Pallet Part and Cant Evaluation for Grading and Processing Using High-Speed Ultrasound

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Abstract

This paper presented the results of several years of testing the use of ultrasound to find structural defects in pallet parts and pallet cants used to produce pallet parts. To determine the magnitude of unsound defects, we inspected full length cants from seven saw mills from Virginia and West Virginia. Split, wane, shake, holes, decay, unsound knots, bark pocket, and mechanical defects were all considered as unsound defects. Regardless of mill and species, split accounted for the highest percentage of defect volume per cant. Decay: bark pockets, shake, and holes also contributed significantly to the total defect volume. The scanning results of deckboards, stringers and cants showed that ultrasound can be used effectively to locate, identify, and quantify the various pallet parts defects. Significant losses of ultrasound signals/energies were observed through these defects. Other ultrasound parameters, such as time of flight, pulse length can be used for characterizing defects. Reconstructed two-dimensional images were able to show the exact position and surface area of the defects. Defects can be classified/distinguished using classifying tools like multi-layer perceptron, probabilistic neural network, and k-nearest neighbor. Results demonstrated that real-time, online inspection and classification of defects in wooden pallet parts are possible by ultrasound scanning. Results also showed that pallet cants can be graded by unsound wood content and that processing full length cants to cut-to-size cants can be optimized with the knowledge of defect size and location provided by the ultrasound scanning.

Introduction

Grading and sorting of pallet parts are important for manufacturing high quality and longer lasting pallets. Cants are the primary raw materials for the production of pallet part components, such as stringers and deckboards. The stringers form the structural center members that support the load, and the deckboards are the top and bottom members that provide dimensional stability and a platform for product placement. Usually, pallet parts are produced from the low grade lumber or cants. These cants have a higher percentage of defects, and therefore have less or no market value for other solid wood products. Use of higher quality cants results in higher parts yields, providing longer pallet life cycle. Higher quality pallet parts will ensure reuse of discarded pallets. Individual pallets are constructed from a variety of wood species and from parts with differing strength properties, resulting in pallets with random and unknown strength durability. Descriptions of allowable defects for minimum pallet component quality are shown in **Table 1** (Anon 1994). These data are incorporated from the Standards for Wood Pallets, National Wooden Pallet and Container Associations (NWPCA). It is obvious from this table that defect information is important for manufacturing quality and durable pallet. Presorting and optimized sawing of pallet parts can reduce processing cost and will produce higher grade pallet parts. Schmoldt et al. (1993) also showed that increased pallet durability and performance impacts in a positive way the cost of using a pallet. Manual grading and sorting of pallet parts is a slow, inaccurate, and difficult process, which depends on the individual skill of the grader. Moreover, the presence, location, and extent of the defects in pallet parts are often difficult to determine accurately, making manual grading complicated.

In the last decades, ultrasound became a popular tool for nondestructive evaluation of wood and wood- based products. The great advantage of using ultrasound is the direct relationship with the density, and elastic stiffness of wood. Generally, the defects found in pallet parts are sound and unsound knots, decay, splits, bark pockets, wane, etc. The location, extension, and type of defects must be characterized for grading and sorting of pallet parts **(Table 2).** The severity and extent of these defects often depends on the species as shown by Araman et al. (2003). **Figure 1** illustrates how ultrasound scanning can be used for optimized sawing and increased yield of pallet parts from cants. The most common way of detecting defects is the measurement of transmission time through clear and defected wood. The measurement of transmission time is useful when there is only a single type of defect in board. Some defect types may not respond well to the transmission time, but may respond the other ultrasonic parameters, e.g., peak amplitude, centroid time, frequency domain energy, etc (Halabe et al. 1994, 1996). The recognition and classification of defect types in a single board is a very difficult and complicated task, since changes in the measurement parameters for many of these defects are similar. For the last few years, research has been conducted to develop an automated pallet part inspection system (Schmoldt 1997, Kabir et al. 2002, 2003). This paper discusses the possibility of ultrasound scanning for cant evaluation and pallet part grading.

Unsound Defect Evaluation of Cants

Seven sawmills were selected in Virginia and West Virginia to inspect pallet cants. Mill selection was based on the convenience of travel, type of sawmill operation, and willingness to participate. The species available and studied were red oak, white oak, yellow-poplar, and basswood. Cants were 10 to 16 feet length, 6 inches in width, and 4 inches in thickness. Defect data was then collected for any occurrence of splits, wane, shake, holes, rot, decay, unsound knots, bark pockets and mechanical defects. Defects were identified and classified according to the NHLA grading rules (Anon 1994). An imaginary rectangular solid was visualized around each defect, such that the entire unsound area was encompassed. Length, width and height dimension measurements were taken of the imaginary solid. All the measurements were taken from the wide face of the cant, even if the defect was located on the narrow face. If a defect was only visible on one face of the cant, the dimensional depth of the defect was estimated. **Figure 2** shows a typical defect measurement on a cant.

Scanning Equipment

The ultrasound scanning machine was designed by the Ultrasonics Group, Forest Products Division of Perceptrons 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, as presented in **Figure 3.** Pallet parts move through the system face down and ultrasonic signal propagates through the board thickness. Perceptron provided the necessary electronics and software to control material movement, signal generation, waveform capture and data analysis. The desired resolution can be achieved by controlling roller speed and the number of pulses per second.

Scanning of pallet material

Twenty one deckboards and eighteen stringers consisting of red oak and yellow poplar were collected from local saw mills. They were fresh cut, unplanned, and of varying lengths. The average thickness of the deckboards and stringers were 1.27 cm and 3.81 cm respectively. The boards were placed into cold storage immediately to keep their moisture content near the fresh cut level. We also collected pallet cant samples from local sawmills for scanning. Scanning of cants, deckboards and stringers were conducted in two ways. First, a line was drawn on lengthwise for each board through a defect of interest, and scanning was performed along the line. This was done just 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 2-D 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

Red oak. white oak, yellow-poplar. and basswood were used for defect characterization. About 823 cants were studied for defects. such as bark pocket, unsound knot, decay, hole, shake, wane, split. etc., majority of which were oak (73%). Regardless of the mills and species, the average unsound defect percentage per cant for each defect type are presented in **Figure 4.** Split was found to be the highest volume-occupying defect, followed by decay. Bark pocket, hole, and shake contribute equally to the total unsound defect volume. The average unsound defect percentage for each species over all mills was shown in **Figure 5.** White oak had the highest average percentage of unsound materials while basswood had the lowest. This study suggests that species information play an important role for any automated processing and grading. Certain species might be prone to certain defect types because of their physical and chemical properties. For example, white oak might be more susceptible to insect damage than yellow-poplar. Cants were classified as a percentage of total defect volume and the results are presented in **Figures 6.** Regardless of the mill and species, only 2% of the cants have an unsound defect volume greater than 30%. Most of the cants (about 90%) are within 10% defect volume.

Pallet material, such as cants, stringers and deckboards were scanned using rolling transducers and some of the results are presented in **Figures 7a** and **7b.** This ultrasound scanning system is able to identify and quantify all type of defects including sound and unsound knots, decay, bark pocket, splits, holes, and wane. The data collection with this system were found repeatable and reliable (Kabir et al. 2002). **Figure 7a** showed energy value through defected cants of about 4" thickness-line 1 through wane and line 3 through unsound knot. The extension/length of the defect can easily be determined since the results are plotted against the length. Some of the defects are not visible from upper face (Fig. 7a), but tremendous loss of energy showed the presence of defects on the other face. This usually happened when thicker sample such as cants and stringers were scanned. Energy loss parameters were found to be very sensitive to all type of defects (Kabir et al. 2002). **Figure 7b** depicted the loss of energy through decay of poplar stringer. The length of the decay in the graph is smaller than that seen in the actual board (dark color). This happened because the wood may not lose its strength in early stage of decay, although color changes drastically. Other ultrasonic parameters, such as time of flight, pulse length, and peak frequency were found useful for characterizing defects as reported earlier (Kabir et al. 2001, 2003).

Two-dimensional images were constructed using energy value data from the multi-line scanning data for deck boards, stringers and cants. The example of the reconstructed image of poplar stringer is shown in Figure 8. The reconstructed images are able to show the exact location and surface area of the defects. However, in the reconstructed images we are unable to identify defect type. In many cases, the reconstructed images have greater surface area of the defect than the actual board or the position of defect moved compared to the actual defect position. This is particularly found in sound or unsound knots since grain deviation around the knot contributes a lot to the defect characterization, which can hard to ascertain visually on the board. The defects can be distinguished or classified using some classification tools such as artificial neural network, probabilistic neural network or k-nearest neighbor (Kabir et al. 2003). All these network were able to classify defective wood efficiently and the recognition rate was as high as 95 percent.

Conclusions

Among white oak, red oak, yellow-poplar, and basswood, white oak showed highest percentage of unsound defects whereas basswood exhibited the lowest. Splits were found to be the largest occurring defect followed by decay. Ninety percent of the cants studied here were found to have less than 10 percent of total volume, and only 2 percent of the cants had more than 30% unsound volume. The rolling transducer ultrasound scanning system was found to be a suitable and effective tool for detecting and quantifying unsound woods in deckboards, stringers and cants. Two-dimensional reconstructed images are able to find the exact location and surface area of defects. Using this ultrasound system and classifying software, unsound wood in pallet cants and parts can be identified and assessed for further processing. This study suggested that sorting and grading of pallet parts are possible using on-line ultrasonic scanning. The unsound volume in cants can be determined using reconstructed images, and thus, optimized sawing practices could be used to increase the value of material obtained from cants.

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Table 1. Minimum pallet component quality for multiple use.

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 x 2/3 (exposed) 1/3 x 2/3 (non-exposed)	3/8 x full thickness (exposed) 1/2 x full thickness (non-exposed)
Decay	Maximum portion of the cross section affected	1/4	1/4

Table 2. Criteria for grading of stringers

Defect	Description	2 & BTR	3	4
Sound knots	Maximum portion of cross section affected	¼ of cross section	1/3 of cross section	½ of cross section
Location of knots	Over notch or in end 6" of the stringer	½" max. diameter	¼ of cross section	1/3 of cross section
Unsound knots/holes	Knots holes, unsound or loose knots, and holes	1/8 of cross section	1/6" of cross section	¼ of cross setion
Cross grain	Slope of general cross grain Max dimension of local cross grain	1" in 10" 1/4 cross section	1" in 8" 1/3 cross section	1" in 6" 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
Wane	Max. portion of cross section affected at point of deepest penetration	1/16 of cross section	1/8 of cross section	3/16 of cross section

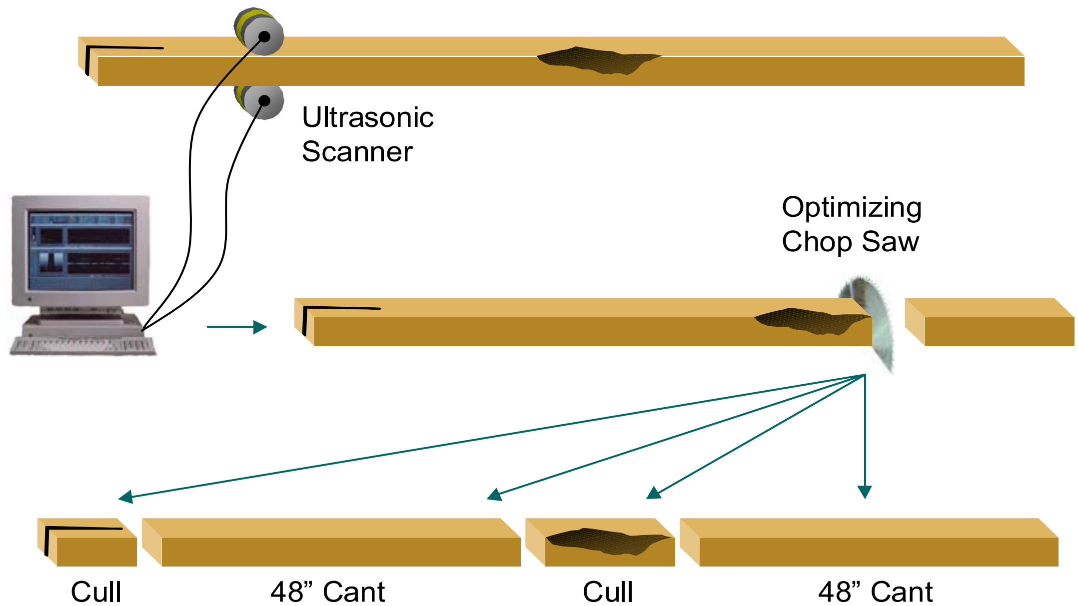

Figure 1. Schematic diagram for potential ultrasonic scanning for pallet cants to optimize value.

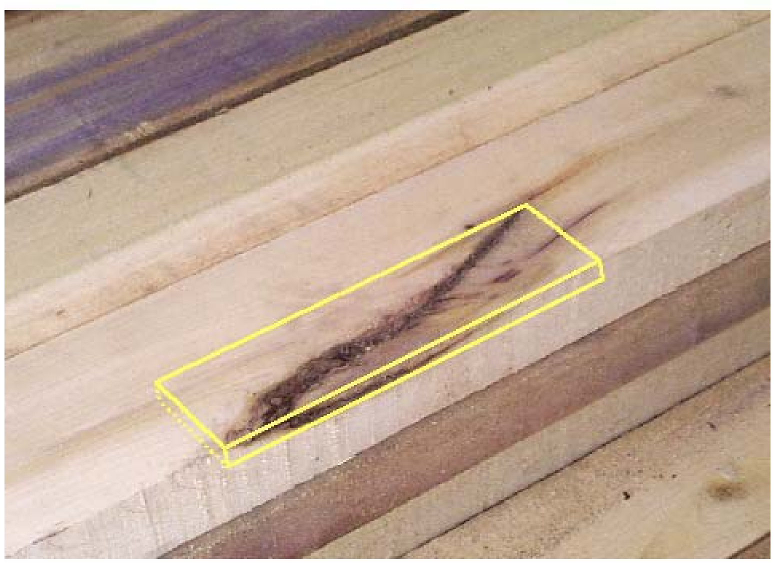

Figure 2. Typical defect measurement on a yellow-poplar cant.

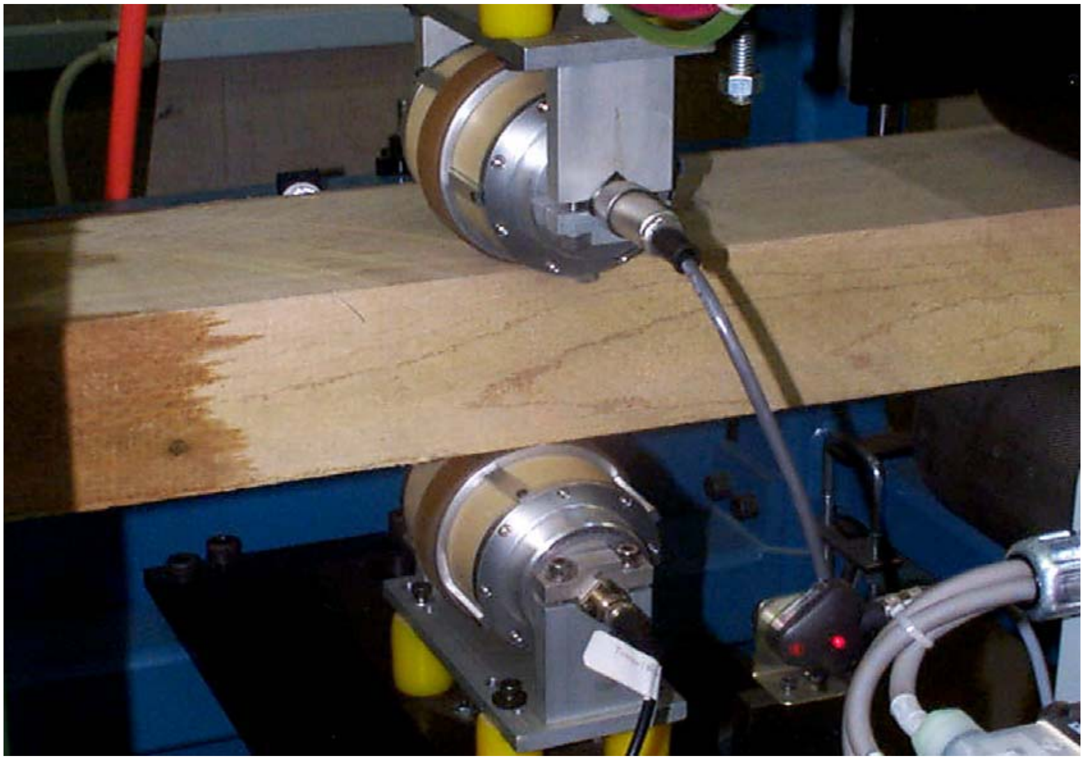

Figure 3. Close view of ultrasonic measurement through cant.

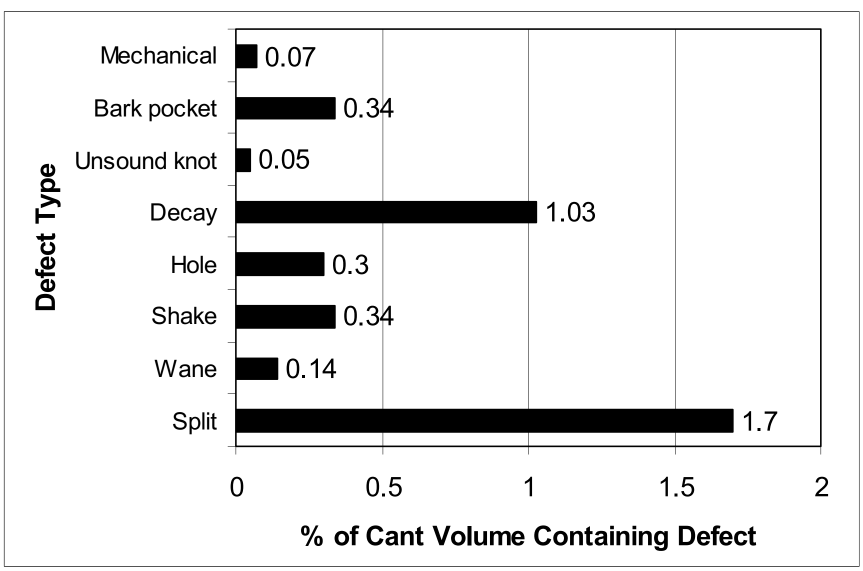

Figure 4. Average unsound defect percentage per cant for all species.

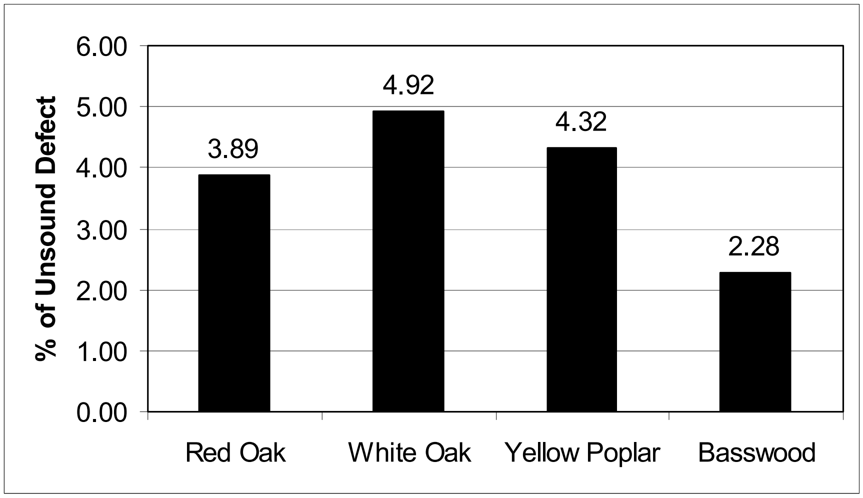

Figure 5. Average unsound defect percentage for individual cants.

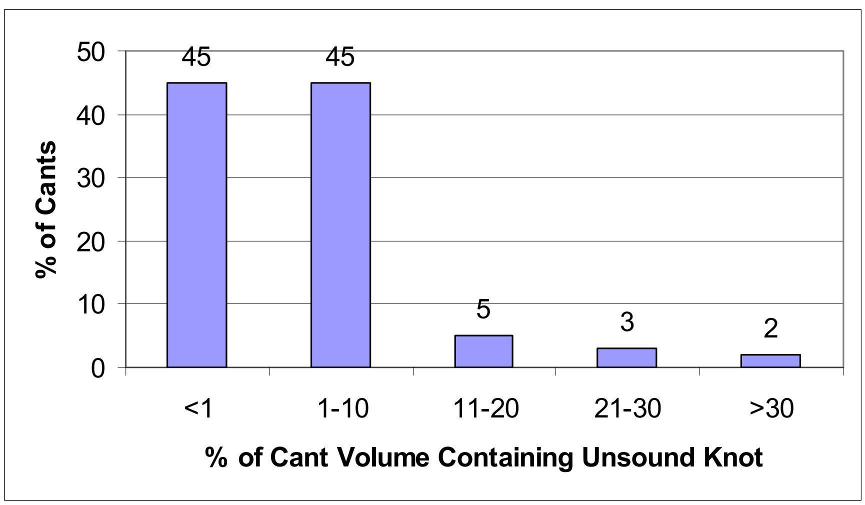

Figure 6. Classification of cants based on unsound defects for all mills and species

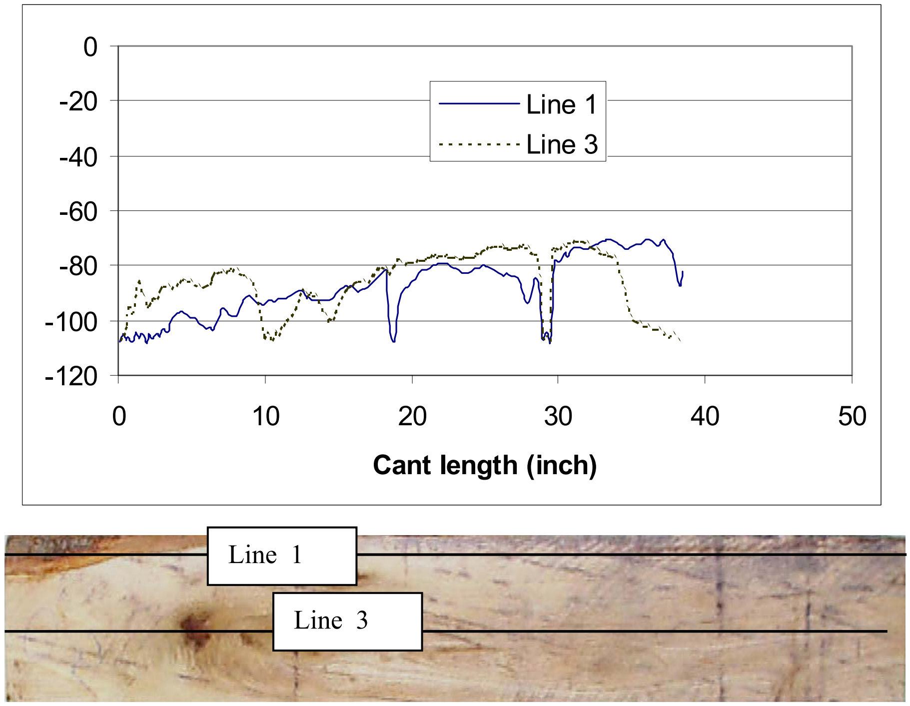

Fig. 7a. Variation of energy value through wane and unsound knot of oak cant.

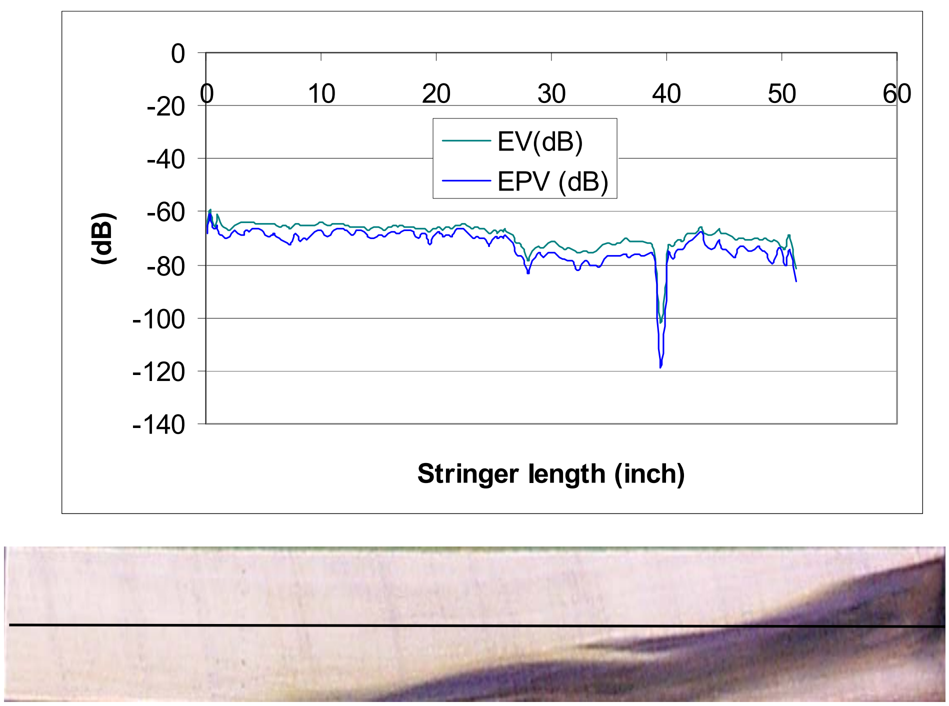

Fig 7b. The response of energy value parameter to decay in a yellow-poplar stringer.

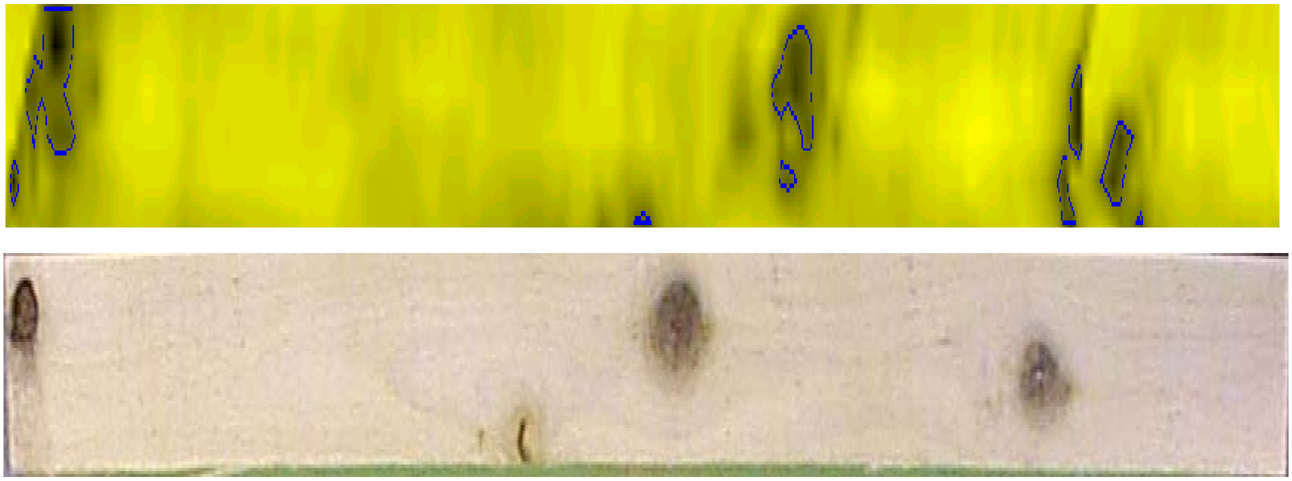

Figure 8. Reconstructed images from energy value data, and face view photo of yellow-poplar stringer.

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