



Laser vibrometry in the quality control of the break of tanned leather



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ABSTRACT

Tanning industry treats hides and the skin of animals for their use in products such as clothes, furniture and car's interiors. The worth of leather is highly affected by defects that may appear prior or during the tanning process. Break, which refers to the wrinkling of the grain surface of leather, is one of the main issues because it affects not only the visual appearance of leather, but also its mechanical properties. The standardized method to classify the break pattern is done by bending the leather with the hand and comparing visually the resulting wrinkles that appear with a reference pattern, which makes the classification subjective and limits the evaluation to small areas. Laser vibrometry is an optical technique that has been applied in vibrational and modal analysis, which are methodologies used to obtain the mechanical properties of materials. This work demonstrates the use of a single-point vibrometer as a noncontact and nondestructive optical method to discriminate among five break levels, which could increase the effectiveness of leather classification for quality control in the tanning industry.

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1. Introduction

In order to tan the skin of animals, the tanning industry treats the raw hides with chemicals. The outcome of this treatment is leather, which is usually used in car's interiors, clothes, furniture, among other products. The tanning industry trades approximately 80 billion USD in raw hides, leather and footwear every year [1]. The worth of leather depends on the presence and magnitude of defects, that can appear prior or during the tanning process. Break (or looseness) is one of the most important issues because it affects both the visual appearance of the surface and the mechanical properties of leather and, therefore, its value. According to reference [2], this defect is due to the separation of the different layers of the hide, as a result of the creation of voids between the fibers. However, it is not completely understood how break appears or how to avoid it, but it is mainly observed until the leather tanning is completed. Several techniques, such as small angle X-ray scattering [3], ultrasound imaging [4] and scanning electron and transmission electron microscopy [5], have been used to study the structure and formation of this defect on early stages of tanning in order to understand where it appears and how to prevent it. One of the main effects of break is the change in the mechanical behavior of leather that results from the separation of the different layers and fibers within the material. Several research papers have analyzed the viscoelasticity [6], the Poisson ratio [7], the stiffness, the tensile strength [8] and other properties of

leather, as well as how such mechanical properties could be applied in the characterization and classification of leather.

Samples with break, i.e. 'loose' leather, present a series of wrinkles in the grain surface when the sample is bent. Hence, the visual assessment of the magnitude of these patterns is traditionally used to classify the leather in terms of quality levels. According to the ASTM standard D2941 [9], the break scale is measured by bending the sample inwards with the hand up to a standard curvature and comparing it to the *Satra Visual Break Scale*. Therefore, this methodology is subjective because the sample is often measured without the real reference pattern, the specialist makes the comparison based on the recall of the previously memorized scale. In addition, the area under inspection is small because is limited to the hand of the specialist. In order to provide an objective metric, it has been proposed to quantify the looseness through its effect on the mechanical properties of leather. For example, Kasturi and Mukhopadhyay [10–12] used the capacitive effect of leather in order to determine the magnitude of the defect, while Liu et al. [13] applied ultrasound to analyze the acoustic response on the surface of the sample.

The main features of light-based methods are their high sensitivity and that there is no need to have physical contact with the sample or to destroy it [14,15]. Optical techniques have been used for several years in the study of the mechanical properties in different kind of materials, from organic to inorganic samples. In particular, laser vibrometry is one of the most sensitive techniques and its implementation is relatively

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simple. Thus, it has been used in a wide range of fields, from medical imaging [16] to civil engineering [17].

In this work, we propose the implementation of a noncontact and nondestructive optical technique that relies on the study of the dynamical response of leather to acoustic stimulation with the aim of classifying leather samples according to their break level. For this purpose, a series of rectangular leather samples are clamped by the sides and stimulated from behind (opposite surface of the measurement) with a speaker with sinusoidal frequencies from 10 to 150 Hz. Then, the magnitude of the vibration in the grain surface is measured with a laser vibrometer. With the calculation of the power spectrum of this signal, the resonant frequencies can be obtained for modal analysis. A single-point vibrometer is focused at the center of the sample, which allows the device to measure the vibration of the membrane for odd resonant modes. It was found that it is possible to discriminate the top five levels of the eight levels in the *Satra Scale* of break in leather by means of the first and third odd vibration modes. This work was made in collaboration with Curtidos y Acabados Kodiak, S. A. de C. V., tannery with more than 27 years of experience.

2. Methodology

In order to explain the relation between the magnitude of the break in a rectangular sample of leather and its resonant frequencies, the basic equations of the modal analysis for a vibrating anisotropic membrane are described. For this purpose, the mechanical properties of leather are presented as the variables used to describe the resonant modes and its frequencies. According to references [2] and [5], break has an impact in the mechanical properties of leather and, thus, it produces a change in the resonant frequencies. Hence, it may be possible to discriminate samples of different mechanical properties by measuring the modal frequencies of the specimen. Although this work does not deal with the mechanical constants of the material, it is important to relate their effect in the resonant frequencies, which allows the discrimination of five different levels of break in leather.

2.1. Vibration of a rectangular membrane

The out-of-plane vibration in modal analysis, denoted as $z_{m,n}$, for a rectangular membrane clamped by its sides is described by the following equation:

$$z_{mn}(x, y; t) = A \sin\left(\frac{m\pi x}{L_x}\right) \sin\left(\frac{n\pi y}{L_y}\right) \sin(\omega_{m,n}t). \tag{1}$$

where A is the amplitude of the deformation of the material, while, m and n represent the horizontal and vertical resonant modes. L_x and L_y are the length of the membrane in the horizontal and vertical direction, respectively, and t indicates the temporal dependency of the vibration. The angular modal frequencies $\omega_{m,n}$ for an anisotropic material, such as leather, depend on its mechanical properties, such as the Poisson ratio ν , the Young's modulus E , the thickness h , and the material density ρ [18]:

$$\omega_{mn} = \pi^2 h \left[c_x \left(\frac{m}{L_x}\right)^2 + c_y \left(\frac{n}{L_y}\right)^2 \right] \tag{2}$$

where

$$c_x = \sqrt{\frac{E_x}{12\rho(1 - \nu_x\nu_y)}} \tag{3}$$

and c_y is equivalent to Eq.(3), but for the y -direction. For example, Fig. 1 shows the tridimensional surfaces for the out-of-plane deformation of the resonant modes (a) $m=n=1$ and (b) $m=1, n=3$ in the maximum deformation instant of a simulated rectangular membrane (190 × 140 mm). As it was described in Eq. (2), the frequencies corresponding to these modes depend on the values of the mechanical properties of the material.

Table 1

Groups of samples as evaluated by experts from the tannery industry.

Break level	Number of samples
1	7
2	8
3	7
4	4
5	4

3. Experimental procedure

In this section, the experimental setup that was used to stimulate the samples with sound and to measure the dynamical response of leather to the acoustic signal is presented. The characteristics of the leather samples used in the experiments are also described, highlighting the variables that might affect the measurements. The procedure to fix the sample into its frame and the steps to stimulate and measure the resonant in the sample are described. Finally, the statistical methods used for the analysis of the data are presented.

3.1. Samples

For this work, thirty rectangular samples (23 × 18 cm) were used. These samples were classified by two expert technicians from the Kodiak tannery company into five levels of break, ranging from 1 to 5, where 1 represents the ‘tight’ leathers and 5 the ‘loose’ ones, using the traditional method described in reference [9]. Since leather is an organic and non-designed material, the thickness of the samples was variable. In particular, the measured specimens were restricted to a thickness between 1.2 and 1.4 mm in order to reduce the impact of this parameter might have in the measurements. Additionally, the specimens were tanned using chrome, which has an impact in the viscoelasticity properties, according to reference [6]. The samples were cut with the shorter side of the sample following a parallel line with respect to the spine of the animal from which the sample was obtained. Once the samples were tanned through the same process, they were dyed with the same color. The use of specimens with similar characteristics was performed in order to reduce the number of variables involved in the experiment. Following the ASTM standard D1610 [19], the specimens underwent a conditioning process of 72 h under controlled temperature and humidity prior to the laboratory testing. Table 1 shows the number of samples that were used for each break level according to the analysis performed by the experts from the tannery industry. Note that the first three groups are larger because they represent the most common grades of the production in the tannery company.

3.2. Optical arrangement

To measure the resonant frequencies of the samples, the optical setup shown in Fig. 2 was used. It combines the single-point measurement of a laser vibrometer with the full-field observation of an Electronic Speckle Pattern Interferometer (ESPI). A SIOS LSV vibrometer with a variable focal length was used, which has a resolution of 20 pm. For the measurements, the vibrometer worked with a sample rate of 4096 samples/s to acquire the signal of the displacement of the surface of the membrane. This vibrometer shows the digital data in nanometers with three decimals, which allows a direct interpretation of the displacement. One limitation of this instrument is the need of a high-reflecting surface in order to increase the signal quality for the signal acquisition. With the aim of minimizing this problem, the head of the vibrometer was placed at a distance of 240 mm to the supporting frame that is holding the sample, which is the minimum working distance of the vibrometer. In order to ensure that the measured frequency corresponded to the desired resonant mode, an ESPI with a high-speed camera was used to observe the

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