discolored), through laboratory culture experiments and examination with a scanning electron microscope (SEM) and by visual inspection of the lumber after drying. Based on these results, patent protection on the use of ultrasound to identify lumber defects was obtained by the USFS (Ross 1994). Perceptron, Inc. licensed the base technology and developed a prototype test bed scanning system. Both time and energy-based ultrasound parameters have been used to identify wetwood and other lumber defects (Schafer, 1999).

Chemical analysis techniques have also been, used to identify the presence of wetwood in red oak lumber (Lawrence 1991, Pettersen et al. 1993). Gas chromatography-mass spectrometry (GC-MS) was used to provide a basic understanding of the wetwood chemistry by analyzing methanol extracts of various wetwood infection levels (Pettersen et al. 1993). Wetwood infected red oak had high levels of resorcinol and pyrogallol that were found in inner and middle heartwood samples. The presence of wetwood was confirmed through laboratory culture experiments and examination with SEM.

The objective of this project was to develop relationships between ultrasound parameters and the level of bacterial infection as identified through GC-MS. An ultrasound test bed was used to evaluate the relationships between energy-based parameters and the level of wetwood infection based on GC-MS results. Previous studies scanned across the width of the lumber sample. In addition to this technique, a subset of material was scanned through its thickness.

MATERIALS AND METHODS

Green red oak lumber was selected from a Pennsylvania sawmill. An effort was made to include lumber with obvious wetwood. The lumber was kept cool and covered before testing to minimize drying. Subsets of this lumber were run through ultrasound scans using a laboratory test bed system developed by Perceptron Inc. and based at the United States Forest Service Forest Products Laboratory (FPL). Schafer (1999) provided a detailed description of this test bed system. The lumber was scanned in two lumber orientations; across the width and through the thickness. Table 1 details the number of samples and the lumber orientation for each ultrasound scan type.

Table 1.--Material description and number of samples evaluated per orientation.

Thickness (in.)	Width (in.)	Length (in.)	Lumber Orientation for Ultrasound Scan	
			Across the Width	Through the Thickness
1.0	4-10	48	25 specimens	13 specimens

Before ultrasound testing, defects and defect positions were diagramed for future reference. Types of defects noted included knots, holes, splits, checks, ring shake and wane. The numbered face of each specimen was photographed after the test.

Width Scan

The lumber was fed through the ultrasound transducers at a speed of approximately 11 ft./minute. The air pressure setting for the transducers was set at 20 pounds per square inch (psi) to ensure good contact between the rolling transducers and the lumber. The transducers were positioned so that they came into contact at the midpoint of the specimen’s thickness. Figure 1 shows the setup of me transducers for the width scan specimens. The raw ultrasound waveform data was saved in a computer file named by board number for further analyses.

Thickness Scan

The test bed was reconfigured so that we could run the lumber on an edge to complete ultrasound scans through the thickness. FPL machine shop staff installed a metal rod type fence to assist in keeping the material from moving out-of-plane during the test. It was evident that just a small angle or changing the angle of the board resulted in significant signal strength reductions. A concentrated effort was made to eliminate that problem and to drive the material through as smoothly as possible. Figure 2 shows the setup used for through-the-thickness scanning.

The scanning bridge was positioned so that the transducers read at least two inches away from the lumber edge. A subset of 12 boards was scanned with this configuration. Several wider boards were run and then turned over so that scans were run 2 inches away from both edges. The transducer pressure was increased to 40 psi for these tests to obtain a clean signal. The lumber was fed through in the automatic mode with assistance from the researchers. The speed setting was approximately 11 ft/minute. The raw ultrasound waveform data was saved in a computer file named by board number for further analyses.

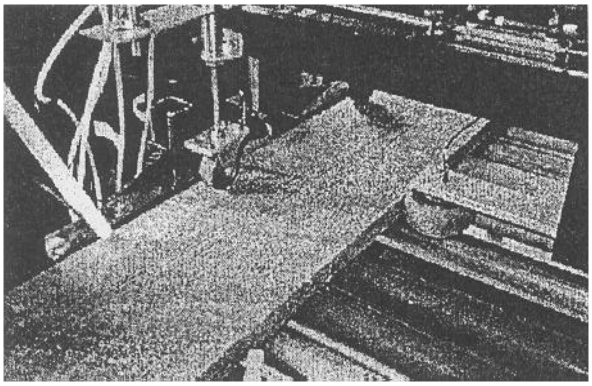

Figure 1.--Ultrasonic width scan of green red oak lumber

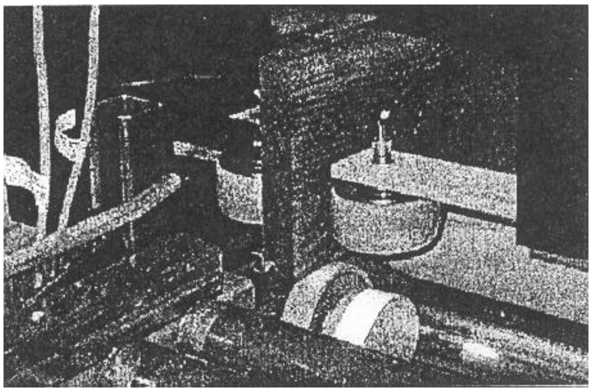

Figure 2.--Ultrasound thickness scan of green red oak lumber.

Gas Chromatography-Mass Spectrometry

Following the completion of ultrasound scanning, the lumber specimens were wrapped in plastic and placed in a cold room for storage before further processing. The temperature of the room was about 36°F. Samples for GC-MS testing were cut from each end of the lumber specimen. One inch of material was cut from each end and discarded. Then a 0.5-in long full-width section was cut from each end, placed in plastic bags, and stored in a refrigerator prior to GC-MS testing.

A full description of the GCMS testing process is found in Pettersen (1993). To summarize, the samples obtained from each board were allowed to air dry and then were ground to a 0.38-mm mesh in a Wiley mill. Each sample was then extracted with 250 mg of methanol. Trimethylsilyl (TMS) derivatives of methanol extract were then evaluated using GC-MS equipment at the FPL for the identification of gallic acid, resorcinol, and pyrogallol, which are indicative of the presence of wetwood in red oak lumber (Pettersen 1993).

RESULTS AND DISCUSSION

The GC-MS results were analyzed and each lumber specimen was classified as having the following relative levels of wetwood; none, trace, low, medium and high. These classifications were based on the relative levels of gallic acid, resorcinol, and pyrogallol present in each sample. Specimens with high levels of resorcinol and pyrogallol were classified as having high levels of wetwood. Table 2 lists the specimens and their level of wetwood as determined through GC-MS.

Table 2.--Red oak lumber samples and their relative level of wetwood as determined through GC-MS.

Sample	Level of Wetwood Based on GC-MS Testing				
	None	Trace	LOW	Medium	High
1				X	
6					X
10		X			
13					X
21					X
26				X	
29					X
30				X	
36		X			
44					X
47					X
58	X				
64				X	
67	X				
70				X	
78			X		
94					X
95				X	
99			X		
100				X	
101		X			
103					X
110	X				
111			X		
112			X		

The ultrasound waveform for each board was analyzed using a proprietary processing program to determine the average energy received response for each specimen. Ultrasound waveforms were captured every 1/8 in. along the length of each specimen. Therefore, for a representative 48 in. long red oak board, approximately 400 waveforms were analyzed to determine the average energy received. The energy received (E) is the time integral of the voltage (v) squared as shown in equation [1]:

$$[1] \qquad E = \int v^2(t)dt$$

The average energy loss (IL.) was also calculated for each board and is defined as the ratio of the ultrasound energy received by the receiving transducer (E_r) to the energy input of the transmitting transducer (E_t) taking into effect the receiver gain (G) as shown in equation [2]:

$$[2] \qquad IL(dB) = 10\log\left[\frac{E_r}{E_t}\right] - G$$

Table 3 shows the average E and IL for each of the wetwood classification levels. Results are shown for both lumber orientations; across the width and through the thickness. The red oak lumber with the greatest level of wetwood as determined through GC-MS had the lowest energy received values. This was expected since it is hypothesized that wood cells with wetwood have increased viscoelastic damping and therefore high energy absorption. Since IL is also an energy function, the relationship is similar. The IL is expressed in dB and is a negative number since the receiver cannot receive more energy than was input to the board. Based on these results it appears that the relationship between the level of wetwood and the energy parameters holds for lumber scanned through both its width and thickness.

It must be pointed out that the average values of E and IL were calculated for the entire 4-ft lumber length. This lumber was relatively clear and the ability to pick out wetwood maximized since there was little effect of other defects on the ultrasound signal response. It is possible to further refine parameters by focusing on lumber sections where the E is low and no evidence of other reducing defect exists. For example, two of the specimens in the low wetwood classification had very high energy levels as compared to the others in the data set. This skews the energy to wetwood relationships in the none to low classifications. It has been shown (Ward et al. 1972) that wetwood occurs conically up a tree and that it is possible that one end of a board is infected while the other is not.

Table 3.--Thomas Timberlands ultrasound data analyses.

Level of CC-MS Wetwood Classification	Lumber Scanning Orientation					
	Across the Width			Through the Thickness		
	Number of Specimens	Energy (mJ)	Insertion Loss (dB)	Number of Specimens	Energy (mJ)	Insertion Loss (dB)
None	3	12.3	-55.5	3	68.3	-37.0
Trace	3	5.4	-59.1	2	48.2	-39.1
Low	4	10.1	-57.0	4	35.4	-40.5
Medium	7	2.2	-63.4	2	15.6	-44.5
High	8	1.1	-68.3	2	4.0	-52.8

Note: mJ = milliJoules, dB = decibels

Figures 3 and 4 show the relationship in the width scanned lumber between E, IL and the extent of wetwood determined by CC-MS. There is generally good correspondence between low E, high IL and medium to high levels of wetwood. For the width scanned red oak, if levels of 2.5 mJ for E and -60 dB for IL were selected as cut-off values, fifteen samples were predicted to have high or medium wetwood. Of these values, fourteen were correctly classified. The one incorrect selection is 78. Using these values, one board (64) with medium wetwood is missed by identifying it as having low wetwood.

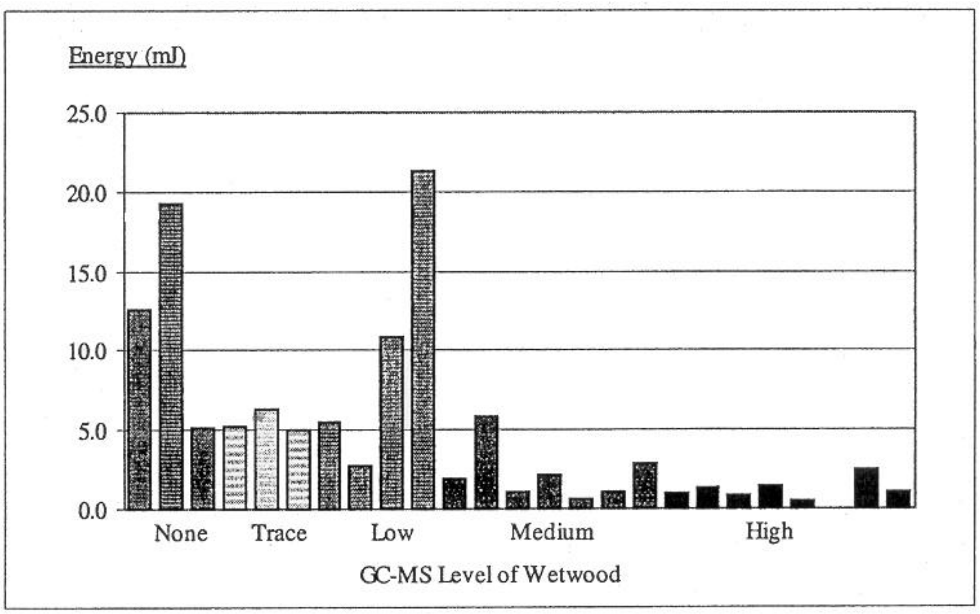

Figure 3.--Relationship in width scanned green red oak lumber between ultrasound energy received and the level of wetwood as defined by CC-MS.

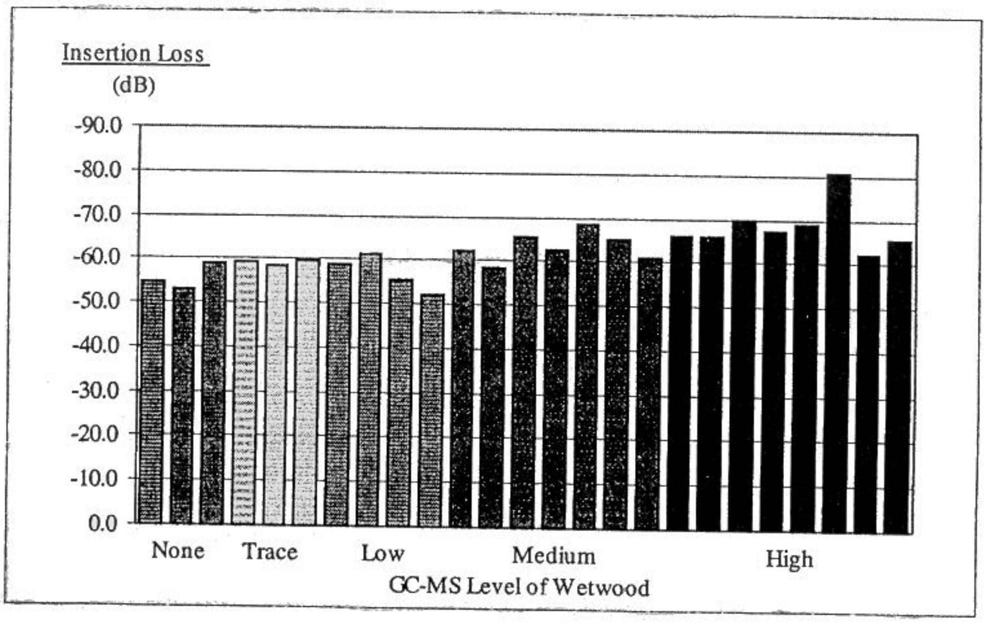

Figure 4.--Relationship in width scanned green red oak lumber between ultrasound energy loss and the level of wetwood as defined by GC-MS.

Figures 5 and 6 shows the relationship between received E, IL and relative wetwood amounts for the lumber that was scanned through its thickness. There was a useful relationship between the energy parameters of E and IL and the degree of wetwood. The data shows that for those specimens classified as having high wetwood, the E was very low (4.0 mJ) and the IL (-52.8 dB) was high as compared to samples without wetwood. These results are preliminary and are based on small sample sizes. Average values for the entire length of the lumber were used for the IL. The received signal through the thickness was greatly influenced by how straight the lumber went through and how the transducers coupled with the lumber. More work should be done on the coupling system to enhance the signal response.

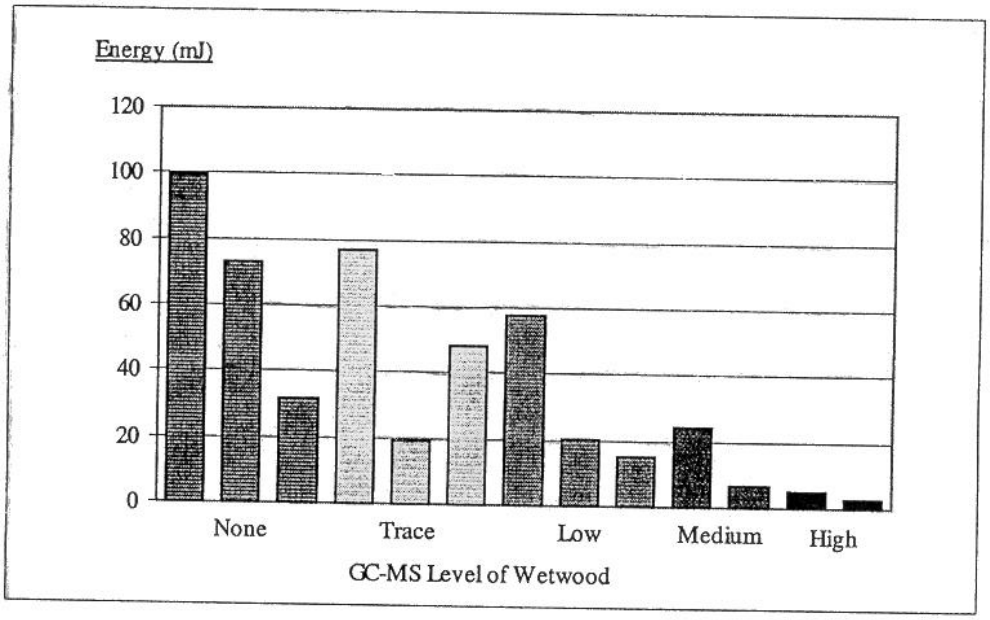

Figure 5.--Relationship in thickness scanned green red oak lumber between ultrasound energy received and the level of wetwood as defined by GC-MS.

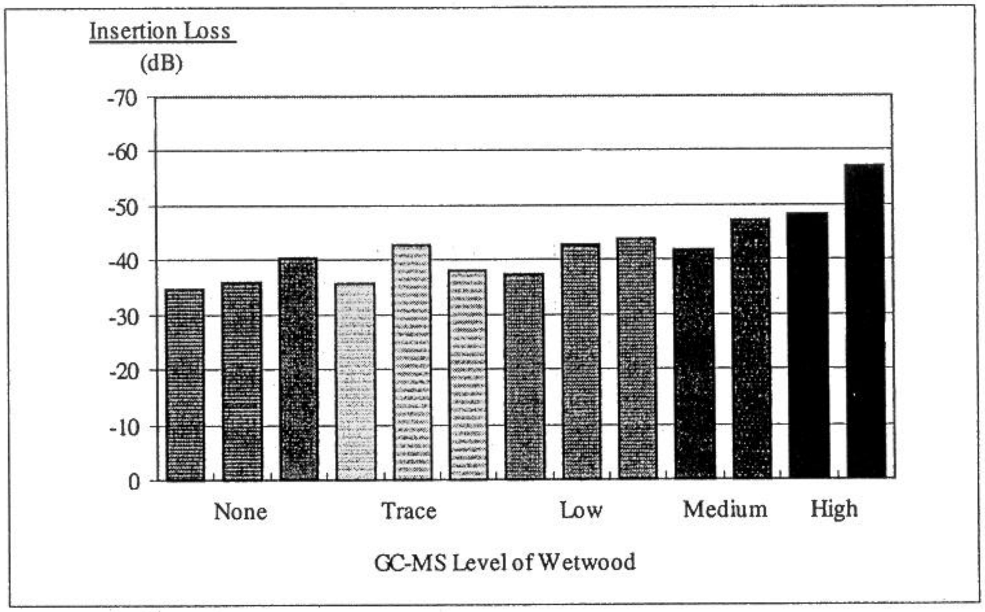

Figure 6.--Relationship in thickness scanned green red oak lumber between ultrasound energy loss and the level of wetwood as defined by CC-MS.

CONCLUSIONS

Based on the ultrasound lumber scanning completed during this project, the following conclusions can be made:

- The lumber supplied by a Pennsylvania sawmill was of high visual grade, with few defects such as knots, splits or other. This made the lumber signal easier to evaluate, since we could be confident that low energy corresponded to the presence of wetwood and was not caused by splits, knots, decay or other defects that reduce energy received.

- CC-MS testing showed that a wide range of wetwood levels was present in the lumber that was scanned. When scanned through the width, E and IL were effective predictors of wetwood levels in the red oak lumber. When E or IL were used as predictor parameters, 88% of the lumber samples were correctly identified as having medium or high wetwood levels. Low E and high IL were indicative of high levels of wetwood.

- Wetwood can also be detected by scanning through its thickness. As with scanning across the width, similar relationships hold between the E, IL and the level of wetwood as identified through CC-MS. When scanning through the lumber thickness, signal coupling was easily affected if the lumber was not firmly held at a 90-degree angle to the face of the transducers. Additional work should be completed to explore scanning through the thickness while perpendicular to the fiber orientation instead of parallel to the fiber orientation that was done during this study.

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The proceedings contains the papers representing the presentations and posters of the 12th International Symposium on Nondestructive Testing of Wood, organised by the University of Western Hungary, Sopron, 13 - 15 September, 2000. The proceedings are prepared before the symposium. Because of the strict deadline, some papers are missing from this volume. The "Proceedings Supplement" contains these papers.

The presentations were organised into the following seven subject areas:

- Sound and ultrasound
- Strength and MOE
- Standing Timber
- Nuclear techniques
- Microwave
- Thermography
- Inspection of structures

On the title page the names of the first six subjects are presented around a figure. This figure represents the top view of a new wooden dome structure at the Sopron campus of the University of Western Hungary. More information about the dome is available in the last poster abstract of this volume.

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