ULTRASONIC INSPECTION OF WOODEN PALLET PARTS FOR GRADING AND SORTING

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INTRODUCTION

Wooden pallets are the largest single use of sawn hardwood logs in the USA. Unfortunately, millions of wooden pallets are discarded annually due to damage or because their low cost makes them readily disposable. High quality wooden pallets, on the other hand, promote longevity and re-use. However, building durable pallets requires high quality pallet parts. Because manual grading and sorting of pallet parts is not feasible, we have as a long-term goal to develop an automated inspection system. It will scan moving parts in a production environment, locate and identify defect areas, and grade the parts according to established visual grading rules.

Most wooden pallets are constructed from two types of pallet parts (Figure 1): (1) stringers--the structural center members and (2) deckboards--the top and bottom facing materials that provide dimensional stability and product placement. There are many variants of this basic design, but most pallets contain solid wood components that are produced from lumber or from the center cant material of logs. A cant is a rectangular volume of wood taken from the center of a log, material that has a high number of defects and is generally not valuable for other products.

Ultrasonic testing has been used by other investigators to examine wooden objects. Previous work has established that knots can be detected in structural lumber [1, 2], decay is detectable in structural timbers [3, 4], beams can be graded for strength *in situ* [5], dry-coupled transducers can be used to detect knots and decay in timber bridge members [6], knots, decay, and cross grain are detectable in small laboratory samples [7], and wooden art objects can be examined for small cracks and other degradation [8]. In each of these studies species, such as southern yellow pine *(Pinus* spp.), Suisse spruce, Douglas-fir *(Pseudotsuga menziesii* (Mirb.) France), white fir *(Abies concolor* (Gord. and Glend.) Lindl. ex Hildebr.), and balsa *(Ochroma lagopus* Sw.), were examined. With the exception of cork-like balsa and work by [6] on oak, these are all softwood species. Hardwoods

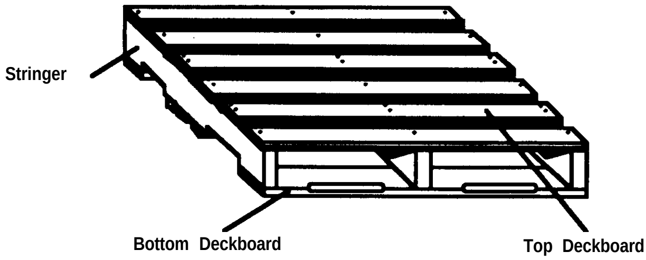

Figure 1. A typical stringer class wooden pallet contains three load-supporting stringers in the center and five to seven deckboards on the top and bottom.

differ substantially in wood structure, however. Therefore physical and mechanical properties also differ, and previous results on ultrasonic examination of softwoods may not apply directly to hardwoods. Because many different hardwood species are used in pallets, our inspection methods must be adaptive to interspecific dissimilarities. Additionally, pallet parts are rough cut, and therefore wood surfaces can vary greatly in smoothness and hence their reflectance of elastic waves.

Previous successes in ultrasonic testing of wood and its ability to characterize internal as well as surface features led us to select it for this application. Nevertheless, flaws that degrade pallet parts must be characterized in unique ways that have not been specifically quantified in previous studies. For example, Table 1 contains an abbreviated set of grading rules that are applied to categorize pallet stringer quality into grades "2 and better," 3, and 4. Therefore, this study has sought: (1) to determine the ultrasonic parameters (mode and frequency of excitant, couplant, scan pattern) that are most effective for circumscribing pallet part defects and (2) to specify what aspects of ultrasonic response signals (time of flight, RMS voltage, amplitude, etc.) best mirror actual defect size and location and the descriptors (e.g., cross section) used to measure them.

Table 1. Partial list of grading criteria employed for stringers

Defect	Description	2 & BTR	3	4
Sound knots	Maximum portion of cross section affected	1/4 of cross section	1/3 of cross section	1/2 of cross section
Location of knots	Over notch or in end 6" of the stringer	1/2" max. diameter	1/4 of cross section	1/3 of cross section
Unsound knots/holes	Knot holes, unsound or loose knots, and holes	1/8 of cross section	1/6 of cross section	1/4 of cross section
Cross grain	Slope of general cross grain	1" in 10"	1" in 8"	1" in 6"
	Max. dimension of local cross grain	1/4 cross section	1/3 cross section	1/2 cross section
Splits, checks, and shake	Max. length singly or in combination Defects 3" or less are ignored	1/4 of length of part	1/2 of length of part	3/4 of length of part

METHODS

To understand the interaction of wood and ultrasound, it is important to know something about the structure of wood. The wood raw material is the stem of a tree. It consists of cellulose and hemicellulose fibers oriented with the axis of the stem (longitudinal). A new layer of wood is added to the circumference of the tree annually. This creates a radial axis, and perpendicular to the radial direction there is a tangential axis. Figure 2 depicts these three axes in relation to a typical piece of lumber. Depending on how lumber is cut from a log, however, the tangential and radial axes may rotate 90° with respect to lumber dimensions. The rotation of these two axes across different pieces of wood makes ultrasonic examination extremely variable. The 3-dimensional orientation of wood fibers gives wood a strong orthogonal structure and makes it highly anisotropic.

Ultrasonic testing of pallet parts was performed using the equipment depicted in Figure 3. An ultrasonic sine pulse was generated every 10 milliseconds at 250KHz and 0.3 volts in a through-transmission arrangement. Petroleum jelly was used as a couplant. Peak amplitude and time of flight were measured. On the basis of material thickness measurements, propagation velocity was then calculated. Two sets of experiments were carried out in this manner.

RESULTS

Experiment 1

In the first experiment, samples of rough cut, undried northern red oak (Quercus *rubra* L.) were obtained from a local pallet manufacturer. There were 7 stringers with dimensions: 52 inch long by 3-1/4 inch wide (± 1/8 inch) by 1-11/16 inch thick (± 1/16 inch) and 9 deckboards with dimensions: 36 inch long by 3-3/16 inch wide (± 1/16 inch) by 11/16 inch thick (± 1/16 inch). Edge-to-edge through transmission of ultrasonic pulses was applied every 2 inches along their length. Because of the way in which pallet parts are cut from cant material the direction of ultrasound transmission varied from radial to tangential. We selected the edge-to-edge arrangement because of its simplicity. In an industrial setting this method would only require two stationary transducers and pallet parts could move between them.

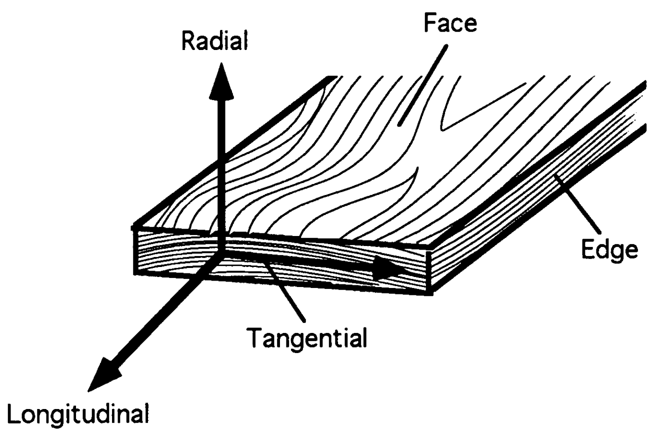

Figure 2. A typical piece of lumber has three orthogonal components that are derived from the structure of wood fibers in a tree. Orientation of the radial and tangential directions will vary (up to 90°) with respect to lumber dimensions depending on the log sawing pattern.

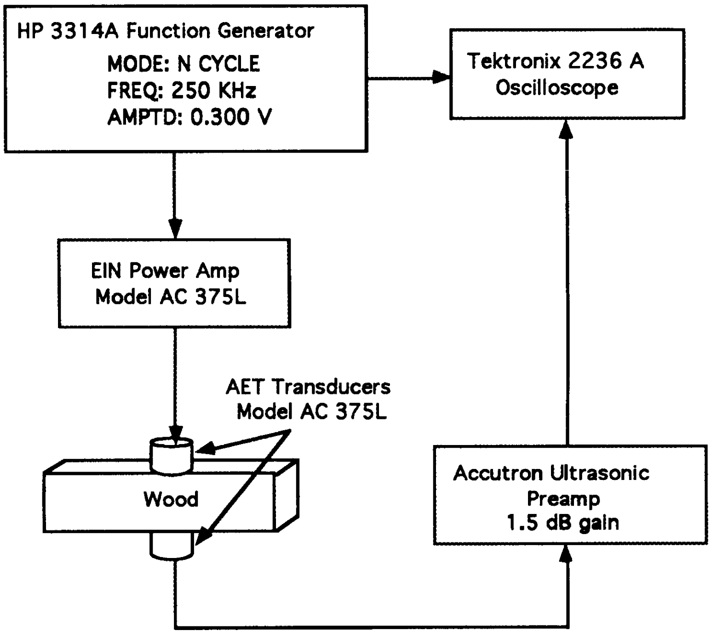

Figure 3. A through-transmission arrangement was used to scan pallet part samples.

Actual values for velocity and amplitude varied considerably from sample to sample. To analyze the response of these signals to different wood characteristics, however, we needed to pool the data from all deckboards and from all stringers. Therefore, we normalized the amplitude and velocity values for each sample. Figure 4 contains plots of normalized amplitude versus normalized velocity for all deckboards with respect to different wood characteristics, namely clear wood, sound knots, unsound knots, cross grain, and splits/check/shake. Similar plots were obtained for the stringers tested. For space reasons they are not included here.

Experiment 2

A second experiment investigated ultrasonic signals in a single deckboard. The sample was again red oak with dimensions 36 inch X 3-1/4 inch X 11/16 inch. The experimental apparatus was identical to the first experiment. In this case, however, the sample was scanned in a face-to-face manner. Through-transmission measurements were taken every 1 inch in a raster fashion across the face of the deckboard. Pulses were generated every 1/2 inch near defect areas. In addition to time of flight and peak amplitude measurements, time-to-peak amplitude was also recorded. From these, velocity and velocity to peak amplitude were calculated. As in the previous experiment, data were normalized. Only one type of defect (sound knots) was present on this board. Figure 5 depicts pairwise plots of velocity, peak amplitude, and velocity to peak amplitude.

CONCLUSIONS

Clear wood areas and defect areas exhibit different response trends for both velocity and peak amplitude. Velocity is either below the mean (Figure 4) or unaffected (Figure 5) by clear wood, whereas sound and unsound knots have velocities above the mean. Unsound knots tend to have peak amplitudes below the mean value, and similarly for split/check/shake areas. Velocity-to-peak values in Figure 5 do not exhibit any recognizable pattern for either clear wood or sound knots. There does seem to be, however, a two-cluster pattern in the latter two clear wood plots; this result remains unexplained at this time.

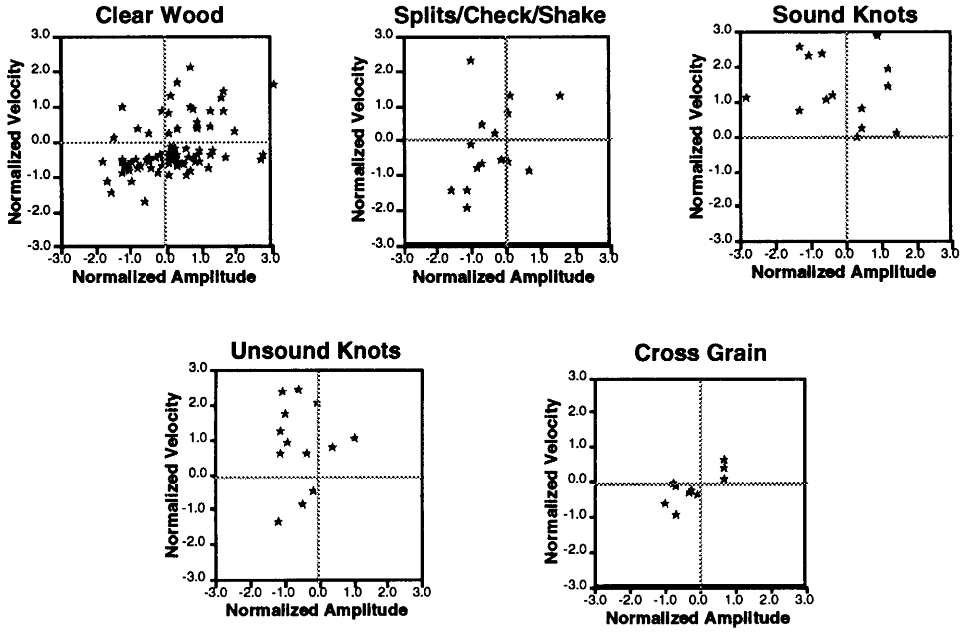

Figure 4. Five plots relate normalized velocity to normalized peak amplitude for clear wood, splits/checks/shake, sound knots, unsound knots, and cross grain.

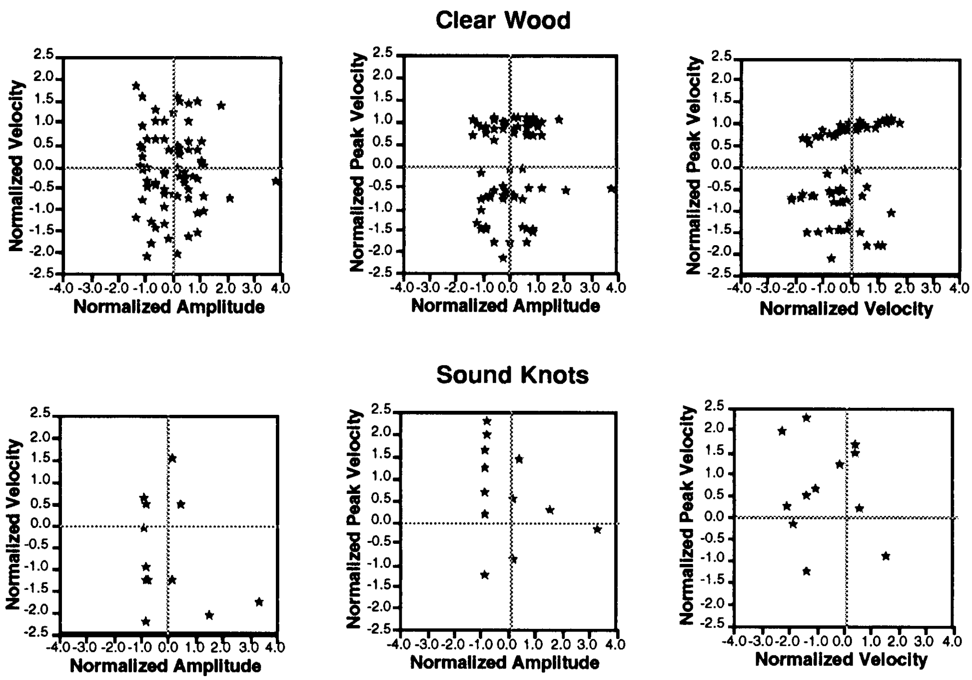

Figure 5. Pairwise plots of normalized peak amplitude, normalized velocity, and normalized velocity to peak amplitude illustrate the impact of knots versus clear wood for face-to-face through transmission of a single oak deckboard.

Structural lumber and appearance lumber are cut from the outside portions of logs. Consequently, they have orthogonal characteristics similar to those in Figure 2 that are consistent throughout a single piece of material. Pallet parts, however, are cut from the centers of logs. In this case, the orthogonal geometry can vary throughout the piece. For example, face-to-face scans across a stringer cut from the center of a log can have both entirely radial and entirely tangential ultrasound transmission as one moves the transducers along a face from one edge to the other. Because the radial axis tends to have higher ultrasound velocity [2], this can limit the use of velocity measurements for defect detection.

Although the data exhibit some obvious patterns with respect to velocity and peak amplitude, the amount of variation in the data precludes the direct application of these results for classifying arbitrary ultrasound signals. There may be other aspects of ultrasound response signals that can distinguish these features more clearly, e.g., RMS voltage, frequency domain analysis, or response signal signatures. We are also investigating higher ultrasound frequencies and smaller transducer diameters to probe the microstructure of pallet parts in finer detail.

ACKNOWLEDGEMENTS

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