Nondestructive Evaluation of Defects in Wood Pallet Parts by Ultrasonic Scanning

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Abstract

Ultrasonic scanning experiments were conducted for detecting defects in wood pallet parts using rolling transducers. The characterization of defects is important for sorting and grading pallet parts, as well as for manufacturing quality and durable pallets. This paper reports the scanning results for stringers and deckboards – the two main components of pallet for red oak and yellow-poplar species. Sound and unsound knots, bark pockets, decay, splits, holes, and wane were characterized using several ultrasonic parameters. Each ultrasonic waveform collected was characterized using eight ultrasonic variables – three involving time of flight, two involving ultrasound pulse energy, one using ultrasound pulse duration, and peak frequency. The amplitude of ultrasound signals was significantly reduced by defects. The degree of dispersion of the power spectrum mostly depends on the severity and type of defects. The energy loss parameters are more sensitive to defects compared to time of flight measurements. Unsound knots, bark pockets, decay, holes, and splits are easily detectable and distinguishable using power spectrum, energy loss, and peak frequency parameters. Two-dimensional images were constructed from multi-line scanning data for each sample. The constructed images are able to show the exact location and area of the defects. Scanning properties of this prototype system suggest that an on-line system to inspect, sort, and grade wooden pallet parts is possible using rolling transducer ultrasonic inspection.

Introduction

Detection of defects in wood pallet parts is required to sort and grade components. High-quality pallet parts produce high-grade pallets, which ultimately extends a pallet's life and promotes multiple use. Typically, a wood pallet consists of two parts – stringers, the structural center members that support the load and deckboards and the top and bottom members that provide dimensional stability and a platform for product placement. The most common defects in pallet parts are knots, cross grain, bark pockets, insect holes, splits, decay, shake, wane, etc. Usually, pallet parts are produced from solid wood (lumber) or from the center cant material of logs. These cants have a high percentage of defects and have less market value for other solid wood products. An economic analysis by Schmoldt et al. (1993) showed that improved pallet durability and performance imparts much greater value to carefully manufactured pallets. Description of allowable defects for minimum pallet component quality are shown in **Table 1** (Anon 1994). Manual grading and sorting of pallet parts is a slow and inaccurate process, which depends on the individual skill of the grader. Moreover, the presence, location, and extent of defects in pallet parts are often difficult to ascertain accurately, making grading complicated.

Detection of defects in wood by nondestructive ultrasonic methods have been investigated by many researchers with a variety of ultrasonic parameters (McDonald 1980; Patton-Mallory and DeGoot 1990; Ross et al. 1992; Fuller et al. 1995; Niemz et al. 1999; Raczkowski et al. 1999; Karsulovic et al. 2000). Most of this work was carried out using ultrasonic waveform parameters such as time of flight (TOF) or propagation velocity measurements for the detection of defects. The basis of these studies is that the defects in wood changes ultrasonic signal propagation. Simple ultrasonic propagation velocity, however, may not be suffi-

Table 1. ~ *Minimum pallet component quality.*

Defect	Description	Defect limitations	
		Multiple use (M)	Limited use (L)
Sound knots	Maximum portion of the cross section affected	1/2	7/8
Frequency of knots	Number of maximum size knots per component	2 in 6 in.	1 in every half length of component
Unsound knots and holes	Maximum portion of the cross section affected	1/4	2/3
Wane	Maximum portion of the actual deckboard or stringer board width by thickness	1/4 by 2/3 (exposed) 1/3 by 2/3 (non-exposed)	3/8 by full thickness (exposed) 1/2 by full thickness (non-exposed)
Decay	Maximum portion of the cross section affected	1/4	1/4

cient to characterize all types of defect; especially, when there are different types of defects in one sample. Some defect types may not affect velocity, but may impact other ultrasonic parameters, e.g., peak amplitude, time to peak amplitude, centroid time, energy loss, frequency domain energy, etc. Individual past studies have only looked at a single type of defect in relation to clear wood, e.g., knots (McDonald et al. 1969; Kabir et al. 1997; Niemz et al. 1999), incipient decay (Wilcox 1988), decay (Patton-Mallory and DeGoot 1990), checks (Fuller et al. 1995). Halabe et al. (1993, 1994, 1996) reported that the frequency domain analysis is useful for detecting decay in wood. These studies were additionally restrictive in using either specially prepared laboratory samples or surfaced lumber. But in practice, the situation is quite different because pallet manufacturers use low quality, unsurfaced wood during manufacturing.

For the last few years, research has been conducted to develop an automated ultrasound scanning system for pallet parts (Schmoldt et al. 1994, 1997; Kabir et al. 2002; Brashaw et al. 2000). These studied showed that ultrasonic scanning is useful for detecting defects in pallet parts. This paper describes the scanning results for yellow poplar and red oak deckboards and stringers.

Materials and Methods

The ultrasound scanning equipment was designed by the Ultrasonics Group, Forest Products Division of Perceptron Inc. The system consists of in-fed and out-fed roll beds, two pinch rollers for part movement, and two rolling transducers which are mounted in an ultrasonic scanning ring. Pallet parts move through the system face down and an ultrasonic signal propagates through the board thickness. Perceptron provided the necessary electronics and software to control material movement, signal generation, and waveform capture and data analysis. Data were collected, stored, and processed using Lab View™ software modules. The desired resolution can be achieved by controlling roller speed and the number of pulses generated and received per second.

Eight ultrasonic variables – energy, pulse length (PL), time of flight-centroid (TOF-centroid), time of flight-energy (TOF-energy), time of flight-amplitude (TOF-amplitude), energy value (EV), energy/pulse value (EPV), peak frequency (PF) – were measured. The wave energy of the received signal can be expressed as the time integral of the voltage:

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

The energy value or loss is expressed as the ratio of the energy received by the receiving transducer to the energy input to the transmitting transducer, and is given by:

$$EV = _{10}\log\left[\frac{E_r}{E_t}\right] - G \qquad [2]$$

where:

E_r = the energy received by the receiving transducer,

E_t = the energy input to the transmitting transducer, and

G = the receiver gain.

This parameter is normally expressed in decibels (dB) and by convention on a logarithmic scale (and hence a negative number), with lower signal ratios being more negative. The pulse length parameter (in units of microseconds) is simply the time for which the pulse is "on" and depends upon the ultrasound frequency. It is defined as the time required for the received energy to rise from 10 to 90 percent of its total energy. The energy value and pulse length can be combined into a single parameter, known as energy/pulse value (EPV) to provide more defect resolution. Again, because of the wide range of energy levels, EPV is also expressed on a logarithmic scale (dB). TOF-energy is calculated as the time at which the integral crosses a threshold value-as a percentage of final (maximum) value. If the threshold value is, for instance, 40 percent, then TOF-energy is simply the time at which the integral value reaches 40 percent of the final value. Similarly, TOF-amplitude is the time at which the amplitude of the signal first reaches 40 percent of the final value. TOF-centroid is the time to the centroid of the time waveform, which is based on the ratio of the first- and zeroth order moments.

Twenty-one deckboards and eighteen stringers consisting of red oak and yellow poplar were collected from local sawmills for oak and yellow poplar. They were fresh cut, unplanned, and of varying lengths. The average thickness of the deckboards and stringers were 1.27 cm and 3.8 1 cm, respectively. The boards were placed into cold storage immediately to keep their moisture content near the fresh cut level. Scanning of deckboards and stringers were conducted in two ways. First, a line was drawn lengthwise on each board through a defect of interest, and scanning was performed along the line. This was done to get data for clear wood and defected wood. Second, similar lines were drawn from end to end across the width of the board, and scanning was conducted along the six lines. These multiple lines scanning were used for reconstructing two-dimensional images. The scanning resolution was 0.1 inch. Measurements were carried out at 12 kHz transmitting frequency and received signals were sampled at 500 kHz.

Results and Discussions

Eight ultrasonic parameters-energy, pulse length (PL), time of flight-centroid (TOF-c), time of flight-energy (TOF-e), time of flight-amplitude (TOF-a), energy value (EV), energy/pulse value (EPV), peak frequency (PF) were collected from each scan. The amplitude of the received ultrasonic signal through clear and defective wood in frequency domain are shown in **Figure 1.** A substantial change in signal amplitude was noted for almost all types of defects for both deckboards and stringers of oak and poplar. The defects, such as bark pocket, and decay reduced the signal amplitude significantly as shown in **Figure 1 (top and bottom).** However, it is hard to classify each defect using signal amplitude, because the reduction of amplitude for many of these defects are similar. The power spectrum, which is the average of the magnitude squared of multiple frequency spectra, is presented in **Figure 2 (top and bottom)** for clear and defective wood. It is clearly seen from these figures that the defective wood has a more dispersed spectrum compared to the clear wood. The variation of the magnitude of the spectrum can be used as a tool for classifying the defects. The power spectrum for decay is more dispersed than for the bark pocket as seen in **Figure 2.** The magnitude and the characteristics of the spectrum mostly depend on the severity and type of defects.

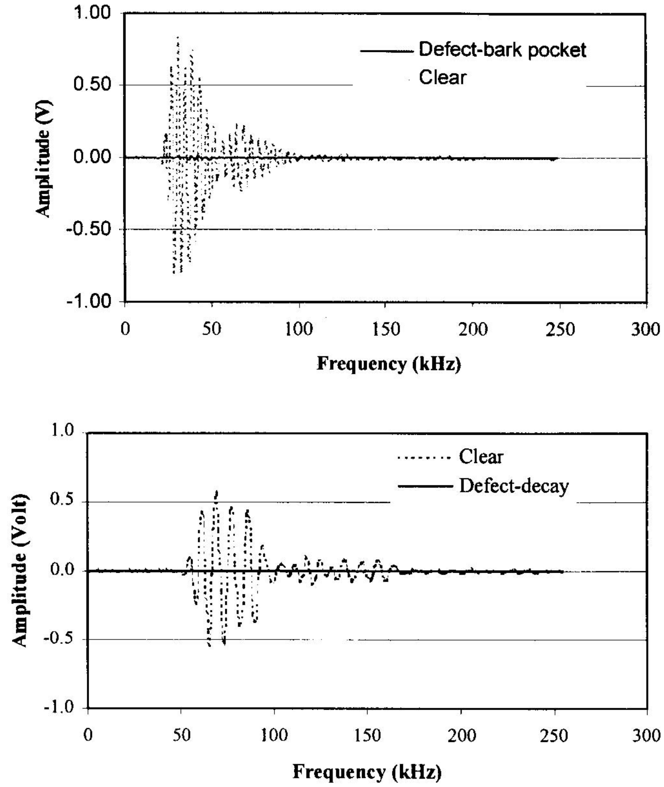

Figure 1. ~ *Frequency domain ultrasonic signal amplitude through defective and clear wood. (Top) bark pocket of poplar deckboard; (bottom) decay of oak stringer.*

Figure 3 presents the response of different ultrasonic parameters to an unsound knot of an oak deckboards. The parameter's value was plotted against the board length. All the parameters values change rapidly in the region of the unsound knot, except PF and TOF-a. Sound and unsound knots have very little effect on the TOF measurement and represent longitudinal fiber orientation in the sound transmission. In this experiment, the scanning was conducted perpendicular to the grain, either in the radial or tangential direction. Usually, knots are associated with cross grain or interlocked grain. For that reason, a small change in TOF was observed between clear wood and knots. The energy of the received signal decreases to near zero through the unsound knot. The EV and EPV decrease considerably, as the energy vanishes **(Fig. 3b).** Similar results were also found for other defects, but to a different extent. Unsound defects exhibit some disintegration of wood material and may contain bark or decay. This loss of material integrity reduces the energy trans-

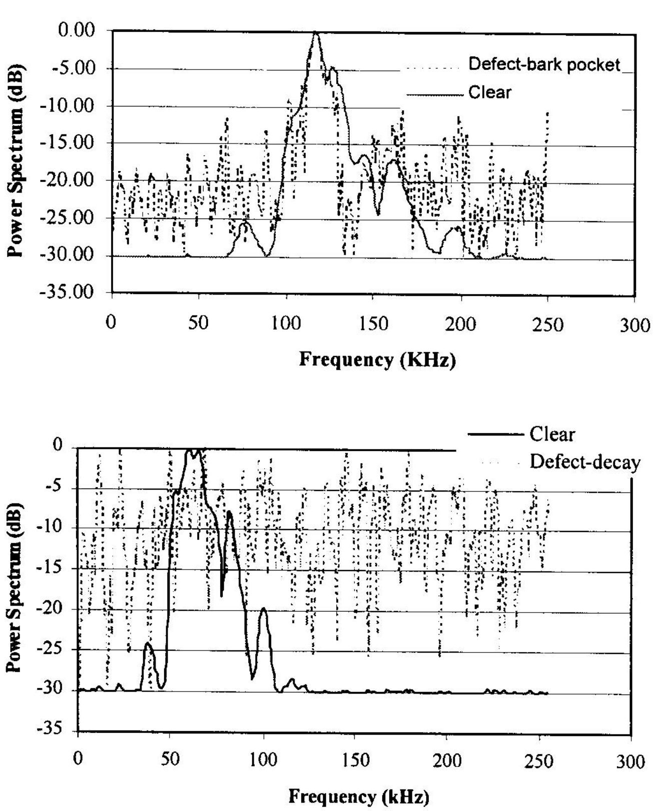

Figure 2. ~ *Power spectrum through defective and clear wood, (top) bark pocket of poplar deckboard (bottom) decay of oak stringer.*

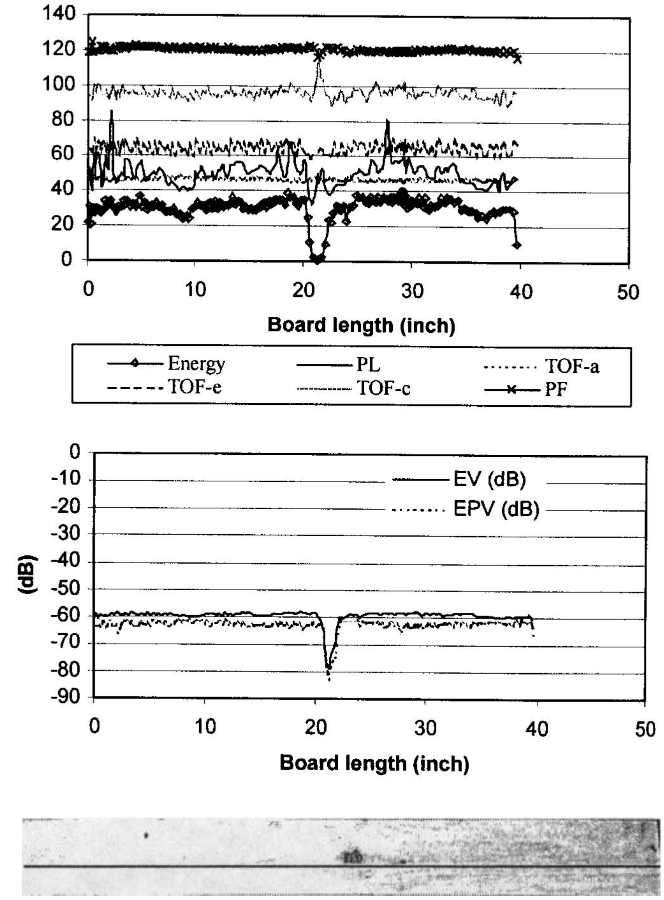

Figure 3. ~ *The response of different ultrasonic parameters to the unsound knot of an oak deckboard, a) energy, PL, TOF-a, TOF-e, TOF-c, and PF, (b) EV and EPV.*

mitted (increased loss) and increases the time that it takes for the energy to move through the material. The effect of decay on the ultrasonic parameters for poplar stringer are shown in **Figure 4.** Decay has a greater effect on measured ultrasonic parameters compared to unsound knots. Unlike unsound knots, PF increases sharply in the region of decay **(Fig. 4a).** The energy loss through decay is much higher than for other defect types. As clearly seen from the **Figures 3 and 4,** the extent of the defect can easily be determined as it is plotted against the board length.

Two-dimensional images were constructed for each ultrasonic parameter from multi-line scanning data. The reconstructed images for oak stringers using EV are shown in **Figure 5.** The reconstructed images are able to show the exact position and surface area of the defects. In some cases, the defects in the reconstructed images have greater surface area than the actual defect. This can be explained by the fact that the position of the knot on both the faces deviated from perpendicular position affecting ultrasonic measurements. The grain deviation around the knot contributes a lot to the defect characterization, which can be hard to ascertain visually on the actual board.

Conclusions

Most of the measured ultrasonic parameters were affected by the presence of defects in yellow poplar and oak deckboards and stringers. The amplitude of ultrasonic signals were reduced significantly by all types of defects, such as sound and unsound knots, bark pockets, decay, wane, holes, etc. A substantial change of the power spectrum through defective wood was also observed both for deckboards and stringers. The degree of dispersion of the power spectrum depends on the severity and type of defect. This observation can be used for classifying defects. The EV and EPV were the most sensitive parameters for detecting defects. These parameters were reduced considerable by unsound knots and decay. Decay has a greater effect on the ultrasonic measurements. Reconstruction of two-dimensional images were able to provide the exact location and surface area of the defect. This study suggests that on-line quality evaluation, sorting and grading of pallet parts is possible using ultrasonic scanning.

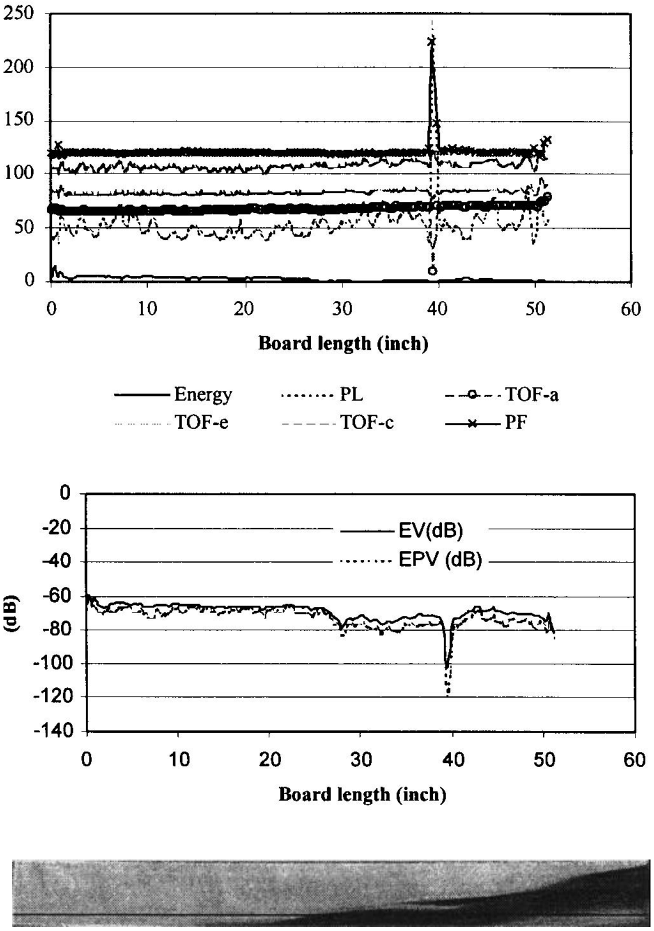

Figure 4. ~ *The effect of decay on the ultrasonic parameters of a poplar stringer, a) energy, PL, TOF-a, TOF-e, TOF-c, and PF, (b) EV and EPV.*

Figure 5. ~ *Reconstructed images from the scanning data of EV and side view photos of the board for oak stringers.*

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