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American Research on the Mechanical Properties of Leather: Fracture Energy, Tearing Strength, and Acoustic Emission

Report by Cheng-Kung Liu, Michael D McClintick, and William N Marmer, United States Department of Agriculture, Agricultural Research Service, Eastern Regional Research Center, 600 E. Mermaid Lane, Wyndmoor, PA 19038-8598, USA

Summary

The hides and leather research program at the Eastern Regional Research Center near Philadelphia is the only public research program of its kind in the United States. The program exists to add value to the 35 million hides produced domestically each year. Research is conducted on hide preservation, beamhouse chemistry, tanning, waste management, the role of hide components, and mechanical properties of hides and leather, all by seven senior scientists and their associated technical staff. The Center also houses the only public research tannery in the United States. Our recent research on the mechanical properties of leather has been focusing on three areas, namely, fracture energy methodology, understanding tearing behavior, and the use of acoustic emission to quantify leather's physical qualities. The fracture resistance of chrome-tanned bovine hides was quantitatively characterized by measuring the total energy required to break the leather. This physical quantity, "fracture energy," was observed to represent more accurately the fracture resistance of leather than does the tensile strength or breaking elongation. The statistical model obtained concisely expressed the relationship between variables and fracture resistance. This statistical model is extremely important to the leather industry for quality control as well as future research on processing treatments to improve the physical and chemical properties of leather. Tearing tests were performed along with tensile tests on chrome-tanned leather to clarify the difference between the tearing and tensile behaviors and their fracture mechanisms. Observations showed that strain rate does not significantly affect tearing strength, but slightly affects tensile strength. Both strengths increase with additional moisture content until certain levels, beyond which they decrease with increasing moisture content. A drastic difference between these two strengths is demonstrated in their response to sampling angle change. Statistical analysis showed that the tensile strength does not correlate well to tearing strength, whereas a good correlation was observed between fracture energy and tearing strength. Acoustic Emission (AE) studies have been targeting the development of nondestructive testing, which will be useful to the leather industry for predicting tensile strength of semi-products or finished leather without damaging the samples. The preliminary results showed that there is a correlation between the tensile strength of leather and the cumulative acoustic energy released from the initial stretching. This correlation provides an essential basis for facilitating the possible design of a portable leather stretcher equipped with an acoustic sensor, which would allow the prediction of tensile strength by measuring the cumulative acoustic energy during initial stretching without breaking or damaging the leather.

Fracture Energy

The fracture resistance of any material is, of course, an important factor in determining the end uses for which the substance will be suitable. Our ongoing research projects on improving processing and properties of leather have propelled us to look for a physical quantity that can better represent the strength characteristics of leather. This will enable us to more effectively optimize the leather making processes. The ideal physical quantity should not be sensitive to sampling angle, and it should faithfully reflect the fracture resistance of leather. More importantly we hope this physical quantity can be used to characterize the toughness of leather and will correlate well with other specific strength requirements, such as tearing strength. Our approach to this goal is to use an energy concept.[1] We have characterized the fracture resistance of leather by measuring the energy needed to fracture a sample, which is obtained by integrating the area under the force-elongation curve as illustrated in

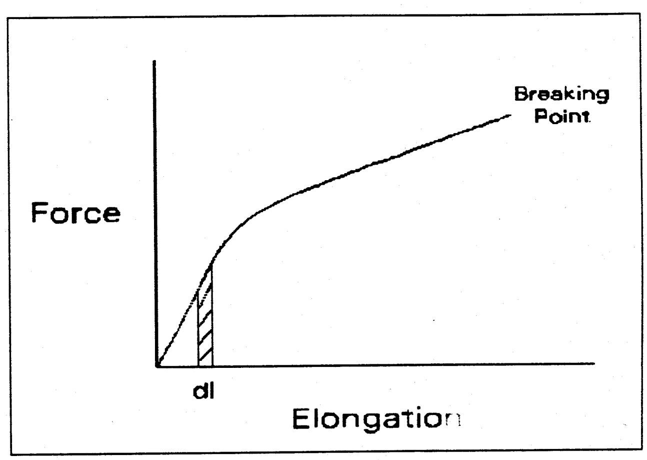

Figure 1 Fracture energy

Figure 1. In this investigation we have utilized the technique of experimental design and statistical analysis to mathematically model the influence of strain rate, moisture content and sampling angle upon the fracture energy.[2] Results show that strain rate is a complex factor in its interaction with fibrous materials such as leather. The fracture energy at first decreases then increases with increasing strain rate. The increasing heat generated during high speed stretching induced an effect of plastication upon the fiber bundles, therefore increasing the fracture resistance of leather. Water acts as a plasticizer, lubricating the fiber bundles

and enhancing the resistance to fracture. When it reaches a certain limit, however, it has an adverse effect on leather integrity. Most importantly, contrary to tensile strength and breaking elongation, the sampling angle shows little effect on the fracture energy. Staked and fatliquored leather clearly showed improved fracture energy in our study. In this study we have also discovered the applicability of a dimensionless parameter, the ratio of the tensile strength to Young's modulus. This ratio provides a quantitative expression of the toughness of leather; we therefore named it the toughness index. A correlation has been demonstrated between this index and fracture energy, as demonstrated in Figure 2. Actually the term fracture energy has been

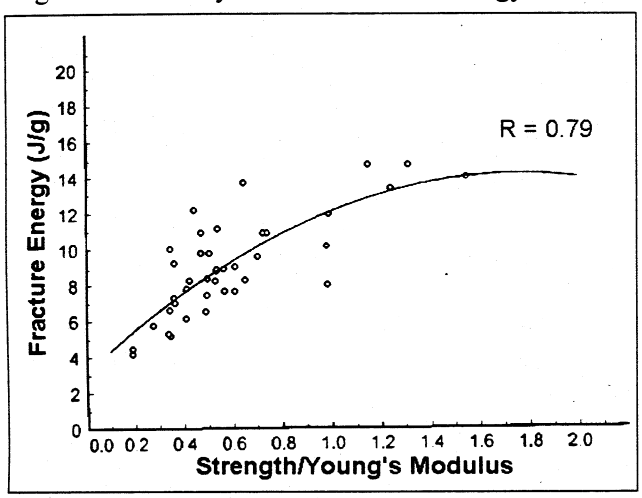

Figure 2 Fracture energy vs the ratio of tensile strength to Young's modulus

used interchangeably with "toughness". It is obvious that toughness is an important criterion in most leather products such as upholstery and garments. In other words, fracture energy is the leather property about which one really needs to be concerned, not the tensile strength or breaking elongation alone. Good fracture energy generally reflects a superior balance of strength and flexibility. We hope to draw the leather industry's attention to the importance of fracture energy to the leather it manufactures.

Tearing Behavior

The ability to withstand tearing forces is one of the most significant mechanical properties required for leather products, particularly those used for upholstery. In the tannery, one of the frequent questions being asked is why leather high in tensile strength is not necessarily high in tearing strength. Although some limited investigations[3,4] indicated that a slight correlation exists between tensile strength and tearing strength, the relationship between tensile strength and tearing behavior has never been fully explored. Because of the lack of such knowledge, it is often very difficult for tanners to tailor their processes to produce leather having both good tensile strength and good tearing strength. We have conducted a systematic study to investigate the relationship between tensile strength and tearing strength.[5] We hope that the results of this investigation can lead to a more effective optimization of the leathermaking processes and yield a high quality leather strong in both tensile strength and tearing strength. The tearing and tensile tests were performed on the same leather samples, thereby minimizing experimental error incurred by sample variation. Results showed that for the tearing tests a unique zigzag tearing pattern was observed due to the fluctuations in the tearing force, whereas the tensile tests demonstrated a uniform fracture pattern. Results also showed that strain rate does not significantly affect tearing strength, but does affect tensile strength. Moreover, both strengths increase with increasing moisture content up to certain levels, at which they start to decrease with increasing moisture content. A drastic

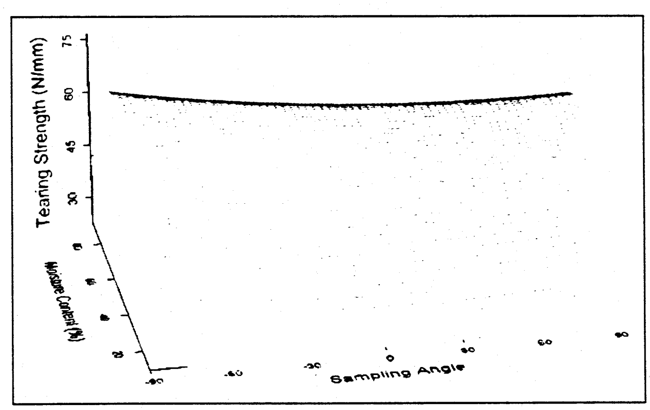

Figure 3 Effect of sampling angle on tearing strength

difference between these two strengths is demonstrated in response to sampling angle change. Tearing strength in Figure 3 showed little variation with a change of sampling angle, whereas tensile strength in Figure 4 (overleaf) showed a maximum at close to parallel to the backbone direction, then

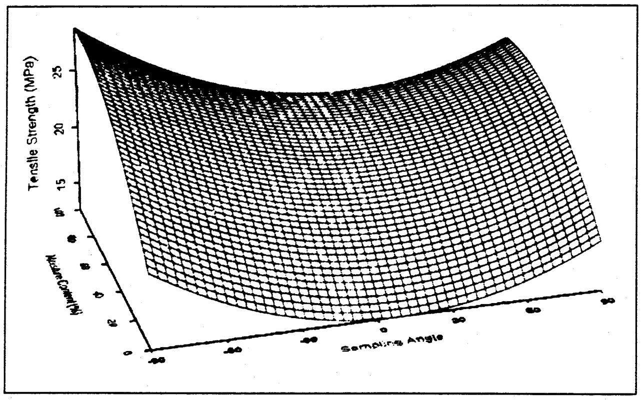

Figure 4 Effect of sampling angle on tensile strength

steadily decreased when sampling angle deviated from the backbone line. Most importantly, we have demonstrated the importance of fracture energy to tearing strength, as illustrated in Figure 5. Good fracture energy reflects a superior balance of strength and flexibility. On the other hand, a brittle leather produced by over-drying or insufficient removal of glue-like protein substances yields poor tearing strength. Proper fatliquoring and moisture content are crucial factors for a good tearing strength. Good deformability can minimize the stress concentration and yield a better tearing strength.

Acoustic Emission

Currently, there is no on-line test method to monitor the physical properties of semi-products such as wet blue or crust during the leather-making processes.[6] This causes a tremendous waste in terms of chemicals and energy. With the right monitoring tool, inferior leather semi-products, such as wet blue, could be downgraded earlier or removed from production prior to being subjected to expensive leather-making processes including retanning, fatliquoring, dyeing, drying, staking, and finishing. Therefore, developing a nondestructive tester to perform on-line testing of the physical properties of semi-products is very desirable. By early detection of weakness or defects, tanneries will be able to adjust the processing parameters to correct the problems or remove the inferior semi-product. Acoustic emission (AE) has been recognized for some years now as a valuable nondestructive test method for detecting the onset of cracking or other kinds of failure in engineering structures, aircraft wings or pressure vessels, for example, which are exposed to considerable stress

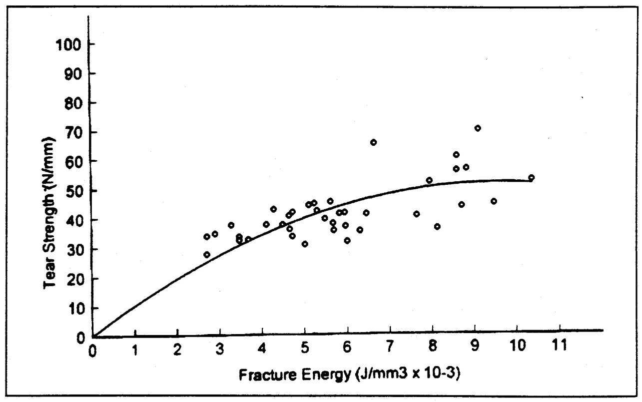

Figure 5 Correlation between tearing strength and fracture energy

or strain in service.[7] AE is a passive procedure in that propagating cracks emit a noise and ultrasonic transducers are used to detect it. The AE method has also been applied in coatings research and the technique is proving extremely useful in earlier identification of coating adhesion failure.[8] For leather, Kronick and Thayer have demonstrated that the strength of fiber adhesions can be determined by "listening" to the sounds emitted by the sample while it is stretched.[9] Moreover, Kronick and Maleeff reported that by observing a sudden increase in energy and the frequency of acoustic pulses, they were able to determine when the leather was about to fail far before it broke or tore.[10] The implication of this finding is that AE methods can be a useful tool to monitor the tensile strength of leather during the leather-making processes without interrupting the processing.

Tensile strength is one of the most important qualities of leather. To determine the tensile strength, samples are cut from a side of leather, brought to a quality testing room, and measured for tensile strength. This operation not only is time-consuming, but can also damage or even waste the whole side. Together with BLC Leather Technology Centre, under a Co-operative R & D Agreement, we therefore aim to develop a nondestructive process control tool based on the AE methods to monitor the tensile strength of leather. Our first task is to examine whether there is a relationship between tensile strength and any of the AE data—number of hits, the acoustic energy generated during stress-strain tests, or amplitude distribution.

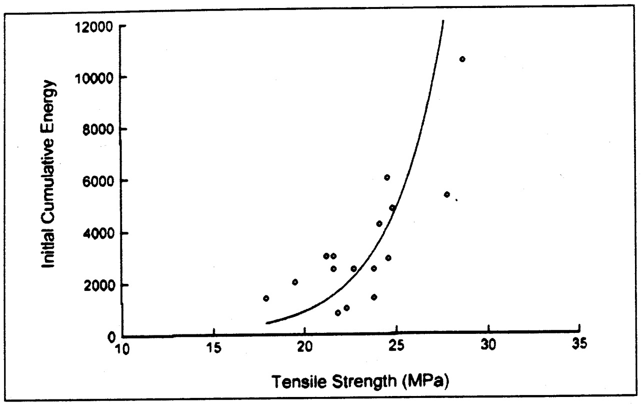

Figure 6 Relationship between initial cumulative energy and tensile strength

Results of AE hits measurements do not show a correlation with tensile strength.[11] This is attributed to the fact that AE hits only represent the number of significant deformations or fiber/fiber bundle fractures, which have no bearing on the tensile fracture resistance, ie, tensile strength. On the other hand, the results of AE amplitude distributions indicate that the hits with a good uniformity and higher amplitude may imply a higher tensile strength material. The correlation, however, is hardly conclusive and very difficult to represent in a quantitative manner. Finally, the acoustic energy data give a more well defined correlation with tensile strength. Leather having better tensile strength shows a more rapid increase in acoustic energy, particularly before the leather is about to break.

For nondestructive testing, the AE data must be collected from early stretching regions without inducing a non-recoverable deformation or fracture. Since the AE energy is associated with the elastic energy released during deformation or stretching, it should be proportional to the displacement of samples according to Hooke's law[12,13] and consequently, proportional to the time of stretching or the degree of stretch (strain). Therefore, one may expect that a close relationship may exist in cumulative energies between the initial deformation and final breaking points. Ten percent strain is a recoverable deformation for most leather, and that strain produces sufficient detectable AE signals. As a result, the initial cumulative energy at 10 percent strain was used to correlate to final cumulative energy. This hypothesis was confirmed by the excellent correlation between the cumulative energy and the initial cumulative energy at ten percent strain. A further encouraging finding is shown in Figure 6, which demonstrates a fair correlation between tensile strength and initial cumulative energy. As mentioned earlier, the implication of this finding is an essential basis to the feasibility of the design of an AE non-destructive tester to predict the tensile strength. Based on the relationship derived from this study, one may use a tensile stretcher to elongate a leather sample to ten percent strain and obtain an initial cumulative energy pattern using an AE analyzer. The tensile strength can then be predicted without damaging or fracturing the leather.

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