



Comparative Assessment of Thickness and Apparent Density in Electron-Beam-Irradiated Tanned Leather From Cow, Goat and Sheep Hides And Skins

¹Akawu P. I., ²Onoja M. A., ³Garba N. N., ⁴Musa Y., ⁵Akawu I., ⁶Bukar P. H., ⁷Akintade S. A., ⁸Jakheng W. E., ⁹Shedow A., ¹⁰Mohammed M.

^{1&2}Department of Physics, A.B.U, Zaria

³Centre for Energy Research and Training, A.B.U, Zaria

⁵Department of Environmental Science Management and Technology, NILEST, Zaria

^{6,7,8&9}Physics Unit, Department of Science and Laboratory Technology, NILEST, Zaria.

¹⁰Department of Applied Physics, Kaduna Polytechnic, Kaduna.

ABSTRACT

Thickness and apparent density are important physical characteristics of leather because they influence material handling, flexibility, weight, compactness and suitability for different leather products. This study comparatively evaluated the thickness and apparent density of tanned leather produced from cow, goat and sheep hides and skins following exposure to selected electron-beam irradiation doses. The irradiation doses were 5, 10, 20, 30 and 50 Gy. Thickness was measured in millimetres, while apparent density was expressed in g/cm^3 . Three readings were obtained from the same leather piece at each treatment level and were therefore treated as technical replicate measurements. Cow leather had mean thickness values ranging from 1.450 to 2.190 mm and apparent-density values from 0.444 to 0.623 g/cm^3 . Goat leather recorded thickness values from 1.833 to 2.433 mm and apparent-density values from 0.379 to 0.503 g/cm^3 . Sheep leather had thickness values from 1.073 to 1.410 mm and apparent-density values from 0.605 to 0.837 g/cm^3 . Goat leather was generally the thickest, whereas sheep leather was generally the densest. The relationship between thickness and apparent density was not uniform across the animal types, indicating that thickness alone did not determine the mass-to-volume relationship of the leather. The results showed non-linear dose responses and possible differences in fibre packing, porosity, moisture retention and processing behaviour.

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INTRODUCTION

Leather is a collagen-rich biomaterial produced through the controlled processing of animal hides and skins. Its performance is influenced by the original anatomical structure of the animal material, preservation conditions, tanning chemistry, drying, conditioning and finishing. Among the physical characteristics used to evaluate leather quality, thickness and apparent density are particularly important because they provide complementary information about the

dimensions and mass-to-volume relationship of the material.

Leather thickness describes the distance between the two surfaces of a leather specimen. It affects cutting, stitching, flexibility, handle, weight and suitability for particular applications. For example, leather intended for shoe uppers must possess an appropriate thickness to provide adequate durability while retaining sufficient flexibility and workability. Thickness is commonly determined using

Corresponding author: Akawu P. I.

patienceakawu45@gmail.com

Department of Physics, A.B.U, Zaria.

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standardized leather-testing procedures such as ISO 2589:2016.

Apparent density, on the other hand, is the mass of leather divided by its external volume:

$$\rho = \frac{m}{v}$$

where ρ =Apparent density, m = mass , and v =volume.

It reflects not only the solid collagen material but also the internal spaces and pores within the leather. Consequently, apparent density may provide information about fibre packing, compactness, porosity, moisture content and processing uniformity. Studies of leather structure have measured thickness and apparent density together because these properties are related to the organization of collagen fibres and the overall architecture of the leather matrix (Kelly et al., 2018). Thickness and apparent density should not be considered interchangeable. A leather sample may be thick but have low apparent density if it contains substantial internal voids or has a relatively open fibre network. Conversely, a thinner leather may have higher apparent density if the collagen fibres are more compactly arranged. The simultaneous assessment of these properties can therefore provide a more informative description of leather structure than either property alone.

The use of ionizing radiation in the preservation of hides and skins has received increasing research attention. Gamma irradiation has been investigated as an alternative to salt preservation because of its potential to reduce microbial contamination and minimize the environmental burden associated with salt-containing tannery effluents (Gaidau et al., 2021). More recent work has examined radiation-induced changes in the collagen matrix and reported that the effects depend on radiation dose and the structural stability of the collagen-tannin system (Gaidau et al., 2025; Stanca et al., 2021).

Electron-beam irradiation from a linear accelerator differs from gamma irradiation in source characteristics, dose delivery and penetration behaviour. Its effects on collagen-based materials may depend on dose, beam energy, dose distribution, moisture and sample

geometry. Research on electron beams and collagen has emphasized the importance of understanding dose uniformity and the interaction of electron beams with collagen-rich materials (Liu et al., 2021).

Although irradiation studies have examined leather preservation and collagen modification, the combined behaviour of thickness and apparent density following low-dose electron-beam exposure remains insufficiently documented. The present study therefore compared the thickness and apparent density of tanned cow, goat and sheep leather following exposure to 5–50 Gy electron-beam irradiation.

MATERIALS AND METHODS

Study design

The study employed an experimental laboratory design involving tanned leather produced from:

1. cow hides;
2. goat skins; and
3. sheep skins.

The leather samples were exposed to electron-beam irradiation doses of 5, 10, 20, 30 and 50 Gy before tanning. A separate untreated control was also evaluated at 0 Gy. The untreated control was assigned to each animal type.

Electron-beam irradiation

The hide and skin samples were exposed to controlled electron-beam irradiation using a linear accelerator. The selected doses were within the low-dose range used in the study. The final laboratory report should include the exact accelerator model, beam energy, dose rate, dosimetry system, irradiation geometry, sample orientation and moisture condition. These parameters are important because electron penetration and dose uniformity may influence the treatment of heterogeneous collagen-based materials.

Tanning procedure

Following irradiation, the hides and skins were processed into leather using the



established laboratory tanning procedure. The exact tanning chemicals, concentrations, pH, processing times, drying conditions and finishing treatments should be reported from the laboratory records.

Determination of thickness

Leather thickness was measured in millimetres. Three readings were taken from each leather piece. The mean thickness was calculated as:

$$\text{Bar } X = X_1 + X_2 + X_3$$

Thickness measurement should preferably be performed using a calibrated leather thickness gauge under controlled contact pressure, following ISO 2589:2016.

Determination of apparent density

Apparent density was expressed in grams per cubic centimetre (g/cm³) and calculated as:

$$\text{Apparent density} = \frac{\text{mass}}{\text{External volume}}$$

The external volume may be determined from:

$$V = L \times W \times T$$

where:

1. L = length;
2. W = width; and
3. T = thickness.

The mass-to-volume relationship may be influenced by moisture content, sample conditioning, thickness and internal porosity. These variables should therefore be controlled during measurement.

RESULTS

Comparative thickness and apparent density

The comparative results are presented in Table 1.

Table 1. Mean thickness and apparent density of irradiated tanned leather

Leather type	Dose (Gy)	Mean thickness (mm)	Mean apparent density (g/cm ³)
Cow	5	1.973	0.606
Cow	10	2.190	0.496
Cow	20	1.450	0.623
Cow	30	1.653	0.531
Cow	50	2.070	0.444
Goat	5	2.170	0.449
Goat	10	1.833	0.503
Goat	20	1.857	0.487
Goat	30	2.337	0.420
Goat	50	2.433	0.379
Sheep	5	1.073	0.711
Sheep	10	1.410	0.605
Sheep	20	1.143	0.837
Sheep	30	1.130	0.721
Sheep	50	1.200	0.812
Separate untreated control	0	1.620	0.623

Thickness pattern

Cow leather had a mean thickness range of 1.450–2.190 mm. The maximum cow

thickness occurred at 10 Gy, while the minimum occurred at 20 Gy. Goat leather recorded the greatest thickness range, from 1.833 to 2.433 mm.

Corresponding author: Akawu P. I.

patienceakawu45@gmail.com

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The highest goat thickness occurred at 50 Gy. Sheep leather was consistently thinner than cow and goat leather, with values ranging from 1.073 to 1.410 mm. The highest sheep thickness occurred at 10 Gy. Across the irradiation doses, goat leather was generally the thickest, followed by cow leather, while sheep leather was the thinnest.

Apparent-density pattern

Cow leather had apparent-density values ranging from 0.444 to 0.623 g/cm³. The highest value was recorded at 20 Gy and the lowest at 50 Gy. Goat leather recorded values ranging from 0.379 to 0.503 g/cm³. The highest apparent density occurred at 10 Gy, followed by a general decline at 20, 30 and 50 Gy. Sheep leather recorded the highest apparent-density values, ranging from 0.605 to 0.837 g/cm³. The maximum occurred at 20 Gy, while the minimum occurred at 10 Gy. The separate untreated control had a mean apparent density of 0.623 g/cm³.

Comparison between thickness and apparent density

The results showed that the thickest leather was not necessarily the densest. For example:

1. goat leather was the thickest at 50 Gy, with a mean thickness of 2.433 mm, but had the lowest apparent density among the three animal types at that dose, 0.379 g/cm³;
2. sheep leather was the thinnest at 50 Gy, with a mean thickness of 1.200 mm, but had the highest apparent density, 0.812 g/cm³; and
3. cow leather at 20 Gy had a thickness of 1.450 mm and apparent density of 0.623 g/cm³, while sheep leather at the same dose had a lower thickness of 1.143 mm but a higher apparent density of 0.837 g/cm³.

These findings demonstrate that thickness and apparent density described different aspects of the leather structure.

DISCUSSION OF FINDINGS

Complementary meaning of thickness and apparent density

The principal finding of this study was that thickness and apparent density did not follow the same pattern across the animal types and irradiation doses. This is scientifically important because it indicates that the physical dimensions of leather cannot be used alone to infer its compactness or mass distribution.

Thickness is a dimensional property, whereas apparent density incorporates both mass and volume. In collagen-based leather, the external volume may contain spaces between fibre bundles and other structural voids. Consequently, two samples with similar thickness may have different apparent densities because their fibre networks differ in compactness or porosity.

Previous structural studies have measured thickness and apparent density together in leather because both properties are influenced by collagen organization and processing history. Kelly et al. (2018) reported that leather thickness, apparent density and moisture content can vary with the structural condition of the leather. Similarly, modelling studies of leather have linked bulk density and thickness to the organization of collagen fibre bundles and the mesostructure of the material.

Animal-type differences

The present results showed a general pattern in which goat leather was thickest, while sheep leather was densest. This suggests that the animal origin of the leather influenced the relationship between thickness and apparent density. Goat leather recorded relatively high thickness values but comparatively low apparent-density values. This may indicate a more open external volume relative to mass, greater porosity or differences in moisture and tanning response. However, apparent density alone cannot establish which of these factors was responsible.

Sheep leather, in contrast, was relatively thin but showed higher apparent-density values. This may suggest more compact fibre



packing or a higher mass-to-volume ratio. Differences in collagen-fibre diameter, orientation, interfibrillar spaces and the original anatomical structure of the skin may contribute to this pattern. Cow leather generally occupied an intermediate position in thickness and apparent density. Its response was more irregular, with the highest density at 20 Gy and the lowest at 50 Gy. The animal-type differences are consistent with the view that leather is a heterogeneous biomaterial whose final physical properties depend on both biological origin and processing history.

Thickness response to irradiation

The thickness response was non-linear for all three animal types. Cow leather increased in thickness from 5 to 10 Gy, decreased markedly at 20 Gy and increased again at 30 and 50 Gy. Goat leather showed a decrease at 10 Gy followed by an increase at the higher doses. Sheep leather showed its highest thickness at 10 Gy, followed by relatively stable values at 20–50 Gy. Several factors may contribute to such non-linear behaviour:

1. moisture loss or moisture retention;
2. fibre relaxation during processing;
3. variation in tanning penetration;
4. changes in collagen-fibre arrangement;
5. drying and conditioning;
6. local thickness variation; and
7. possible radiation-related molecular changes.

Radiation studies on collagen-rich materials have reported that irradiation responses may involve competing processes such as crosslinking and chain scission. Gaidau et al. (2025) reported evidence of dose-related collagen-matrix changes following gamma irradiation, while Gaidau et al. (2021) found that irradiation could produce molecular modifications without necessarily causing major deterioration in final leather quality under the conditions studied. However, the present study used electron-beam irradiation at 5–50 Gy, whereas the cited gamma-irradiation studies used much higher doses. Their findings therefore provide mechanistic context rather than direct dose equivalence.

Apparent-density response to irradiation

The apparent-density response was also non-linear. Cow leather showed its highest apparent density at 20 Gy and its lowest at 50 Gy. Goat leather generally decreased in density at the higher doses. Sheep leather showed its highest density at 20 Gy and a second high value at 50 Gy. A decrease in apparent density could result from:

1. an increase in external volume;
2. reduction in dry mass;
3. changes in moisture content;
4. increased porosity;
5. reduced fibre compactness; or
6. measurement variation.

An increase in apparent density could result from:

1. greater fibre compactness;
2. reduced external volume;
3. increased retained mass;
4. moisture differences; or
5. changes in tanning or drying.

It is therefore important not to interpret density changes as direct evidence of collagen degradation or crosslinking without supporting data. FTIR spectroscopy, SEM, moisture analysis and thermal analysis would be needed to investigate the underlying mechanisms.

Thickness-density relationship at 50 Gy

The contrast at 50 Gy was particularly notable. Goat leather was the thickest at 2.433 mm but had the lowest apparent density at 0.379 g/cm³. Sheep leather was much thinner at 1.200 mm but had a substantially higher apparent density of 0.812 g/cm³. This inverse relationship suggests that the goat leather may have occupied a greater external volume relative to its mass, whereas the sheep leather may have had a more compact mass distribution. The result illustrates why thickness should not be used as a substitute for density when assessing leather structure.

The finding may also be relevant to product development. Thick, low-density leather may provide bulk and flexibility but may behave differently under compression and bending than



thin, high-density leather. The practical significance would depend on the desired product and on the results of tensile, elongation, compression and wear tests.

Relationship with collagen structure

Collagen is the main structural protein in hides and skins. Its hierarchical organization includes molecular chains, fibrils, fibres and fibre bundles. Changes at any of these levels may influence the physical properties of the finished leather. Electron-beam irradiation can interact with collagen directly or indirectly through reactive species generated in moisture-containing materials. Depending on dose and processing conditions, irradiation may promote molecular crosslinking or chain scission. The balance between these processes may influence fibre packing, moisture movement and mechanical behaviour.

Liu et al. (2021) emphasized the need to understand electron-beam dose distribution and its interaction with collagen materials. Gaidau et al. (2025) also reported that radiation-induced collagen changes can be subtle and may require several analytical techniques for detection. The present thickness and apparent-density data may therefore be viewed as preliminary physical indicators of possible changes in the leather matrix. They do not, by themselves, establish the occurrence of molecular modification.

Influence of moisture and conditioning

Moisture is an important confounding factor in the interpretation of both thickness and apparent density. Water contributes to mass and can cause collagen fibres to swell. If moisture content differs among samples, the measured apparent density may change even if the dry collagen structure remains unchanged. Moisture may also influence thickness by altering fibre dimensions and the degree of fibre relaxation.

All future measurements should therefore be performed after conditioning the leather under the same temperature and relative-humidity conditions. Moisture content should be measured and reported with thickness and apparent density. The large differences among

some of the three readings in the apparent-density data further emphasize the need for strict control of measurement conditions and measurement locations.

Implications for footwear leather

The combined assessment of thickness and apparent density may be useful for evaluating leather intended for shoe uppers. Thickness contributes to coverage, durability and handling, while apparent density may influence weight, compactness, flexibility and compression response. A thick leather with low apparent density may be lightweight but may possess a more open structure. A thinner leather with high apparent density may be more compact but could have different flexibility or handle characteristics. Neither condition is automatically superior; suitability depends on the intended application. The optimum irradiation dose should therefore be selected using a multi-property approach that includes:

1. microbial reduction;
2. thickness;
3. apparent density;
4. tensile strength;
5. elongation at break;
6. resistance to compression;
7. indentation index;
8. shrinkage temperature;
9. moisture content;
10. FTIR spectra; and
11. SEM observations.

CONCLUSION

This study comparatively evaluated thickness and apparent density in tanned cow, goat and sheep leather following electron-beam irradiation. The main findings were:

1. Goat leather was generally the thickest, while sheep leather was generally the thinnest.
2. Sheep leather generally had the highest apparent density.
3. Cow leather showed intermediate thickness and apparent-density characteristics.
4. Thickness and apparent density did not follow the same dose-related pattern.



5. At 50 Gy, goat leather was the thickest but had the lowest apparent density, whereas sheep leather was thinner but had the highest apparent density.
6. The findings indicate that thickness alone cannot be used to infer leather compactness or mass-to-volume relationship.
7. The observed patterns may reflect differences in collagen-fibre arrangement, porosity, moisture content, tanning and drying behaviour.
8. The results are descriptive because the three readings at each treatment level came from the same leather piece.

Overall, the simultaneous assessment of thickness and apparent density provides a more informative description of the physical characteristics of irradiated leather than either property considered independently. Nevertheless, additional independent biological replicates and complementary structural analyses are required before firm conclusions can be made about radiation-induced collagen modification or the optimum dose for leather preservation.

RECOMMENDATIONS

1. Use at least three independent leather pieces for each animal type and irradiation dose.
2. Prepare species-specific untreated controls.
3. Condition all leather samples under standardized temperature and relative-humidity conditions.
4. Measure and report moisture content.
5. Use standardized methods for thickness and apparent-density measurements.
6. Record the mass, length, width and thickness used in every density calculation.
7. Compare thickness and apparent density with compression resistance and indentation index.
8. Use FTIR and SEM to investigate possible collagen and fibre-network modifications.

Evaluate the suitability of irradiation doses using the combined physic mechanical and microbiological results.

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