TMMOB Tekstil Mühendisleri Odası
UCTEA Chamber of Textile Engineers
Tekstil ve Mühendis
Journal of Textiles and Engineer

Yıl (Year) : 2025/2
Cilt (Vol) : 32
Sayı (No) : 138

Araştırma Makalesi / Research Article

EVALUATION OF THE EFFECTS OF ARTIFICIAL AGING ON THE UPPER LEATHER OF MILITARY COMBAT BOOTS

Nilay ÖRK EFENDİOĞLU[1]
Ali YORGANCIOGLU[1]
Ersin ÖNEM[1]
Hüseyin Ata KARAVANA[1*]

[1] Leather Engineering Department, Engineering Faculty, Ege University, Izmir, Türkiye

Gönderilme Tarihi / Received: 05.02.2025
Kabul Tarihi / Accepted: 28.04.2025

ABSTRACT: The upper leathers used in military combat boots must have more advanced performance characteristics given the different conditions of use to which they are exposed, especially compared to leathers used in garments and saddlery. Unlike casual footwear, combat boots are exposed to extreme climatic conditions and mechanical stress. Therefore, the upper leather must meet the highest performance standards to ensure durability and functionality under these conditions. In this study, the most important physical and mechanical properties such as tensile strength, elongation at break, tear load, distension and strength of surface, upper-sole adhesion resistance and color change of upper leathers for combat boots are examined before and after artificial aging. These properties are crucial for ensuring comfort and protection in demanding environments. The results show that artificial aging leads to a deterioration of certain mechanical properties, such as surface distension and upper-sole adhesion resistance. At the same time, there is no significant deformation in other critical properties. This suggests that upper leathers used in combat boots can maintain sufficient durability for prolonged use in harsh environments. Nevertheless, further material development is required to optimize specific properties for military use. This study provides valuable insights into the development and selection of combat boot leathers, guiding future innovations towards materials that are more resistant to prolonged extreme climatic conditions and intense mechanical wear.

***Keywords*:** Leather, upper leather, military combat boot, artificial aging

ASKERİ SAVAŞ BOTLARINDA YAPAY YAŞLANDIRMANIN YÜZLÜK DERİLER ÜZERİNDEKİ ETKİSİNİN DEĞERLENDİRİLMESİ

ÖZ: Askeri savaş botlarında kullanılan yüzlük derilerin, karşılaştıkları farklı kullanım koşulları göz önüne alındığında, özellikle giysilik ve saraciyelik derilere kıyasla daha gelişmiş performans özelliklerine sahip olması gerekmektedir. Günlük ayakkabıların aksine, savaş botları zorlu iklim koşullarına ve ağır mekanik strese maruz kalmaktadır. Bu nedenle, yüzlük derinin bu koşullar altında dayanıklılık ve işlevsellik sağlamak için en yüksek performans standartlarını karşılaması gerekmektedir. Bu çalışmada, savaş botlarında kullanılan yüzlük derilerin yapay yaşlandırma öncesi ve sonrası çekme mukavemeti, kopma anındaki uzama, yırtılma yükü, yüzey gerilimi ve mukavemeti, saya-taban yapışma direnci ile renk değişimi gibi temel fiziksel ve mekanik özelliklerini araştırılmıştır. Bu özellikler, zorlu ortamlarda konfor ve koruma sağlamak için kritik öneme sahiptir. Sonuçlar, yapay yaşlandırmanın yüzey gerilimi ve yapışma direnci gibi belirli mekanik özelliklerde azalmaya yol açtığını göstermektedir. Bununla birlikte, diğer kritik özelliklerde önemli bir deformasyon olmadığı gözlemlenmiştir. Bu durum, savaş botlarında kullanılan yüzlük derilerin zorlu çevre koşullarında uzun süreli kullanım için yeterli dayanıklılığı koruyabildiğini göstermektedir. Yine de, askeri kullanıma yönelik belirli özelliklerin optimize edilmesi için daha fazla malzeme geliştirmesi gerekmektedir. Bu çalışma, savaş botu derilerinin geliştirilmesi ve seçimi konusunda değerli bilgiler sunarak, uzun süreli zorlu iklim koşulları ve yoğun mekanik zorlanmalara daha dirençli malzemelere yönelik gelecekteki yeniliklere rehberlik sağlamaktadır.

***Anahtar Kelimeler*:** Deri, yüzlük deri, askeri savaş botu, yapay yaşlandırma

---

****Sorumlu Yazar/Corresponding Author:*** *huseyin.ata.karavana@ege.edu.tr*
DOI: *https://doi.org/10.7216/teksmuh.1633953* *www.tekstilvemuhendis.org.tr*

1. INTRODUCTION

Boots are very popular around the world and are often used in various sports and work environments, such as military operations, firefighting, hiking and other outdoor activities [1]. Military boots are primarily designed to protect the foot while minimizing the impact on performance during training and operations [2]. The performance of the upper leathers used in military boots is of paramount importance, especially given the extreme and often unpredictable conditions they must withstand. Unlike conventional leathers, these materials are subject to stringent requirements as they are expected to provide exceptional durability, flexibility and resistance to harsh environmental factors and prolonged use [3, 4]. The upper leather of combat boots must meet stringent criteria, not only in terms of durability, but also in terms of resistance to wear, tear and environmental factors, to ensure that it provides reliable protection and functionality even under the most challenging conditions.

The quality of upper leather begins with the careful selection of raw hides, which are categorized according to their inherent quality values such as grain structure, thickness and the presence of defects. The hides selected for military applications often come from calves raised in specialized environments, which contributes to the overall quality and performance characteristics of the final product. During production, processing parameters are carefully selected to ensure optimal physical and mechanical properties, including tensile strength, tear strength and elongation at break [5]. These parameters are crucial as they have a direct impact on the boot's ability to withstand the severe stresses of military operations. The specially developed leathers are then used to make combat boots specifically designed for military use. Factors such as abrasion resistance and environmental resistance are also taken into account [6].

At this stage, it is essential that both the boots and their upper leather components have exceptional physical and mechanical resistance to adverse conditions to ensure that they can withstand prolonged use without immediate deformation or failure. Any errors or omissions during the production process can lead to irreversible problems, highlighting the need for rigorous quality control and assessment. This may involve a combination of visual inspections, physical tests and artificial aging tests to ensure that the leather retains its integrity over time.

Despite advances in material science and the availability of synthetic alternatives, genuine leather remains the preferred choice [7] for military footwear, as it offers a favorable balance between durability, flexibility and comfort—qualities that are essential for soldiers operating in diverse and often extreme conditions. The performance of these leathers is influenced by three key environmental factors: temperature, relative humidity and UV radiation [8]. Understanding these influences is vital to improving the endurance and resilience of combat boots, ensuring they meet stringent performance standards and provide lasting protection during critical operations.

An essential part of assessing the durability of leather materials is artificial aging, a process designed to simulate the long-term effects of environmental conditions in a compressed time frame [9]. Artificial aging involves exposing leather samples to controlled conditions that mimic natural wear, such as temperature fluctuations [10], humidity [11] and UV irradiation [12]. In military applications, this process is critical to understanding how leather reacts to the harsh environment in which soldiers are deployed. Artificial aging tests can reveal changes in strength, elasticity, color and surface integrity, providing crucial insights into the material's potential vulnerabilities. By accelerating these aging processes in a laboratory environment, researchers can quickly gather data on how the material behaves over longer periods of time, enabling faster assessments and improvements in leather treatment.

While previous studies have generally looked at the effects of aging on leather materials [13-16], there has been no research specifically examining the durability and resistance of upper leather under the rigorous and controlled conditions required for military applications. Furthermore, previous research has not systematically investigated the interplay between various environmental stresses such as extreme temperature fluctuations and humidity cycles on the durability of upper leather. Military personnel often work in very different climates, ranging from arid deserts to humid jungles and icy mountainous regions. It is therefore crucial to understand how upper leathers react to these extreme conditions. The present study aims to fill this gap by investigating the physical and mechanical properties of upper leather - used in combat boots - before and after exposure to artificial aging processes. This study uniquely simulates the real-world conditions that military personnel are exposed to by incorporating a combination of severe temperature fluctuations, high humidity and intense UV radiation. Unlike previous studies that have assessed the effects of aging in isolation, this study takes an integrated approach to better understand the cumulative effects of multiple stressors.

This approach will investigate whether these leathers maintain their key performance characteristics over time, particularly in demanding environments where high or low temperatures are commonplace. The results of this research are expected to provide important insights into the durability of upper leather under real military conditions contributing to the further development of high-performance boots that improve protection, reliability and comfort for military personnel. By identifying potential weaknesses and areas for improvement, this study aims to facilitate the development of innovative leather processing techniques and ensure that combat boots remain effective and reliable under the most demanding operational conditions.

2. MATERIALS AND METHODS

2.1. Materials

In this study, a total of ten pairs of flawless and defect free combat boots with rubber soles (Figure 1) made of chrome-tanned upper leathers were used. All boots were selected to ensure uniformity of design and specifications. The upper parts of the boots were cut out for testing, with the resulting leather samples having an average thickness of 2.10 ± 0.03 mm. For the experimental design, one boot from each pair was selected for the pre-aging tests, while the corresponding boot from the same pair was designated for the post-aging evaluations.

Figure 1. Military combat boots

2.2. Methods

2.2.1. Artificial Aging Process

Artificial aging of leather samples was performed in a controlled climate chamber (Angelantoni, model CH 600) according to the TS EN ISO 17228 (2015) standard [17]. This standard includes several methods that differ in temperature, humidity and number of cycles depending on the intended application and the environmental conditions of the product or material. The methods are divided into thermal aging (Category 6), thermal aging and increased humidity (Category 7) and cyclic temperature/humidity aging (Category 8). Method 8B within the cyclic temperature/ humidity aging category represents the most extreme conditions as it involves aging at temperatures below freezing. The criteria for this method are explained in more detail below. This method was developed to replicate the long-term effects of different climatic conditions. The samples were subjected to accelerated aging under precisely defined temperature and humidity conditions to simulate the environmental stresses to which combat boots are exposed in real use.

The artificial aging process was carried out under the following conditions (8B), where RH refers to relative humidity:

70 °C ± 2 °C and 20% RH ± 5% RH for 4.0 hours ± 0.2 hours;

38 °C ± 2 °C and 95% RH ± 5% RH for 16 hours ± 1 hour;

-30 °C ± 2 °C for 4.0 hours ± 0.2 hours.

This cycle was repeated 10 times under these conditions. After completion of the aging process, the leather samples were removed from the chamber and allowed to return to room temperature. They were then subjected to a series of mechanical and physical property assessments to evaluate any changes caused by the aging process.

2.2.2. Tensile Strength and Elongation at Break

The thickness of the leather samples was measured in accordance with the TS EN ISO 2589 (2016) standard using a thickness gauge (SATRA, model STD 483) [18]. The tensile strength and elongation at break of the leather samples were determined using a testing machine (Shimadzu, model AG-IS) with a 5 kN load cell and Trapezium-2 software in accordance with TS EN ISO 3376 (2020) [19]. The tests were performed on samples from each boot in horizontal and vertical direction as two parallel tests.

2.2.3. Double-Edge Tear Load

The determination of tear load was carried out in accordance with the TS EN ISO 3377-2 (2016) standard, which specifies a method for evaluating the tear strength of leather using a double-edge tear test. The leather samples cut according to the standard were positioned between the jaws of the Shimadzu AG-IS testing machine with a 5 kN load cell [20]. For each boot, two parallel samples were tested in both horizontal and vertical orientations. The machine was operated until the test sample tore. The maximum force exerted during the tearing process was recorded in Newtons.

2.2.4. Determination of Distension and Strength of Srface (Ball Burst Method)

The conditioned leather samples were cut according to the principles described in TS EN ISO 3379 (2015) [21]. Each leather sample was placed on the lastometer with a compression ring fitted to ensure that the center of the leather sample remained clear. While the lastometer was operating at a speed of 12 mm/min, a ball was advanced towards the leather sample. The force (kgf) and elongation (mm) at the time of cracking in the grain were measured and recorded while the device continued to run. In addition, the force at which the burst occurred and the corresponding elongation of the burst were noted.

2.2.5. Adhesion Strength of Upper-Sole

The samples were tested according to the standard test method TS EN ISO 17708 (2018) to determine the resistance to separation of the upper and outsole. The test was performed using the Shimadzu AG-IS testing machine equipped with a 5 kN load cell [22]. The samples were securely clamped in the jaws of the machine and the separation between the outsole and upper leather was achieved at a controlled speed of 100 ± 20 mm/min. A force-deformation curve was recorded throughout the process, from which the average separation force was determined. From this, the adhesion force was calculated in N/mm (force/width). The failure modes were evaluated according to this standard.

2.2.6. Colorimetric Measurement

The color change due to aging was measured using a Konica Minolta CM-3600d spectrophotometer under a CIE D65 light source and a viewing angle of 10°. The measurements of the leather samples were taken both before and after the artificial aging process to evaluate the degree of color change. These measurements allowed an accurate comparison of the color properties of the samples and provided information on the effects of accelerated aging on the appearance of the leather. By comparing the data before and after aging, the changes in color properties could be quantified, which are crucial for assessing the durability and performance of the material under long-term environmental stress.

2.2.7. Statistical Method

To evaluate the differences in mechanical properties between the leather samples before and after aging, a two-sample t-test was performed to compare mean values between two independent groups. Before performing the t-test, the assumptions of independence, normality and homogeneity of variances were checked using the Shapiro-Wilk and Levene's tests. The mechanical properties, including tensile strength, elongation at break, tear load, ball burst strength and upper-sole adhesion resistance, were measured for each leather sample before and after artificial aging and the results were recorded as mean values and standard deviations for each group. The t-test was performed using statistical software to compare the mean values of the groups before and after aging for each mechanical and physical property. The significance level (α) was set at 0.05, with a p-value of less than 0.05 indicating a statistically significant difference between the means of the two groups. The results of the t-test were then interpreted to determine whether the mechanical properties of the leather samples differed significantly between the pre and post-aging conditions, with significant findings on the effects on the durability and performance of combat boot upper leathers discussed.

3. RESULTS

Key parameters such as tensile strength, elongation at break, tear load, cracking and bursting elongation, cracking and bursting strength and upper-sole adhesion resistance were tested to evaluate the effects of artificial aging on these properties both before and after aging. Comprehensive analysis results of the mechanical properties of upper leathers used in combat boots before and after artificial aging are shown in Table 1.

The tensile strength, which measures the maximum stress the leather can withstand before it breaks, decreased slightly from 20.86 N/mm^2 to 19.76 N/mm^2 after artificial aging. The t-test shows that this difference is not statistically significant (*P=0.396*), which means that the aging process had no noticeable effect on the tensile strength of the leather. According to UNIDO standards (UNIDO, 1996), the tensile strength of upper leather should be at least 20 N/mm². While the leathers had slightly higher values than this threshold before aging, they only just failed to meet the standard after the aging process [23]. This means that the leather retains its resilience even after aging and is therefore suitable for combat boots exposed to harsh environments. Karavana et al. (2012) investigated the effects of acidic and alkaline mud solutions on the durability of military boots. They reported tensile strength values of 23.76 N/mm² before treatment, which dropped significantly to 16.65 N/mm² and 16.05 N/mm² after exposure to acidic and alkaline soils, respectively, with a statistically significant difference [6].

Elongation represents the flexibility of the leather or the degree to which it can stretch before breaking. Interestingly, the elongation increased from 53.64% to 58.13% after the artificial aging process, which could indicate that the leather became slightly more flexible after aging. According to UNIDO standards (UNIDO, 1996), the elongation at break for shoe upper leather should be at least 40%. It was found that all measured values were well above this requirement [23]. However, this increase was not statistically significant (*P=0.129*). This suggests that although artificial aging contributed to some softening of the leather, the mechanical properties were not significantly affected.

Tear load evaluates the resistance of the leather to tearing. Işık and Karavana (2012) investigated the effects of artificial aging on chrome-tanned garment leather under different conditions, including temperature, temperature combined with UV irradiation and temperature combined with humidity. The study found a time-dependent decrease in tear load values under all aging conditions, highlighting the effects of aging on the mechanical properties of leather. [13]. According to UNIDO standards (UNIDO, 1996), the tear strength of upper leather should be at least 40 N/mm. All measured values significantly exceeded this requirement [23]. When examining Table 1, before aging, the leather had a tear load of 199.13 N, while after aging it fell slightly to 188.23 N. The difference between these values is not statistically significant (*P=0.205*), which indicates that the leathers largely retained their tear load even after the aging process. The wide range of standard deviations (± 35.72 for pre-aging, ± 44.52 for post-aging) indicates that tear strength varies between the different samples, but on average the material remains durable after aging.

The surface distension and strength test systematically evaluates the extent to which leather can be stretched before cracking and the force required to cause such damage. In addition, this test determines the maximum stretch that can be achieved before cracking and quantifies the force required for the material to fail. Such rigorous analysis is essential to understand the mechanical properties and resilience of leather in demanding applications where maintaining structural integrity is critical. According to UNIDO standards (UNIDO, 1996), the surface distension of shoe upper leather should be at least 7 mm. All measured values were met this requirement [23]. In terms of surface distension, the results show a slight reduction in the pre-aging condition with values of recorded at 9.87 mm, dropping to 9.45 mm after aging. Although this decrease is not statistically significant (*P=0.507*), it indicates that the material retains a relatively stable surface flexibility despite the aging process. This could mean that although the surface of the leather still stretches well, its overall elasticity may be compromised due to internal structural changes that occur during artificial aging, affecting its long-term durability under extreme conditions. In contrast, a significant decrease from 50.45 to 39.27 kgf (*P=0.038*) is observed when evaluating the distension strength. This significant decrease indicates that the leather's ability to withstand high loads has significantly decreased after aging. Such a loss of strength could be due to the degradation of the leather's fiber structure and the potential loss of moisture content, which may lead to increased brittleness and reduced toughness. Similarly, the burst tests showed a significant decrease in distension strength from 69.55 kgf to 58.73 kgf (*P=0.021*), further confirming the results observed in the cracking tests. This decrease indicates that the leather is less able to withstand the pressure before cracking, supporting the suggestion that artificial aging compromises the integrity of the material. Hossain (2021) investigated various physical properties of ten different upper leathers collected from different footwear and leather industries. The study reported that the cracking strength values were between 14.50 and 25.00 kgf, while the burst strength values were between 18.50 and 30.50 kgf [5]. Although the values in the present study showed a statistically significant decrease after aging, they were still above the standard limits for footwear.

The adhesion resistance between the upper leather and the outsole, an important indicator of adhesive strength, decreased significantly after the aging process. Despite this decrease, all samples exhibited adhesion resistance values that met or exceeded the minimum requirement of 5 N/mm specified by the TS EN 15307 (2015) standard for high-performance footwear. Initial adhesion resistance measured at 17.33 N/mm decreased to 8.58 N/mm after aging, which corresponds to a reduction of approximately 50.5%. Statistical analysis confirmed that this decrease was highly significant (*P=0.001*), indicating that aging significantly affects the adhesion strength between these components. Múgica-Vidal et al. (2021) reported adhesion strength values between 5.6 and 8.9 N/mm before the 30-day aging, with their study finding a further decrease in these values after the aging period [24]. It is known that adhesive strength is strongly dependent on temperature. Experimental studies on adhesive bonds in footwear show that bond strength decreases at both high and low temperatures [25-27]. At higher temperatures, this decrease is primarily due to the weakening of the adhesive layer, while at lower temperatures, increased thermal stresses and the brittleness of adhesive contribute to reduced adhesive performance [28]. The durability of the adhesion between the upper leather and the sole is also likely to be temperature-dependent. These results show how important it is to select adhesives with high aging resistance and optimized thermal stability to ensure durable bonding performance in demanding applications. The ability of an adhesive to maintain its mechanical integrity over a wide temperature range is critical to prevent premature failure, especially in footwear that is inevitably exposed to changing environmental conditions.

These results indicate that although certain mechanical properties (cracking and burst strength and adhesion strength between upper and sole) of the leather were affected by artificial aging, most mechanical properties such as tensile strength, elongation, tear load, cracking and burst elongation remained intact, suggesting that the leathers are suitable for prolonged use under different environmental conditions. The most affected properties after aging were the grain cracking and burst strength values, as determined by statistical analysis. Above all, the aging process led to a significant deterioration in the properties relating to the grain. In addition, the values for the upper-sole adhesive strength also showed lower values, as they are related to both the grain and the adhesive.

Table 1. Mechanical properties of the upper leathers before and after aging.

	n	Mean Value Before Aging (± SD)	Mean Value After Aging (± SD)	t-Value	P-Value	Significance
Tensile Strength (N/mm^2)	40	20.86 ± 5.91	19.76 ± 4.42	0.86	0.396	Not Significant
Elongation (%)	40	53.64 ± 13.13	58.13 ± 14.09	-1.55	0.129	Not Significant
Tear Load (N)	40	199.13 ± 35.72	188.23 ± 44.52	1.29	0.205	Not Significant
Elongation of Cracking (mm)	10	9.87 ± 1.40	9.45 ± 1.43	0.69	0.507	Not Significant
Cracking Strength (kgf)	10	50.45 ± 19.78	39.27 ± 9.86	2.39	**0.038***	**Significant**
Elongation of Burst (mm)	10	11.79 ± 1.30	11.66 ± 1.24	0.22	0.830	Not Significant
Burst Strength (kgf)	10	69.55 ± 15.45	58.73 ± 8.01	2.75	**0.021***	**Significant**
Upper - sole adhesion resistance (N/mm)	10	17.33 ± 0.66 (Failure Code: N)	8.58 ± 1.16 (Failure Code: N)	11.41	**0.001***	**Significant**

*means a statistically significant difference at the confidence level α=0.05.

The results presented in Table 2 show the effect of aging on the colorimetric properties of the leather samples, in particular the evaluation of the parameters L*, a*, b* and ΔE.

The mean value of L* before aging of 23.89 (± 0.69) and the mean value after aging of 23.94 (± 0.50) show a slight increase in lightness after aging. However, the t-value of -0.34 and a P-value of 0.745 indicate that this change is not statistically significant, which means that the aging process has not noticeably changed the lightness of the leather.

The mean value of a* before aging of 0.01 (± 0.05) compared to a mean value after aging of 0.02 (± 0.03) reflects a negligible change in the green-red colorimetric color coordinate. With a t-value of -0.40 and a P-value of 0.703, this also indicates that aging has no significant effect on this color coordinate.

The mean value of b* before aging of -0.41 (± 0.18) in contrast to a mean value after aging of -0.35 (± 0.15) indicates a marginal shift towards a less blue hue. The t-value of -1.09 and the P-value of 0.305 support the lack of a significant change.

Although the ΔE value is given without a comparative mean value after aging, it represents the overall color difference between the two conditions. A value of 0.45 (± 0.26) indicates a minimal perceptible color change due to aging, as the typical threshold for a perceptible color difference is generally 1.0.

In summary, the statistical analyzes show that the aging process does not significantly affect the colorimetric properties of the leather, which indicates that the material retains its color properties even after artificial aging. This finding is crucial for applications where esthetic consistency is of utmost importance.

The results of this study indicate that artificial aging has a differential effect on some of the mechanical and physical properties of the upper leathers used for combat boots. While the tensile strength, elongation and tear load showed no statistically significant differences between the samples before and after aging, the surface distension and strength parameters showed remarkable results. In particular, the samples showed a significant decrease in the cracking and burst strength after aging, indicating a decrease in the force required to cause cracking and burst, which may affect the overall durability of the leather under demanding conditions. The adhesion resistance between the upper leather and the outsole also decreased significantly by approximately 50.5%, suggesting a significant reduction in the adhesion strength. In addition, the colorimetric analysis showed that the colorimetric color coordinate parameters (L*, a*, b*) did not change significantly, indicating that the aging process does not visibly change the color properties of the leather.

4. CONCLUSION

This study provides important statistical insights into the mechanical and physical changes in upper leathers used for military combat boots due to artificial aging. The analysis shows that most of the mechanical parameters, including tensile strength, elongation, tear load and surface distension to cracking and burst, remained statistically unchanged between the samples before and after aging, while a significant decrease in the corresponding characteristics was observed for surface distension strength to cracking and burst. In addition, the study revealed a significant reduction in the adhesion resistance between the upper leather and the outsole. This decrease is primarily due to the degradation of the adhesive rather than the leather itself, highlighting the need for adhesives with improved aging resistance. These changes suggest that while the leather retains much of its structural integrity after aging, its ability to withstand extreme forces may diminish, which is critical for military applications where durability under high stress is crucial. The results therefore highlight the need to carefully consider the treatment processes for leather to maintain its structural integrity over time.

In addition, the colorimetric measurements showed that the aging process does not significantly affect the colorimetric color coordinate parameters of the leather, suggesting that visual esthetics can be maintained despite mechanical degradation. These results underline the importance of considering both the mechanical performance and visual qualities of leather materials when assessing their suitability for demanding environments.

Further research is recommended to investigate the long-term effects of aging on leather properties and to identify possible treatments or formulations that could improve the durability and performance of combat boots in extreme conditions. Such investigations could contribute to the development of more resistant materials that meet the stringent requirements of military operations.

Table 2. Colorimetric color coordinates of upper leathers before and after artificial aging.

	n	Mean Value Before Aging (± SD)	Mean Value After Aging (± SD)	t- Value	P-Value	Significance
L*	10	23.89 ± 0.69	23.94 ± 0.50	-0.34	0.745	Not Significant
a*	10	0.01 ± 0.05	0.02 ± 0.03	-0.40	0.703	Not Significant
b*	10	-0.41 ± 0.18	-0.35 ± 0.15	-1.09	0.305	Not Significant
ΔE			0.45 ± 0.26			

*means a statistically significant difference at the confidence level α=0.05.

REFERENCES

1. Haghighat, F., Rezaie, M., Majlesi, M., (2024), *How Boots Affect the Kinematics and Kinetics of Lower Limb Joints During Walking Compared to Casual Footwear*, Scientific Reports, 14 , DOI: 10.1038/s41598-024-68533-1.
2. Mara de Souza Muniz, A., Sizenando, D., Lobo, G., Borba Neves, E., Gonçalves, M., Marson, R., Palhano, R., Menegaldo, L., Rico Bini, R., (2021), *Effects from Loaded Walking with Polyurethane and Styrene-Butadiene Rubber Midsole Military Boots on Kinematics and External Forces: A Statistical Parametric Mapping Analysis*, Applied Ergonomics, 94, 103429, DOI: 10.1016/ j.apergo.2021.10342.
3. Sarı, Ö., Bitlisli, B.O., (2000*)*, *Problems stemming from upper leathers in military shoes and boots and suggested solutions*, Infantry 2000 Symposium CD, Tuzla Infantry Cadet School Command, Istanbul, Turkey.
4. Pantazi-Băjenaru, M., Foiaşi, T., Gurău D., (2020), *Production of Multifunctional Footwear for Prison Police Officers*, Leather and Footwear Journal 20, 1, 59-64, DOI: 10.24264/lfj.20.1.7.
5. Hossain, M.D., Azam, F.A.B., Chowdhury, M., (2021), *Quality Assessment of Shoe Leather Based on the Properties of Strength and Comfort, Collected from Different Footwear and Leather Industries in Bangladesh*, Textile and Leather Review, 4, 1, 30-37. DOI: 10.31881/TLR.2020.20.
6. Karavana, H.A., Gulen, C., Guzel, S.C., Yalcin, F., (2012), *Determination of the Changes in the Military Boots Used under Acidic and Alkaline Conditions*, 4th International Conference on Advanced Materials and Systems (ICAMS), 341-346, 27-29th September, Bucharest, Romania.
7. Bitlisli, B.O. Karavana, H.A., Basaran, B., Aslan, A., (2005), *Importance of Using Genuine Leather in Shoe Production in Terms of Foot Comfort*, Journal of the Society of Leather Technologists and Chemists, 89, 3, 107-110.
8. Kite, M., Thomson, R., (2000), *Conservation of Leather and Related Materials*, Elsevier, Oxford.
9. Hu, Y., Liu, J., Han, G., Li, X., Zhang, Z., Zheng, X., Wang, F., Pei, Y., Lei, Y., Tang, K., (2022), *Artificial Deterioration of Vegetable-Tanned Leather under Synergistic Effect of Temperature and Humidity*, Journal of Cultural Heritage, 53, 118–126. DOI: 10.1016/j.culher.2021.11.007.
10. Thomasset, A., Benayoun, S., (2024), *Assessing the Durability of Diverse Leather Tanning Techniques for the Manufacturing of Leather Goods through Artificial Aging Processes*, Cleaner Engineering and Technology, 22, 100807, DOI: 10.1016/ j.clet.2024.100807.
11. Bacardit, A., Cobos, M., Font, J., Jorge, J., Ollé, L., (2010), *Study of the Effect of Temperature, Relative Humidity and UV Radiation on Wet-White Leather Ageing*, Journal of the American Leather Chemists Association, 105, 334-341.
12. Serweta, W., Wójcik, J., Rutowicz, J., Olejniczak, Z., (2019), *Influence of UV Aging on Some Rheological Properties of Footwear Leather*, Polimery, 64, 9, 617-624. DOI: 10.14314/polimery. 2019.9.7.
13. Isik, N.O., Karavana, H.A., (2012), *Determination of Some Physical Characteristics of Artificially Aged Chrome Tanned Garment Leather*, Textile and Apparel, 1, 64-69.
14. Ollé, L., Jorba, M., Castell, J.C., Font, J., Bacardit, A., (2011), *Comparison of the Weathering Variables on both Chrome-Tanned and Wetwhite Leather Ageing*, B21, XXXI IULTCS Congress, 27-30th September, Valencia, Spain.
15. Ollé, L., Jorba, M., Font, J., Bacardit, A., (2011), *Comparison of the Effect of the Tropical Test on both Chrome-Tanned and Wet-White Upholstery Leather*, Journal of the Society of Leather Technologists and Chemists, 95, 3, 109-115.
16. Li, R., Wang, Y.Z., Shan, Z.H., (2016), *Effects of Accelerated Ageing on the Physical and Chemical Properties of Chrome-Free Leather*, Journal of the Society of Leather Technologists and Chemists, 100, 1, 19-24.
17. TS EN ISO 17228 (2015), Leather-Tests for colour fastness-Change in colour with accelerated ageing, Turkish Standard Institution, Ankara, 19p.
18. TS EN ISO 2589 (2016), Leather-Physical and mechanical tests-Determination of thickness, Turkish Standard Institution, Ankara, 11p.
19. TS EN ISO 3376 (2020), Leather-Physical and mechanical tests-Determination of tensile strength and percentage elongation, Turkish Standard Institution, Ankara, 18p.
20. TS EN ISO 3377-2 (2016), Leather-Physical and mechanical tests-Determination of tear load-Part 2: Double edge tear, Turkish Standard Institution, Ankara, 18p.
21. TS EN ISO 3379 (2015), Leather-Determination of distension and strength of surface (Ball burst method), Turkish Standard Institution, Ankara, 18p.
22. TS EN ISO 17708 (2018), Footwear-Test methods for whole shoe-Upper sole adhesion, Turkish Standard Institution, Ankara, 22p.
23. UNIDO, (1996), Acceptable Quality Standards in the Leather and Footwear Industry, United Nations Industrial Development Organization, Vienna.
24. Múgica-Vidal, R., Mercadal-Guillén, J., Sainz-García, E., Alba-Elías, F., (2021), *Atmospheric-pressure Plasma Treatments of NBR for the Improvement of Adhesion in Footwear Applications*, International Journal of Adhesion and Adhesives, 108. DOI: 10.1016/j.ijadhadh.2021.102865.
25. Silva, L.F.M. da, Adams, R.D., (2005), *Measurement of the mechanical properties of structural adhesives in tension and shear over a wide range of temperatures*, Journal of Adhesion Science & Technology, 19, 2, 109-141. DOI: 10.1163/1568561053148449.
26. Adams, R.D., Mallick, V., (1993), *The effect of temperature on the strength of adhesively-bonded composite-aluminium joints*, The Journal of Adhesion, 43, 1-2, 17-33. DOI: 10.1080/ 00218469308026585.
27. Kang, S.G., Kim, M.G., Kim, C.G., (2007), *Evaluation of Cryogenic Performance of Adhesives Using Composite-Aluminum Double Lap Joints*, Composite Structures, 78, 3, 440-446. DOI: 10.1016/ j.compstruct.2005.11.005.
28. Banea, M.D., Silva, L.F.M. da, Campilho, R.D.S.G., (2010), *Temperature Dependence of the Fracture Toughness of Adhesively Bonded Joints,* Journal of Adhesion Science and Technology, 24, 2011–2026. DOI: 10.1163/016942410X507713.