AIRBORNE ULTRASONIC INSPECTION FOR HIDES AND LEATHER

by

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ABSTRACT

Currently, hides and leather are visually inspected and ranked for quality, sale price and usable area. Visual inspection is not reliable for detecting defects, which are usually hidden inside the material. This manual assessment is non-uniform among operators, and often leads to disputes over fair price. Development of a nondestructive method to accurately evaluate the quality of hides and leather is needed. We have investigated airborne ultrasonic (AU) testing using non-contact transducers for the nondestructive evaluation of hides and leather. The AU test system is designed for automated and moving process applications, thereby providing an ideal inspection method for large hides or leather. This research examined the ability of AU to reveal defects in hides and leather that are difficult to be found during visual inspection. The AU transducers were mounted on a computer-controlled X-Y scanner that allows the transducer array to be moved over the entire surface of the hide. The AU testing involves pulsing ultrasonic waves and measuring the amplitude of those waves transmitted through the material. The key for success in AU testing is to use AU transducers with low resonant frequencies, which leads an effective transmission of ultrasound waves through the leather or hides. The variations in the amplitude were colored coded into C-scan images to reveal the location and shape of the defects or some other physical discontinuity that could affect the hides or leather quality. Using AU C-scan images could advance the industry in how it assesses and grades raw hides, wet blue, wet white and finished leather.

RESUMEN

En la actualidad, las pieles y los cueros son inspeccionados visualmente y clasificados por calidad, precio de venta y superficie útil. La inspección visual no es confiable para detectar defectos, los cuales están ocultos en el interior del material. Esta evaluación manual no es uniforme entre los operadores y lleva a menudo a disputas sobre el precio justo. El desarrollo de un método no destructivo para evaluar adecuadamente la calidad de las pieles y el cuero es necesario. Hemos investigado pruebas con ultrasonido en el aire (AU) empleando transductores sin contacto, para la evaluación no destructiva de pieles y cueros. El sistema de prueba AU está diseñado para aplicaciones automatizadas y procesos en movimiento, proporcionando de esta manera un método de inspección ideal para pieles y cueros grandes. Esta investigación analizó la capacidad de la AU para revelar defectos en pieles y cueros que son difíciles de encontrar mediante la inspección visual. Los transductores AU fueron montados sobre un scanner X-Y controlado por computadora que permite que el transductor se mueva por toda la superficie de la piel. La prueba AU implica pulsaciones de ondas ultrasónicas y midiendo la amplitud de estas ondas transmitidas a través del material. La clave para el éxito de la AU es el uso de transductores con baja frecuencia de resonancia, que nos lleva a la efectiva transmisión de las ondas ultrasónicas a través de las pieles o cueros. Las variaciones en la amplitud fueron codificadas por color en imágenes de C-Scan para revelar la ubicación y la forma de los defectos o cualquier otra discontinuidad física que pueda afectar la calidad de la piel o del cuero. Empleando imágenes C-Scan con AU se podría avanzar en la industria en cómo se evalúa y clasifica los cueros crudos, wet blues, wet white y cueros terminados.

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INTRODUCTION

Animal hides are the highest value coproduct of the meat industry. The U.S. beef industry produces approximately 35 million cattle hides annually. The export market for raw and wet blue hides is currently valued at more than $2.2 billion annually.[1] Hides are visually inspected and ranked for quality and sale price. Because visual inspection is not reliable for detecting defects when hair is present, hides cannot be effectively sorted at the earliest stage of processing. Furthermore, this subjective assessment is non-uniform among operators, and leads to disputes over fair price.[2] Development of an objective and nondestructive method to accurately evaluate the quality of hides is needed.

Airborne Ultrasonic (AU) inspection techniques have been used extensively in the inspection of lumbers and composites.[3, 4] As this is a non-contact technique, it is an ideal inspection method for large leather hides. We have investigated the use of AU to evaluate the quality of leather and hides. From previous projects, we demonstrated that AU testing without direct contact with samples offers a great potential method for the nondestructive evaluation of the material properties of leather.[5] As this is a non-contact technique, it is an ideal inspection method for large leather or hides. The AU transducer is drastically different from a traditional acoustic emission (AE) transducer configuration, which is a static transducer. The AU transducer is designed for dynamic measurements and offers several key advantages in automated and moving process applications. The need for a couplant becomes obsolete, because the airborne transducer does not directly contact the hides being evaluated. AU testing involves pulsing ultrasonic signals at the material and measuring the reflected or penetrated amplitude of those signals emanating from the material.[6] The amplitude of ultrasonic signals reflected at the surface of a planar material (such as films, sheets, fabrics, and leather or hides) is a function of the material's surface morphological variations. Therefore defects, such as scars, insect bites, or knife cuts should be able to be detected because it will change the intensity of the AU signal penetrating through the material. Observation indicated that AU testing can reveal the presence of defects in the leather or any other physical discontinuity that could affect the leather quality. AU waves must travel from a medium with low acoustic impedance (air) to a medium with considerable high acoustic impedance (leather), therefore selection of the proper AU transducers and frequency are critical to achieve enough penetration of ultrasonic waves in order to extract important information related to the structure and properties of leather such as, the amount of defects, morphology, strength and softness.[5]

We further investigated and built on these AU methods mentioned above to develop an advanced technology to evaluate the quality of hides. The AU testing in this research involves pulsing ultrasonic waves and measuring the amplitude of those waves transmitted through the material. Previous studies as mentioned earlier, measured the reflected amplitude of those signals emanating from the material.[5] We believe that by using the through transmission mode on the samples, more useful information can be extracted from the AU scan, particularly for hides, which are covered by hair. The key for success in AU testing is to use AU transducers with low resonant frequencies, which leads an effective transmission of ultrasound waves through hides or leather. To effectively determine the defects within or on the hides, the major challenges will be to identify the right transducers, frequency, and scanning speed as well as establishing a correlation between the quality of hides (related to integrity and defects) and the corresponding AU quantities. The variations in the AU quantities or amplitude are colored coded into C-scan images to reveal the location and shape of the defects or some other physical discontinuity that could affect the hides or leather quality.

EXPERIMENTAL

In this research, the airborne ultrasonic experimental setup consisted of two ultrasonic transducers approximately 3 cm apart (Figure 1), which have a central frequency of 200 kHz, a transmitter (NCG200-D50, The Ultran Group, State College, PA) with a 50 mm active area pulsed with a tone burst through a power amplifier, and a receiver (NCG200-D25) with a 25 mm active area connected to a preamplifier. As demonstrated schematically in Figure 2, the transducers were mounted on a computer-controlled X-Y scanner (as shown on the left portion of Figure 2) using the software UTWIN version E1.81 (NDT Automation, Princeton Jct., NJ) that allows the transducer array to be moved over the entire surface of the hide. The right portion of Figure 2 illustrates the detection of defects by the AU transducers; red arrows show the direction of AU waves generated from a pulser and black arrows show AU waves that are either reflected or transmitted through the sample. The amplitudes of the transmitted airborne signals at every point on the hide surface were measured, color-coded, and mapped into an image file for each hide or leather. These color-coded amplitude maps are called "C-scans" and they are commonly used in the field of ultrasonics. The resolution of the C-scans generated was 0.5 mm. The color-coding of the C-scans is set up in the UTWIN software and is determined from the root mean square voltage (V_{rms}) of the receiver between two set time gates (t_1 and t_2) for every point measured on the sample (Equation 1).[7]

$$V_{rms} = \sqrt{\frac{1}{t_1 - t_2}\int_{t1}^{t_2} V(t)^2\, dt} \qquad (1)$$

The voltage (V) is determined by how much of the pulsing wave penetrated through the hides or leather and is detected by the receiver. In the software UTWIN, a dark blue color on the C-scan indicates no penetration while a dark red indicates full penetration of the pulsing wave through the material. The gain was set at 15.5 dB out of a maximum of 36.5 dB, unless otherwise noted. Some of the C-scans will be expected to show a very homogeneous distribution of amplitudes in one sample while other C-scans will show areas of very different amplitudes in another sample. The presence of areas with different amplitudes in the same sample is an indication of local variations of the properties of hides within that sample. These images are expected to reveal the presence of defects (hidden behind hair) in the hide created by healed wounds, knife cuts or any other physical discontinuity that could affect the hides or leather quality. The UTWIN software is used to analyze the ultrasonic quantities and their distribution such as amplitude distribution in these images and create a classifier capable of assessing the type and extent of defects.

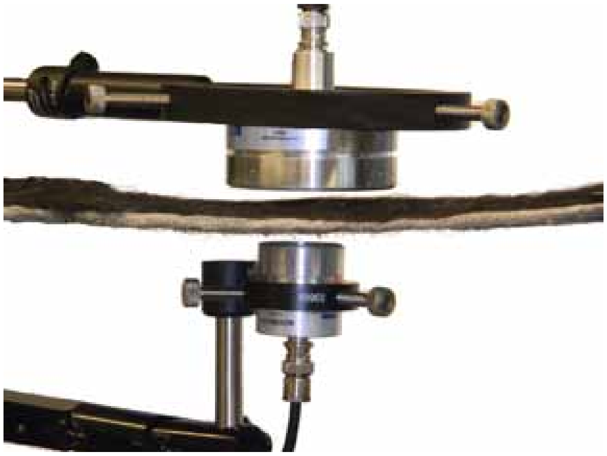

Figure 1. A pair of airborne transducers scans a hide sample with hair on.

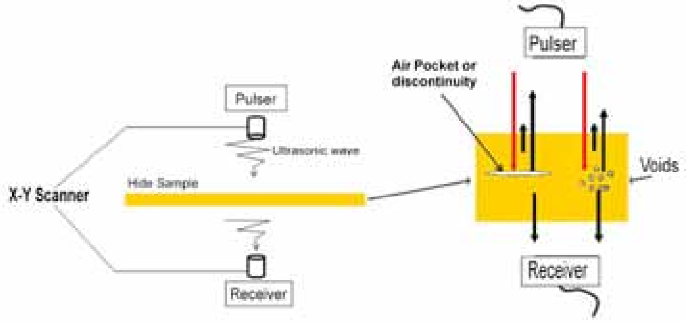

Figure 2. Experimental setup used in the Through Transmission airborne ultrasonic investigation of hide samples.

In our previous study we observed that the amplitude of the ultrasonic reflected signal is related to the stiffness of the leather because it is closely related to the elasticity of a material.[5] The velocity of the sound through a material (v) is determined by the elastic constant (E_{xy}) and the density (ρ) as shown in Equation 2.

$$v = \sqrt{\frac{E_{xy}}{\rho}} \tag{2}$$

Since leather and hides are anisotropic in nature the elastic constant, E_{xy}, could depend on which direction to the backbone the elastic modulus is measured.

RESULTS AND DISCUSSION

There is a multitude of information that can be displayed for one AU scanning result. Figure 3a shows a so-called "A-scan graph," in which the amplitude of the received pulse is represented as a displacement along y-axis and the travel time of the ultrasonic pulse is represented as a displacement along x-axis. It was determined that the first large peak of the waveform in Figure 3a varied with most with the different hide and leather samples tested, therefore the C-scans were based on gate 1. Figure 3b shows a B-scan image, which graphs the waveform vertically, in which each line on the image corresponds to an individual waveform at a data collection point. The travel time of an ultrasonic pulse is represented as a displacement along y-axis, and transducer movement is represented as a displacement along the x-axis. Figure 3c demonstrates a b-scan, which graphs the data horizontally. However, we have selected the graph to be a bar type graph and therefore the featured data is represented by rectangular bars in which the y-axis is the maximum amplitude of the waveform in gate 1 and the x-axis represents the transducer displacement.

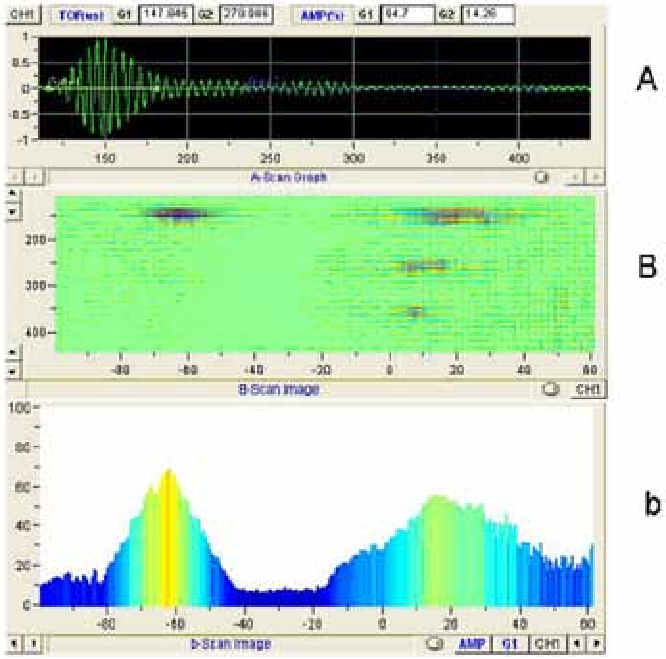

Figure 3. A typical (a) A-scan graph, (b) B-scan image and (c) b-scan image in AU test for hides.

The C-scan is very commonly used in AU testing, in which the transmitted AU pulses are captured and color mapped from the maximum amplitude in gate 1 set on the A-scan (Figure 3a). The drawn color palette is proportional to the amplitude of the signal. This method is commonly applied to transmission techniques. The system illustrated in Figure 2, was used to generate C-scan images of samples. Images obtained from the C-scans comprised primarily of regions varying in color from red to blue with each color representing different amplitudes transmitted through the samples. As an example of these images, Figure 4 shows a color-coded C-scan from a hide sample. The blue areas present low amplitudes while the green areas present medium amplitudes, and red areas are regions where there is a large signal transmitted as indicated on the color bar scale. From the variation of color and shape of color area, one could assess the degree of uniformity and locate the defects in the test samples.

There are many types of defects in hides as shown in Figure 5a, which is a picture of a hide with "mange". We used our AU system to scan the mange area and the ability of the AU system to detect the mange defect is very evident as demonstrated from the C-scan in Figure 5b. The red and yellow color areas are high transmission areas, which is attributable to its relatively high elasticity.

More interestingly as shown in Figure 6a, the corresponding wet blue made from the mange hide clearly indicates the defective area, which is revealed by the C-scan demonstrated in Figure 6b.

One of the most common methods for the preservation of hides is brine curing. In this preservation process, the hides are soaked in brine (NaCl solution) for a certain time, usually in a raceway, in order to allow the salt to diffuse into the hides and preserve the hides by decreasing the moisture content in the hides.[9] AU scans were performed on hides before and after brine curing. The difference in the C-scans is very evident as shown in Figure 7, where the brine-cured hides (Figure 7b) show less transmission of AU waves than un-cured hides (Figure 7a). This could be due to the decrease in elasticity of the hide from brine curing, which contributes to less transmission of ultrasonic waves.

We were also interested in the AU method for determining the freshness of hides. A hide was scanned using the AU over a 10 week time period. The hide was scanned initially, then placed in a sealed plastic bag and stored in a refrigerator, then taken out weekly to scan and then stored in the refrigerator again until the following week. The resultant C-scans are shown in Figure 8. It appears that the longer the storage time, the corresponding hides lost moisture and more elasticity as demonstrated from the increase in red or higher amplitudes and better penetration of the ultrasonic waves.

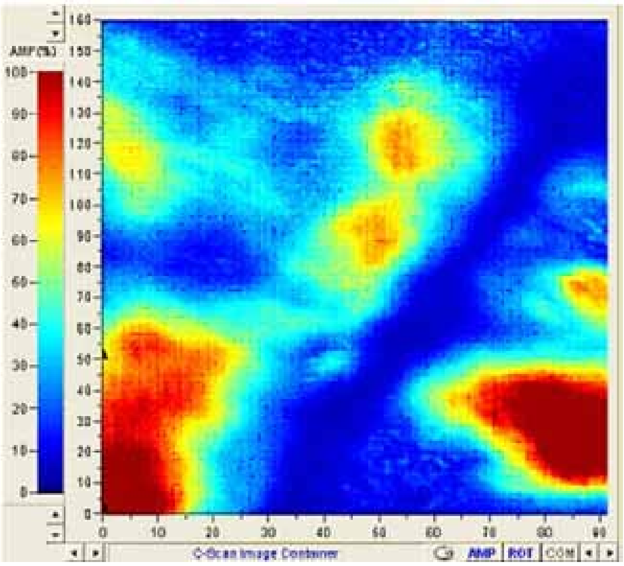

Figure 4. C-scan of a raw hide

We used our current AU method to compare the C-scans between milled and non-milled crust leathers to see whether the AU method will be able to detect the difference between these two types of leathers (Figure 9). Milling is practiced in the tannery by mechanically tumbling the crust in a drum to obtain adequate softness and feel in the leather. Previous observation showed milling caused a significant decrease in stiffness, but brought very little change in mechanical strength and toughness.[8] Electron scanning microscopic observation showed that the milled leather has more of an opened fiber structure; the fibers are well separated from each other, whereas the non-milled samples show the fibers are still stuck together. The opened fiber structure is the key for gaining the desired softness of the end leather product. Figure 9 shows a great difference in the C-scan images between these two types of leather samples. Non-milled leather (Figure 9b) shows a greater transmission of AU waves indicated by the darker red color map because of the greater penetration of the ultrasonic waves and higher amplitudes seen through these leather samples. In contrast, for milled leather, as shown in Figure 9a, the C-scan shows much less penetration (blue color indicates low amplitudes) of AU waves through the samples. This is probably due to the more open fiber structure in the milled samples, which have more space filled by air, thereby disrupting the AU wave transmission through the leather. It can also be better explained from Equation 2, in which the milled leather has a much lower elastic modulus than the non-milled leather and therefore the sound velocity through the milled leather will be much lower than that of the non-milled leather samples. The gain in the UTWIN software needed to be increased to 30 dB in Figure 9a compared to only 15.5 dB needed to scan Figure 9b.

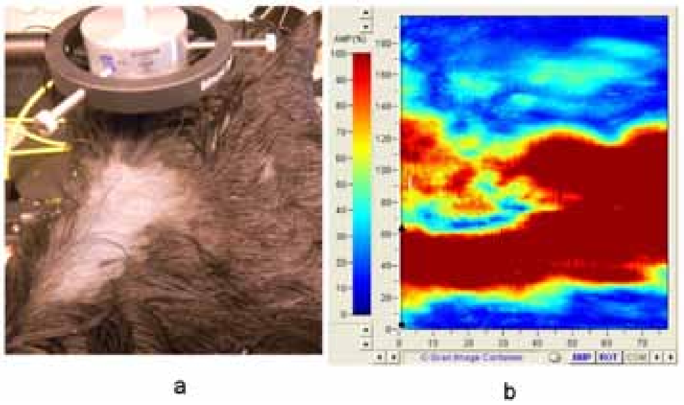

Figure 5. (a) hide with "mange" defect (b) corresponding C-scan

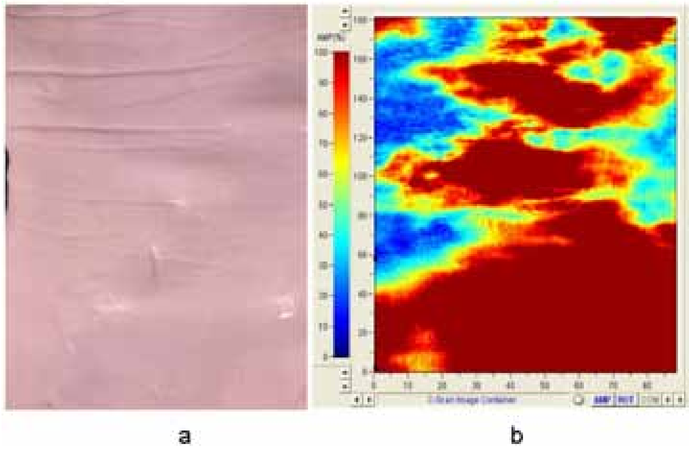

Figure 6. (a) wet blue from the mange hide (b) corresponding C-scan of mange wet blue.

CONCLUSIONS

This study demonstrated that the airborne C-scan imaging technique can be used to reveal the presence of areas of different acoustic properties that are an indication of local variations of the material properties of hides or leather. Transmission of the ultrasonic waves depends on the modulus of elasticity as seen in the milled vs. non-milled crust leather. Softer materials usually have lower acoustic impedance than the stiffer materials. Other important factors are air, water, gain, and frequency. This AU imaging technique revealed the presence of defects in the hides created by healed wounds and other physical discontinuities that could affect the leather quality. In the future, we will develop algorithms to translate the C-scan of a hide into numeric values that reflect the extent of defects and integrity of hides, which can then be used as a more objective grading system. Using the AU C-scan images could advance the industry in how it assesses and grades raw hides. Scars, insect bites or major defects could be detected electronically, causing the hide be downgraded before it is subjected to any expensive leather making operations, thus saving money in processing time, chemicals, etc.

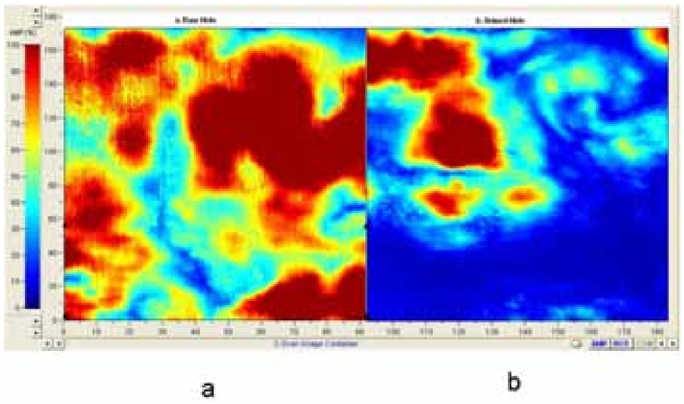

Figure 7. Comparison of C-scan between (a) raw hide (b) preserved hide with salt.

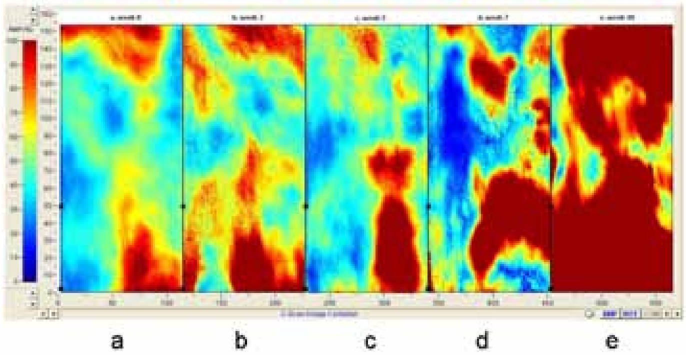

Figure 8. C-scan images of hides after various period of time (a) beginning (b) 2 weeks later (c) 5 weeks later (d) 7 weeks later (e) 10 weeks later.

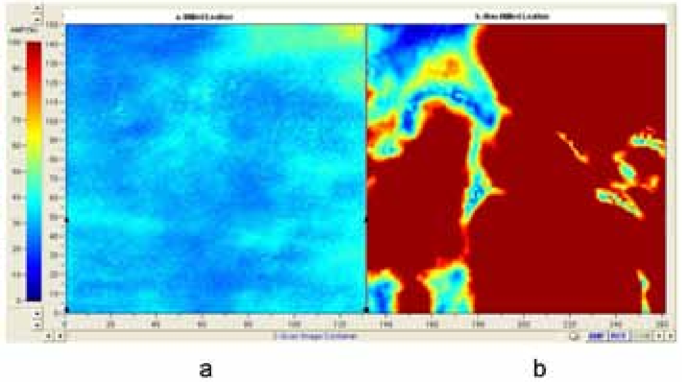

Figure 9. C-scan images: (a) milled and (b) non-milled leather samples

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