

# A STUDY OF THE REALISTIC STRENGTH OF LEATHER: TRUE STRESS

by

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## ABSTRACT

Strength deals with the durability of materials during usage and therefore is an important criterion for performance evaluation. Leather goods, which continue to be preferred by many over artificial substitutes, need to exhibit durable material performance. Strength testing, as related to an understanding of the endurance against force, is an important component of overall material behavior. Therefore, tensile testing should be well developed so as to analyze the properties of finished leathers and acquire realistic practical data. This study deals, in detail, with the evaluation of tensile properties considering the differences between engineering stress and true stress. In this examination of tensile behaviors three groups of garment leathers with different finishes (aniline, semi-aniline, and full pigmented finishes) were used. The samples were evaluated comparing engineering stress and true stress. In a Completely Randomized Design study, the statistical differences were calculated by the Duncan test in the level of  $P \leq 0.05$ . Thereby, statistically significant differences between engineering stress and true stress between each of the three groups was verified.

## RESUMEN

La Resistencia [física] describe la durabilidad de los materiales durante su uso y como tal es un criterio importante para evaluar su desempeño. Los artículos de cuero, los cuales siguen siendo preferidos por muchos sobre sustitutos artificiales, deben exhibir un desempeño durable. Pruebas de resistencia relacionadas al conocimiento de la resistencia contra la fuerza, es un importante componente generalizado del comportamiento de materiales. Así pruebas de resistencia a la tensión deben de ser lo suficientemente desarrolladas para satisfactoriamente analizar las propiedades de cueros terminados para así adquirir datos realistas y prácticos. Este estudio describe detalladamente la evaluación de propiedades ténsiles considerando las diferencias entre la tensión desde un punto de vista solo de la de ingeniería y la verdadera tensión. En este análisis el comportamiento a la tensión de tres grupos de cuero para vestimenta con diferentes acabados (anilina, semi-anilina, y altamente pigmentados) fueron utilizados. Las muestras fueron evaluadas en términos de la tensión definida en la ingeniería y verdadera tensión. En un estudio estadístico completamente diseñado aleatoriamente, las diferencias estadísticas se calcularon por el método de Duncan un nivel de  $P \leq 0,05$ . Así tal, las diferencias estadísticas significantes entre la tensión definida por ingeniería, y verdadera tensión demostrada en cada uno de los tres grupos fue verificada.

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**INTRODUCTION**

Leather is a natural, ductile, unique, and fibrillary organic material produced from animal skins. It is used for the manufacture of different products such as shoes, garments, bags, belts, upholstery, and many other accessories constituting a large market worldwide. Due to its natural character, its incorporation in fashion, the quality, and handiwork behind its manufacture, it's known to be valuable with high price products in trading and also for end users. Along with the increasing customer demands the quality parameters are also increasing for any kind of leather products. During their usage and the special shaping processes the leather materials are exposed to many mechanical actions and must be able to withstand any external forces, ensure the preservation of shape, and dimensional stability of the product over time.<sup>1</sup>

Strength is the resistance of a material against any force. In other words, mechanical behavior encompasses the response of materials to external forces.<sup>2</sup> Tensile strength is one of the most important physical quantities of characterizing the mechanical properties of leather. It's also known to be a routine quality control test in the leather industry, where maximum stress and breaking elongation of leather are defined. These quality parameters are measured to be within the limits or at the desired level of customer demand. For this reason it's very important to understand, define, and perform the tensile test, which is the most significant test of a material's mechanical response, for leather products.<sup>3</sup>

Stress analysis is a substantial part of engineering science, as failure of most engineering components is usually due to stress.<sup>4</sup> The main output of a tensile test is a load versus elongation curve which is then converted into a stress versus strain curve. Stress-strain curves are extremely important graphical measurement of material's mechanical properties.<sup>5</sup> Engineering stress is the form commonly used in applications, testing, and stress-strain curves but does not take into account the reduction in cross-sectional area (Fig 2). It is based on the value obtained by dividing the load by the original unreformed cross-sectional area  $A_0$  (Fig 1). But actually a material is stressed as its cross-sectional area changes. That is the reason why the value of stress starts declining after onset of necking in any ductile material such as leather.<sup>6-8</sup> For ductile materials under tension, the material becomes unstable and begins to neck after a particular load is applied. The engineering stress-strain curve will indicate that less stress is needed to further deform the material, when in actuality; the necked area requires more stress for further deformation. The increase in stress is known as strain hardening. It must be considered that the engineering stress-strain curve does not give a true indication of the deformation characteristics of ductile materials.<sup>9</sup>

In order to provide the correct description of the mechanical behavior of material, the measurement of true stress and true

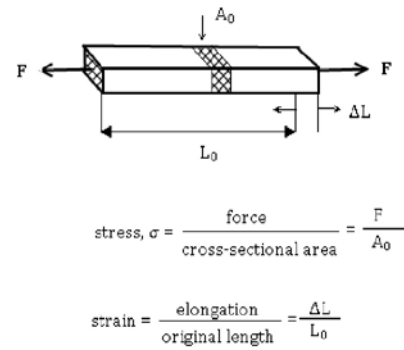


Figure 1. Stress-strain behavior of a material.

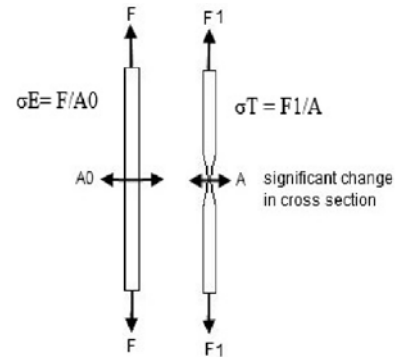


Figure 2. The change of dimensions of a specimen during a tensile test.

strain in local terms is required.<sup>10</sup> True stress is based on the instantaneous material configuration and calculated using the actual, deformed cross-sectional area, and length.<sup>7,8</sup> If the reduction of the cross section area is large, the engineering stress becomes inappropriate<sup>11</sup> because it is based entirely on the original dimensions of the specimen and these dimensions change continuously during the test. The true stress-strain curves usually follow a higher trend than engineering stress curves. The degree of higher trend, of course, highly depends on the structure of the material. In ductile and highly elastic materials, true stress values can be expected to be much higher than engineering stress (Fig 3).

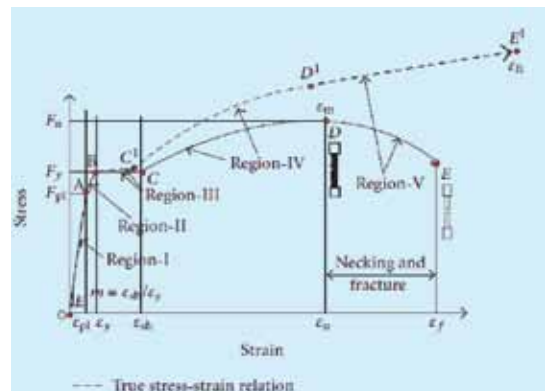


Figure 3. Engineering and true stress-strain curve.<sup>9</sup>

To obtain the true stress for calculation, the load and the cross-sectional area must be measured concurrently during the test. The true stress is defined as the ratio of the applied load to the instantaneous cross-sectional area;

$$\sigma_T = F/A \quad (eq. 1.1)$$

Taking into consideration that there is no volume change in the specimen, the true stress can be calculated according to the instantaneous area derived from total volume and instantaneous length. Under this assumption, true stress can be formulized as follows;

$$A \cdot l = A_0 \cdot l_0; \sigma_T = \frac{F}{A} = \frac{F}{A_0} \cdot \frac{l}{l_0} \rightarrow \sigma_T = \sigma_E (1 + \epsilon_E) \quad (eq. 1.2)$$

The present study deals with the measurement of tensile strength of finished leathers proper for garment production coated with three types of finishes: aniline, semi-aniline, and full pigmented. In the results true stress was calculated according to the mentioned formulas and the difference in comparison to the engineering stress was discussed. Overall results were also examined statistically according to "Completely Randomized Design" and they were evaluated by the Duncan test with a significance level of  $P \leq 0.05$ .

## MATERIALS AND METHODS

### Materials

The raw materials to be used in the tensile tests are 30 finished sheep leathers proper for garment production. The leathers have an area around 6 to 6.5 square feet and an average thickness of 0.4 to 0.6 mm. To perform the test the leathers were divided into three groups according to their finish types: aniline, semi-aniline, and full pigmented opaque, respectively; and each group contained 10 leathers. Although they had different finish types all leathers had the same origin and were processed in the same group until finishing stage.

### Methods

Prior to the tensile test the leathers were conditioned according to the official standard of EN ISO 2419 and the sampling was done according to EN ISO 2418. The tensile measurements of the samples were carried out according to the conditions described in the standard of EN ISO 3376 (Determination of Tensile Strength and Percentage of Extension). To perform the test a Shimadzu AG-IS tensile testing device was used. For the statistical analysis of the results, the SPSS 16.0 (SPS Inc., Chicago, USA) package program was used and the results were evaluated statistically by the Duncan test with a significance level of  $P \leq 0.05$ . The true stress values of the tested samples were calculated by using the aforementioned formulas (eq. 1.1 and 1.2).

## RESULTS AND DISCUSSION

The results obtained from the tensile test are given in Tables I and II and Figures 4 and 5. The data given in Table 1 is the average of 8 repeats tests for each sample. If a general evaluation should be made according to the finish types, it can be said that the results of aniline and full pigmented (opaque) leathers are quite similar, whereas the semi-aniline finished leathers showed slightly decreased engineering stress values. This difference can be due to the mechanical actions applied to the leathers, such as hot press, which may change the thickness and fiber structure of the leathers. The average of engineering strain values of the leathers ranged from 53 to 57 % which shows the ductile structure of the leathers where the true stress calculation gains importance. Thus, the true stress values calculated from the equations (1.1 and 1.2) can also be seen in the table. The results verified the increment of engineering stress values when the real thickness of the samples was taken into account during the test. The average of the engineering stress values of the samples varied from 8.8 to 10.8 N/mm<sup>2</sup> while the true stress values ranged from 13.7 to 17.2 N/mm<sup>2</sup>.

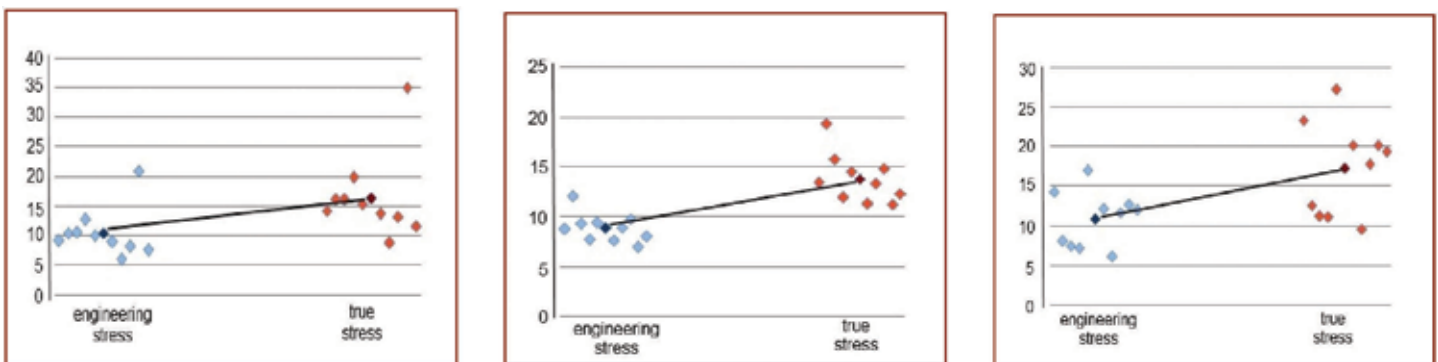


Figure 4. Graphics of the differences between engineering stress and true stress values (respectively; aniline, semi aniline, full pigmented finished leathers).

**TABLE I**  
**Tensile strength properties of finished leathers.**

No	ANILINE				SEMI- ANILINE				FULL PIGMENTED			
	Max Strain (%)	Engineering Stress (N/mm <sup>2</sup> )	True Stress (N/mm <sup>2</sup> )	Difference (%)	Max Strain (%)	Engineering Stress (N/mm <sup>2</sup> )	True Stress (N/mm <sup>2</sup> )	Difference (%)	Max Strain (%)	Engineering Stress (N/mm <sup>2</sup> )	True Stress (N/mm <sup>2</sup> )	Difference (%)
1	54,17	9,21	14,25	54,7	53,50	8,76	13,41	53,0	61,71	14,29	23,25	62,7
2	55,26	10,45	16,13	54,4	61,51	12,02	19,33	60,8	55,07	8,12	12,62	55,3
3	53,18	10,67	16,13	51,1	69,14	9,29	15,70	68,9	49,91	7,51	11,23	49,5
4	57,39	12,81	19,94	55,5	56,45	7,66	11,90	55,4	55,66	7,19	11,07	54,0
5	56,03	9,96	15,41	54,7	55,00	9,38	14,44	53,9	59,89	17,01	27,21	59,9
6	54,62	8,95	13,70	53,1	50,64	7,63	11,30	48,0	65,66	12,15	20,21	66,3
7	47,59	6,02	8,80	46,1	49,64	8,89	13,26	49,0	58,31	6,13	9,59	56,3
8	63,80	8,20	13,25	61,7	53,03	9,73	14,77	51,8	53,82	11,69	17,74	51,8
9	67,44	20,97	35,03	67	60,32	6,96	11,18	60,5	53,38	12,69	20,10	58,3
10	54,99	7,56	11,66	54,2	53,13	8,02	12,28	53,1	62,32	12,02	19,36	61,0
Average	56,45	10,48	16,43	55,2	56,24	8,83	13,76	52,8	57,57	10,88	17,24	57,5

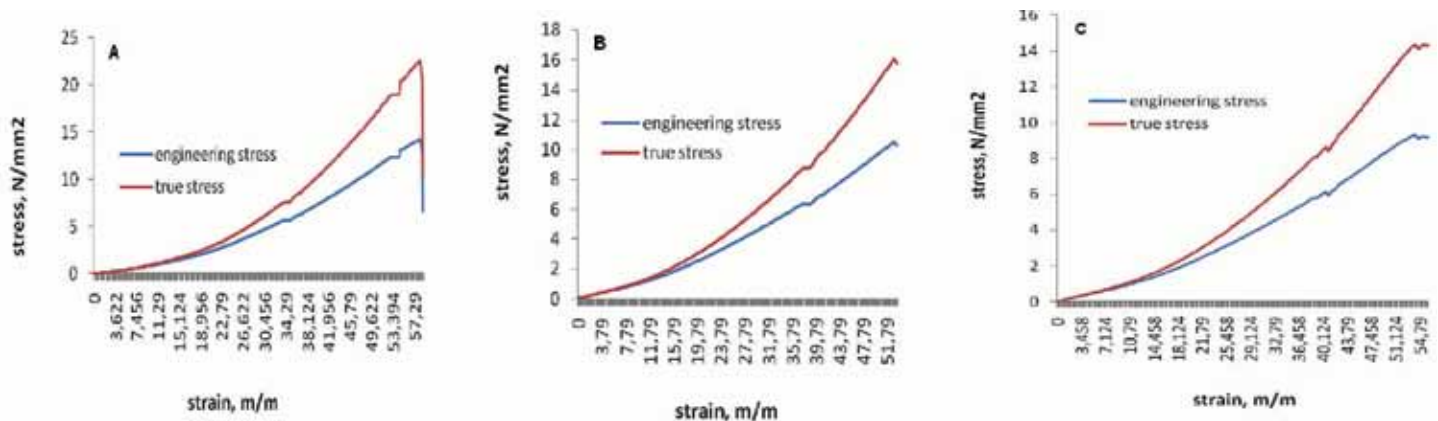


Figure 5. Representative engineering and true stress – strain curves of the samples.

When we calculated the difference between engineering and true stress, the increase of true stress reached an average of 52 to 57%. The difference can be seen more clearly in Fig. 4 which is the graphical representation of some samples from each group. For all types of finishing methods, there is a marked increase from engineering stress to true stress

and in Fig. 5 the engineering stress and true stress curves can be compared. The true stress curves are above the engineering stress curves because of the decreases in the cross sectional area of the specimens. The behavior of the leather samples during the deformation period can also be interpreted. The stress-strain curves of the samples exhibited a continuously increasing trend even between the necking and the fracture point where no clear ultimate strength point can be observed. This behavior shows us that for the leather samples the deformation distributes uniformly along the gauge section after the onset of necking. In this way the true stress can be calculated according to the aforementioned formulas where no independent cross-sectional area measurements are necessary.

A) Aniline, B) Semi aniline, and C) Full pigmented leathers

The statistical analysis of the results obtained from the engineering stress and true stress for each group of samples is

given in Table 4. The evaluation of the analysis was accomplished according to the Duncan test with a significance level of  $P \leq 0.05$  where, the results lower than 0.05 shows us the significance of the difference. According to the evaluation, the significance level values were found to be below 0.05 as seen 0.035, 0.001, and 0.009 for the sample groups of aniline, semi-aniline, and full pigmented leathers, respectively. This shows us that the differences of engineering and true stress are also statistically significant for all sample groups. The difference level was higher in semi-aniline and full pigmented leathers than the aniline finished leathers.

## CONCLUSIONS

Engineering stress is one of the main parameters that is used for the determination of the strength of the material. It is useful especially for brittle materials that show no or small deformations upon stretching of the material. However, for the materials showing a greater strain of more than 1 %, the cross sectional area of the samples changes so that the true stress can give more realistic results for the material strength.<sup>11</sup> The differences between engineering and true stress values can reach significant levels for ductile and elastic material exhibiting very high strain values. For many industries such as

**TABLE II**  
**The results of the statistical analyses obtained from the Duncan test with a significance level of  $P \leq 0.05$ .**

<b>Difference of Aniline Finish</b>	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F</b>	<b>Significance</b>
Between Groups	177,016665	1	177,016665	5,17111005	0,035
Within Groups	616,173305	18	34,23185028		
Total	793,1899701	19			
<b>Difference of Semi- aniline Finish</b>	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F</b>	<b>Significance</b>
Between Groups	101,3161608	1	101,3161608	16,40625555	0,001
Within Groups	111,1582646	18	6,175459143		
Total	212,4744254	19			
<b>Difference of Full Pigmented Finish</b>	<b>Sum of Squares</b>	<b>df</b>	<b>Mean Square</b>	<b>F</b>	<b>Significance</b>
Between Groups	202,2308284	1	202,2308284	8,617131694	0,009
Within Groups	422,4323173	18	23,46846207		
Total	624,6631457	19			

polymer, textile, and leather the tensile properties of the products may be very important due to the end use and the type of product. Depending on the leather product, the required tensile strength properties may change,<sup>12</sup> however, in every case; engineering stress is used for the determination of the strength of leather, which sometimes can be difficult to reach required levels.

The present study showed the difference between the engineering and true stress values obtained from tensile tests performed on finished garment leathers. In the case of true stress, the values were higher, even as much as 50% more than the values of the engineering stress. The statistical analysis also verified the significance of the difference between the stress values being lower than 0.05 according to the Duncan test. For these reasons, the use of true stress for leather which is a highly ductile material may be more efficient not only in scientific terms but also for the good of the manufacturers.

### REFERENCES

1. Secan, C., Harnegea, F.; Experimental research on the behavior of leather substitutes under tensile stress, *Annals of The University of Oradea Fascicle of Textiles-leatherwork*, 2010.
2. Hosford, W.F.; *Mechanical Behavior of Materials*, Cambridge University Press, New York, pp.425, 2005.
3. Boyer, H.F.; *Atlas of Stress-Strain Curves*, ASM International, Ohio, pp. 815, 1987.
4. Case, J., Chilver, A, Ross, C.T.F.; *Strength of Materials and Structures*, Butterworth-Heinemann, pp. 720, 1999.
5. Roylance, D.; *Stress-Strain Curves*, Massachusetts Institute of Technology, Cambridge University Press, 2001.
6. Bhavikatti, S.S.: *Mechanics of Solids*, New Age International Publishers, pp. 241, 2010
7. Vable M., *Mechanical Properties Of Materials*, *Mechanics of Materials*, pp. 83, 2012.
8. Stone, R. M.; *Stress-Strain Relationships*, OPTI 222-Mechanical Design in Optical Engineering, Optical Science Center, University of Arizona, pp.17-23.
9. Arasaratnam, P., Sivakumaran, K. S., Tait, M. J., True stress-true strain models for structural steel elements, *International Scholarly Research Network* ,2011.
10. Kontou, E., Farasoglou, P., Determination of the true stress-strain behaviour of polypropylene, *Journal of Materials Science* **33**, 147-153, 1998.
11. Ling, Y.; Uniaxial True Stress-Strain after Necking, *AMP Journal of Technology* **5**, 37-48, 1996.
12. Jankauskaitė, V., Strazdienė, E. and Laukaitienė, A.; Stress distribution in polymeric film laminated leather under biaxial loading, *Proc. Estonian Acad. Sci. Eng.* **12**, 111–124, 2006.
13. TS EN ISO 2419, Physical and mechanical tests - Sample preparation and conditioning, Turkish Standards Institution, Ankara, pp. 6, 2006.
14. TS EN ISO 2418, Chemical, physical and mechanical and fastness tests - Sampling location, Turkish Standards Institution, Ankara, pp. 11, 2006.
15. TS 4117 EN ISO 2589, Physical and mechanical tests - Determination of thickness, Turkish Standards Institution, Ankara, pp. 7, 2006.
16. TS 4119 EN ISO 3376, Physical and mechanical tests - Determination of tensile strength and percentage extension, Turkish Standards Institution, Ankara, pp.9, 2006