NONDESTRUCTIVE DYNAMIC COMPRESSION MEASUREMENTS ON FULL SIDES OF LEATHER*

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ABSTRACT

A dynamic mechanical instrument was used to investigate nondestructive testing of full sides of light leather of different tannages. The instrument used imparts a sinusoidal compressive force to the material. The resonant frequency from which a relative stiffness (apparent modulus of compression) could be calculated was measured. Comparative measurements of the resonant frequencies were made over the entire area of intact sides of leather. As was expected, a pattern was obtained which showed the variability of the mechanical properties within a single side of leather. These results showed that in compression the greatest stiffness area of side leather is in the backbone and butt area, whereas the most flexible (softest) area is located in the belly region, with a wide variation in between.

INTRODUCTION

The ability to obtain a knowledge of the variations or changes in the mechanical properties throughout intact sides of hides and leathers by a nondestructive test method could be of great value in production, development and research. At present in order to determine the quality of leather, test samples must be removed from the side and tested by such destructive tests as tensile, ball burst, stitch tear and many others. Also, in production, leather is sorted for quality and texture by individuals trained to recognize this by feel and appearance of the leather. Such grading is sometimes controversial because sorters do not always agree in their judgment.

Dynamic mechanical testing lends itself to nondestructive testing as it is carried out with repeated stressing and very low strains causing no distortion or per-

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manent damage to the structure of the test material. It is a very short time test that can readily be run over a wide temperature range, giving numerical values relating to the quality of leather.

Previously the authors (1) evaluated dynamic mechanical testing of leather by means of a vibrating reed instrument, a forced-vibration resonance method. It was found that this method of testing was of value to gain information about the fibrous network structure of leather. The method, although nondestructive to the test specimen, could not be used to evaluate an intact side of leather without cutting samples from the hide.

The instrument used in this study operates as a forced-vibration resonance method, similar to the vibrating reed. The mechanical response at the material's natural resonant frequency is measured as a function of the applied force. This instrument applies a force to the leather in compression, thus making it possible to transport the transducer along the hide surface without removal of test specimens.

Since this instrument is new and has not been described in leather literature, the instrument, its principle and means of measuring will be briefly described.

This apparatus is based on a single coil electro-mechanical transducer previously described by Smith, Ferry and Schremp (2). In this method the transducer that applies the driving force to the specimen also detects the response of the specimen. In the measurement of biological tissue, Keiper (3) first described the basic principles of this instrument developed under contract for the United States Department of Agriculture (4).

Figure 1 shows a simplified block diagram of the basic parts of the test unit. This unit consists of a variable oscillator, variable resistors, variable inductors, two matched resistors, a pair of matched transducers and an oscilloscope. These are set up in a bridge circuit with a transducer on each arm of the bridge. Figure 2 shows the specimen transducer which consists of a hollow cylindrical magnet containing a moving element. This moving element is made up of a coil, coil support, bearing sleeve, and a driver pad. In order to eliminate frictional problems and to permit measurement of the elastic component in compression, the moving element is supported in the magnetic field by a gas bearing using dry nitrogen. This moving element is then driven against the sample which is mounted on a stationary anvil. The moving element is driven by an alternating force supplied by the oscillator at various frequencies from 1 to about 5000 cps. The specimen transducer and the anvil are mounted in a rigid C frame. The blank transducer is identical to the specimen transducer with the exception that its movable element is always locked in place.

The driver pad of the specimen transducer contacts the sample causing it to undergo a displacement which this transducer also senses, permitting the measurement of the dynamic properties of the material being investigated. The

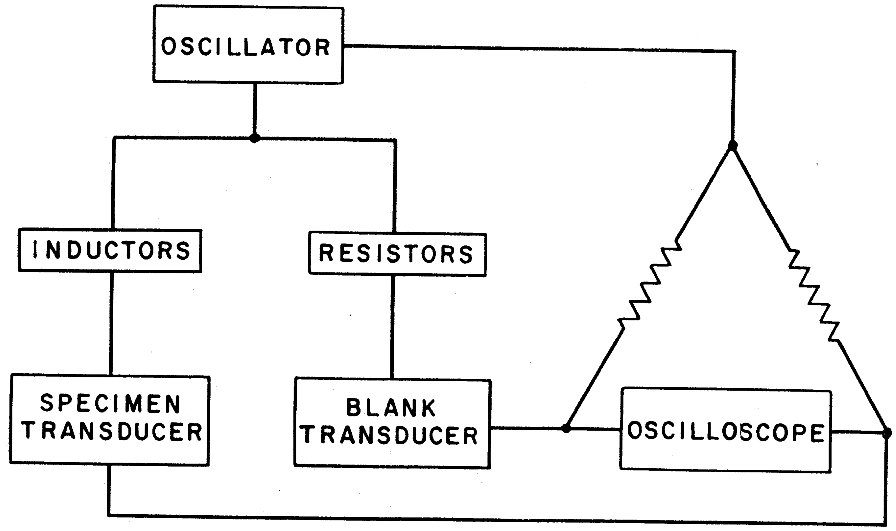

FIGURE 1.—Block diagram of dynamic compression test unit.

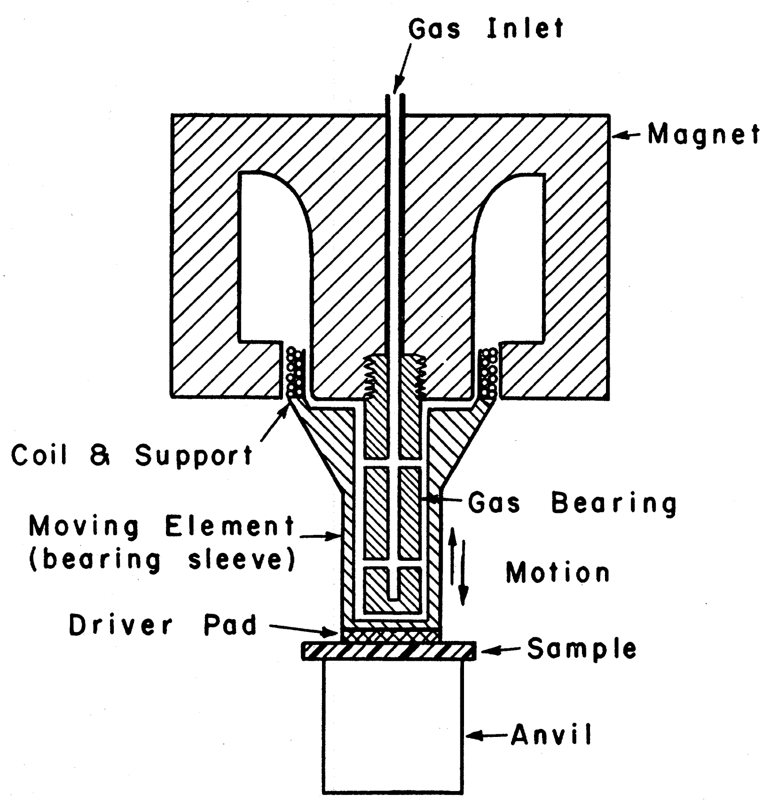

FIGURE 2.—Specimen transducer.

mechanical properties are related to electrical quantities (resistance and inductance) involving the moving element. Any unbalance of the bridge circuit caused by a sample permits measurement of this sample's mechanical impedance electrically. Balancing of the bridge is accomplished by adjustment of the resistors and inductors at the frequency applied to the test materials. With these values, frequency, resistance, inductance, instrument constants and sample geometry, the apparent dynamic mechanical properties of a material can be calculated using the following formulae:

$$E' = \frac{D^2}{10^7}\left[\frac{(2\pi\gamma)^2 \; L^s_{mot}}{(R^s_{mot})^2 + (2\pi\gamma L^s_{mot})^2} - \frac{W_c}{L^f_{mot}}\right]\frac{1}{\pi r^2} \qquad (1)$$

Where E′ is the real modulus (elastic component) in compression, $\frac{D^2}{10^7}$ and W_c are instrument constants, L^f is a calibration constant for each test frequency, L^s_{mot} is electrical inductance due to sample, R^s_{mot} is electrical resistance due to sample, γ is the test frequency, 1 is the sample thickness (cm) and r is the sample radius (cm).

$$E'' = \frac{D^2}{10^7}\left[\frac{2\pi\gamma \; R^s_{mot}}{(R^s_{mot})^2 + (2\pi\gamma L^s_{mot})^2}\right]\frac{1}{\pi r^2} \qquad (2)$$

E″ is the imaginary modulus (viscous component) in compression, and the other symbols have the same significance as above. A further calculation of energy loss or dampening can be made from:

$$\frac{E''}{E'} \qquad (3)$$

A high modulus indicates a stiff material (little compressive response) and a low modulus indicates a more flexible material (high compressive response). Preliminary observations on sides of leather showed that the real modulus (elastic component) covered a much broader range of values than either the imaginary modulus or the energy loss. Therefore, only E′ (real modulus) is necessary for a comparative study of side leather. The resonant frequency (frequency of the test materials maximum response) is used since it is most responsive to changes in stiffness. When making measurements at resonance the inductance difference becomes zero, reducing the real modulus formula to:

$$E' = \frac{D^2}{10^7}\left[-\frac{W_c}{L^f_{mot}}\right]\frac{1}{\pi r^2} \qquad (4)$$

To further simplify this measurement $\frac{D^2}{10^7}$ and W_c can be dropped, as they are instrument constants. The thickness can be dropped as its variation is not large enough within one side to effect this comparative measurement. The radius is constant as the same transducer pad area contacts the hide for all measurements. A further reduction can now be made to where only the resonant frequency is required for comparative studies. A high resonant frequency will cause L^{f}_{mot} to become small; thus, a high frequency will denote high modulus (stiffness) and a low frequency will denote a low modulus (flexibility).

In order to make a measurement of the dynamic properties over an intact side of leather, the transducer was removed from the C frame. The special round aluminum block in Figure 3 was developed, making it possible to transport the transducer over the surface of a side of leather. This block was made 25 cm in diameter in order to distribute the transducer and block weight over a wide area.

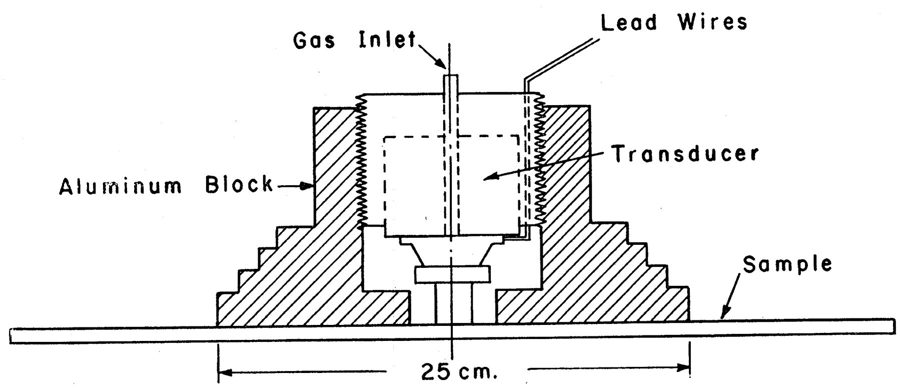

FIGURE 3.—Portable aluminum holder including transducer.

This block and transducer weigh 9000 grams, placing a load of approximately 21 gms/cm^2 on the leather. This is much lower than the load placed on a test specimen in making thickness measurements by the ALCA-ASTM method (5). The thickness method applies a load of 500 gms/cm^2. Therefore, the load applied by the transducer and block should not cause any serious change in the side of leather. To insure a smooth level and solid surface beneath the test material, a terrazo table top was used to back up the leather.

EXPERIMENTAL

Nondestructive Dynamic Test.—The following four experimental sides of finished leather were obtained from four commercial tanners' regular production:

(1) Side leather — chrome tanned — chrome glutaraldehyde retan — finished.

(2) Side leather — enzyme unhaired — chrome tanned — finished — handbag.

(3) Side leather — chrome tanned — patent finished.

(4) Side leather — chrome tanned — finished — dyed black.

The four sides were each marked off into 25 cm squares as shown in Figure 4. Each square was numbered from 1 to 10 along the backbone and 0 to 4 from backbone to belly starting at the neck. This permitted quick location of the test area within the side, such as the two outlined blocks 9-2 and 8-3.

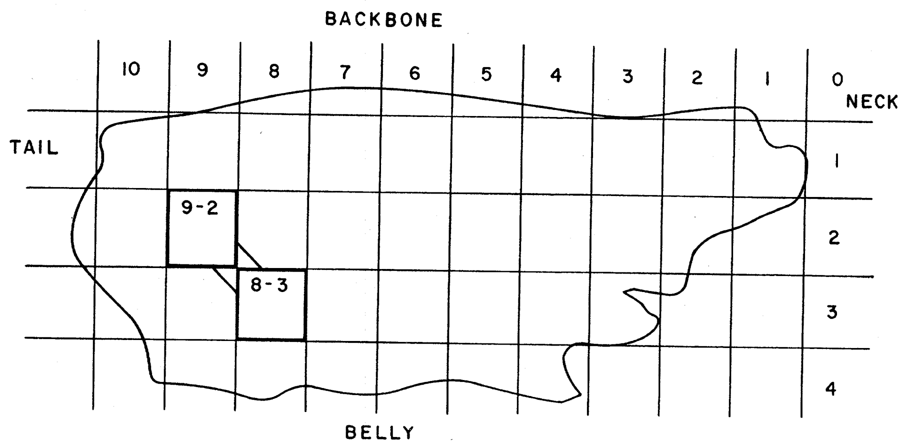

FIGURE 4.—Test pattern for intact sides.

All tests were made by centering the block on the 25 cm square thus placing the transducer driver pad at the center of the square. For the comparative measurements, the compression transducer was driven at 0.125 amperes. At this force the strain on the sample was less than 0.1 percent, which is well below the point where nonlinearity of behavior enters into the test. It was possible to drive the transducer as high as 0.25 amperes before any serious nonlinearity was attained. The driving force was applied to the grain surface unless otherwise noted. A time limit of about one minute was selected to make the resonant frequency measurement.

Other Tests.—After the nondestructive compression testing was completed, the number 4 side of leather was sampled to make a comparison study with other test methods. Figure 5 shows the method of sampling for these tests. Eight blocks 20 cm x 15 cm were marked from 1 to 8. Samples were cut from each of these blocks as shown in Figure 6. The number 1 test specimen (5 cm disc) was cut for the dynamic compression, density, and hardness measurements. The compression test was made by the instrument being reported herein. The apparent

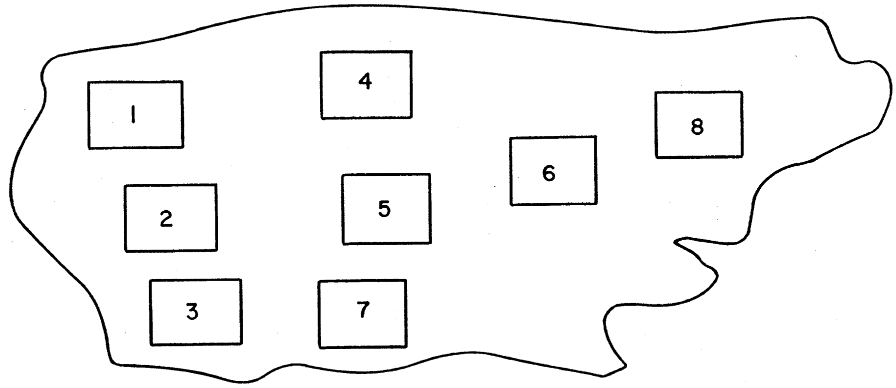

FIGURE 5.—Sampling from full side of leather for destructive tests.

density was determined from the weight and volume of the test piece. The hardness was measured by means of a Shore A‡ durometer, an ASTM method for rubber and plastics (6). Sample 2 was cut parallel to the backbone and sample 3 was cut perpendicular. These were 1 cm x 5 cm and were used for the dynamic flexural modulus. This modulus was measured with the vibrating reed instru-

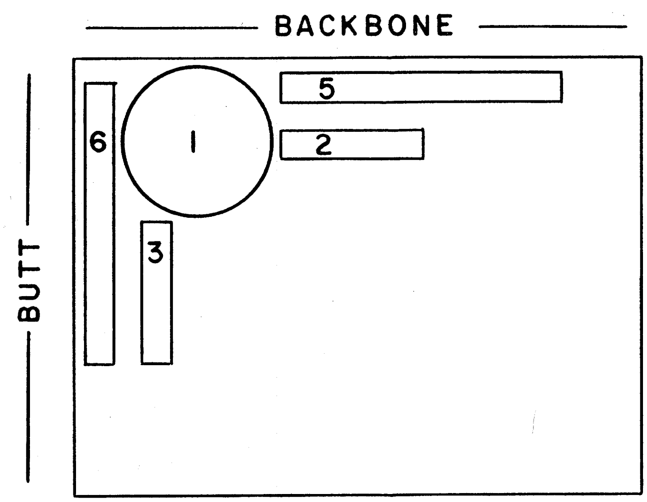

FIGURE 6.—Sampling test specimens for destructive tests.

ment previously described (1). Sample 5 was cut parallel to the backbone and sample 6 was cut perpendicular. These were 1 cm x 12 cm and were used for measurement of the torsional modulus by means of a torsion wire apparatus (7).

The sides of leather were stored and tested at 23°C. and 50 percent R.H.

‡Mention of commercial firms and products does not constitute an endorsement by the Department over others of a similar nature not named.

RESULTS AND DISCUSSION

Comparative Data for an Intact Side of Leather.—Figure 7 shows the resonant frequencies obtained over the number 1 side of leather. The data shown was taken with the driver against the grain of the leather. However, data determined on the flesh side showed no great change from that obtained on the grain side. The area around the butt and backbone of the hide in Figure 7 shows a resonance frequency range of 266 to 312 cycles/sec, the highest stiffness region. The belly and neck areas show a range of resonance frequencies from 173 to 207 cps, indicating these areas as being the most flexible. Midway between the backbone and belly the frequencies ranged from 220 to 247 cps, indicating a stiffness ranging between that of the backbone area and the belly and neck areas.

The other three sides of leather were measured in the same way. These sides also showed the same pattern of stiffness for intact sides of leather. The greatest difference obtained from one side of leather to another was the magnitude of stiffness, which changed due to tannage, finishing, or other modification.

These investigations confirm that there is a definite pattern of stiffness and flexibility throughout a side of leather. The butt and backbone areas contain the highest stiffness region and the belly and neck area have the most flexible regions within a side of leather.

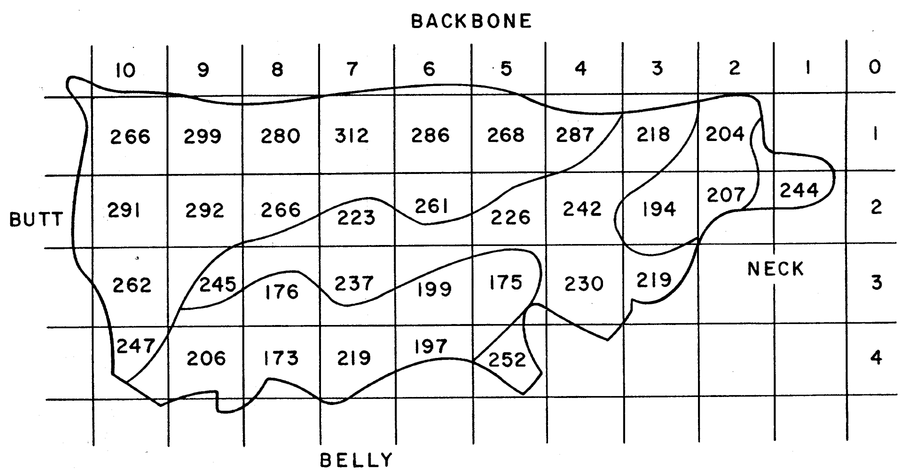

FIGURE 7.—Resonant frequency data obtained over an intact side of leather.

Comparison by Other Test Methods.—Table I shows the values obtained from eight areas within the number 4 side of leather by five test methods. The most apparent difference is the disagreement of the dynamic compression modulus with the other methods of test. Once again the dynamic compression modulus shows that samples from the butt-backbone area have the highest modulus (stiffness) while the samples from the belly and neck areas have the lowest modulus (most flexible). This modulus varies from 2.1 x 10^7 to 4.4 x 10^7 dynes/cm^2. The other test methods all show a reverse trend. The dynamic flexural and torsional tests show high modulus in the neck and belly areas and low modulus in the butt-backbone areas. The density and hardness were also high in the belly and neck areas.

TABLE I

TEST DATA FROM VARIOUS METHODS OF TEST

Location	Nondestructive	Destructive					
	Dynamic* Compression 10^7	Dynamic* Flexure 10^8		Torsion* 10^8		Hardness Shore A	Density gm/cm^3
		∥	⊥	∥	⊥		
1—Butt	4.4	1.9	2.2	1.3	1.1	92	0.76
2—Flank	4.1	1.7	1.2	0.7	0.8	90	0.72
3—Lower Flank	2.6	1.1	1.7	1.6	0.8	88	0.68
4—Back Bone	4.1	2.0	2.5	1.4	1.0	92	0.69
5—Middle	2.9	2.6	2.2	1.3	0.9	92	0.68
6—Shoulder	3.1	3.1	2.2	1.5	1.2	91	0.69
7—Belly	2.5	15.1	3.1	6.1	2.5	99	0.81
8—Neck	2.1	3.4	4.1	3.1	4.1	95	0.72

*Apparent modulus in dynes/cm^2.

The table also shows a large difference in the dynamic flexural modulus and the torsional modulus with respect to sample orientation with backbone direction. The belly and neck regions show the greatest differences due to orientation. The sample cut parallel to the backbone shows a flex modulus of 15.1 x 10^8 dynes/cm^2 while a sample from the same area cut perpendicular to the backbone has a modulus of 3.1 x 10^8 dynes/cm^2. The butt area sample shows the least effect of orientation. This sample cut parallel had a modulus of 1.9 x 10^8 dynes/cm^2 while the perpendicular sample had a modulus of 2.2 x 10^8 dynes/cm^2. All other areas varied between these two, with the greatest changes due to orientation taking place on approaching the belly region. The torsional modulus also demonstrated this same orientation effect. The compression modulus and hardness show no effect due to orientation since the applied force here is directed into the fiber structure and not along the structure as is the case of the other two tests. Figure 8 shows the two patterns obtained for the variation of mechanical properties within a side of leather. The number 1 pattern was obtained from the flexural

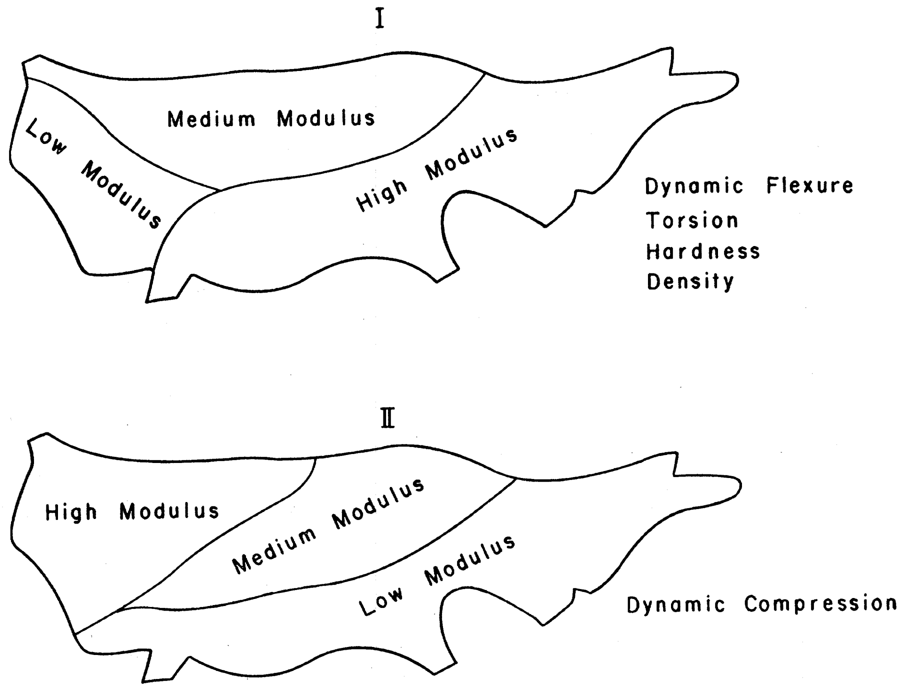

FIGURE 8.—Patterns of mechanical property variation within side leathers.

modulus, torsional modulus, hardness and density, with very slight variations. This number 1 property pattern shows the belly and neck areas to have high modulus (greatest stiffness) with large orientation effects, highest hardness and highest density. The butt and flank areas have the lowest modulus (most flexibility) with very small orientation effects, lowest hardness and density with medium properties between. The number 2 pattern was obtained only with the dynamic compression modulus and was a reverse trend of the number 1 pattern. It shows the neck and belly areas to have the greatest flexibility while the butt and backbone have the highest stiffness. These patterns were maintained regardless of tannage, modifications or any changes made within a hide. The only variation from one side of leather to another has been the magnitude of the numbers measured.

These controversial results could lead to the belief that the results obtained from the compressive study were false. However, measurements made for plasticized or unplasticized polyvinyl chloride agree with data obtained by the other test methods.

Apparently these results demonstrate some structural characteristic of leather. It appears that the butt and backbone areas have a very randomized interwoven fiber structure, indicated by the small variations found in modulus values with respect to the test specimen's orientation to the backbone. The belly and neck areas have a more aligned or oriented structure, as shown by the large variation found in modulus values due to sample orientation with respect to the backbone. Therefore, it is very possible that the butt area shows a high compression modulus due to randomized fiber structure. Because of this randomized fiber structure, there are many more fiber-to-fiber cross contacts with no possibility of the fibers slipping alongside each other at low strains; thus there is strong resistive force to compression (high modulus). In the belly area the fibers are more aligned and therefore, when the compressive force is applied at low strain, the fibers can possibly slip alongside each other and therefore offer low resistance to compression, or a low modulus.

SUMMARY

A relatively rapid nondestructive test has been demonstrated for the measurement of the dynamic mechanical properties of intact sides of leather. The information obtained from this dynamic compressive measurement indicates that the butt-backbone area of leather considered to be of highest quality and most desirable for practical application gives a higher compression stiffness value than the lower quality areas. The data obtained has established a definite pattern of compression modulus (stiffness) throughout an intact side of leather. This modulus pattern shows high stiffness in the butt-backbone area, medium stiffness in the neck area, and low stiffness (most flexibility) in the belly and neck.

Using this pattern of modulus variability, it should be possible to check quality and changes taking place in a hide during processing into leather. Any large deviations from this regular pattern of variation should indicate poor quality while increases or decreases in modulus would indicate changes due to processing.

Further studies are in progress to expand the significance of the results obtained from this study.

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DISCUSSION

Chairman Lollar: Mieth Maeser will be the discussion leader on this most interesting paper.

Mr. Maeser: After Mr. Palm sent me this paper, I realized it was in a field that I am not very familiar with, so I took it to Dr. Earl Jackson, who is a member of this association, and asked him if he would make some comments on it. I should like to read the comments which he gave me.

"As evidence of a property of individual pieces of leather that can be measured nondestructively and of the way samples can differ in that property, this work is quite interesting. Any interpretation of significance at this stage, however, must be only tentative because no firm quality relationships are established — at least in this paper.

"In the course of trying to interpret this work, it should be pointed out that the great difference in rate of application of force between the acoustic technique and the other methods may be the important factor in these results. That is, there may be an entirely different mode of strain in the material at high rates due to inertia at the macroscopic bonds at these rates and amplitudes. This would be analogous to the 'silly putty' type of phenomenon, in which, you remember, at low stress rates the material will flow like heavy oil, but at high stress rate it will shatter like glass.

"I don't know enough about the structure of leather to do more than guess, but it may be that at low rates and high strains, hydrogen bonds between fibers are ruptured, while at high rates and low strains they hold and force the deformation to occur by coiling and stretching fibers.

"An interesting experiment might be to study the influence of the transducer area in contact with the leather. As the radius increases, the area being compressed goes up as the square, while the perimeter which is under tension goes up only as the first power. This could be informative about the types of stresses that are being encountered here.

"I realize these comments are not definite, but they are all I could provide without more study than I have time for."

Those are Dr. Earl Jackson's comments. Have you any comment?

Mr. Palm: As to Dr. Jackson's comments, most of the work we are doing at present is in line with what he mentions. We have tests in progress where we are varying strains at different frequencies and also varying the area of the transducer. We are proceeding along the lines that he has mentioned.

Mr. Maeser: There's one thing that occurred to me personally about the paper, and that was the great difference in the measured values of modulus obtained by this method compared to measurements made by other methods, as explained by Mr. Palm. But I have one other thing I want to inquire about.

I listened to Mrs. Tancous' paper Monday and I listened to this paper today. It occurred to me you might throw this principle into her work and have a fairly good method for selecting the pulpy butts, that she was talking about. If this procedure was properly handled, it might be a rather direct measurement of that characteristic.

Mr. Palm: We are actually studying some of her samples now. She had sent us samples since we had discussed this at a previous meeting. She sent samples and they are actually being studied now. We haven't had anything definite, but we are going to follow it closely.

Mr. Maeser: Any comments from the floor?

Mr. Joseph Naghski (Eastern Regional Research Laboratory): Prior to getting our instrument — we were having it built — we obtained a pulpy butt side and at that time we had Dr. Kanagy check it over for us, using a capacitance type of measurement. He found there was a difference of density between specimens of this side and normal leather. I think, Bill, you also ran the same specimens after you got our machine, and I think we can add there was a definite difference in the modulus within the pulpy area. Of course, that was only one side.

Mr. Palm: The changes in values were not large, but they were different.