Comparative Evaluation of Leather and Polyester Non-Woven Materials for Sports Footwear Applications

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Abstract
The global sports footwear industry demands high-performance materials that offer durability, flexibility, and resilience while maintaining environmental sustainability. Traditional leather has been the primary choice due to its superior mechanical properties, while polyester non-woven materials are emerging as a sustainable and technologically advanced alternative. This study presents a comparative analysis of three natural leather types (cow, goat, and sheep) with polyester non-woven materials, assessing their suitability for sports footwear applications. A series of standardized tests, including shape retention, collapsing load, resilience, and moisture resistance, were conducted to evaluate the materials' mechanical and functional properties. The results indicate that natural leather exhibits superior tensile strength, flexibility, and breathability, making it an ideal material for high-end sports footwear. However, polyester non-woven materials outperform leather in durability, water resistance, and shape retention, positioning them as a promising alternative, particularly for high-impact and water-resistant applications. This study highlights the trade-offs between traditional and synthetic materials, emphasizing the need for hybrid materials that combine the advantages of both. The research further underscores the importance of sustainable material development, reducing environmental impact while maintaining high-performance standards in the footwear industry.

Keywords: Sports Footwear, Leather, Polyester Non-Woven, Material Performance, Mechanical Testing, Sustainability.

1. Introduction

The footwear manufacturing industry is a dynamic, multi-billion-dollar sector that continuously adapts to changing consumer demands, technological advancements and sustainability requirements [1-3]. Historically, leather has been the dominant material in footwear production due to its exceptional flexibility, durability, breathability and aesthetic appeal [4-5]. It has been widely used across different types of footwear, from luxury and fashion shoes to athletic and industrial footwear. However, leather production involves complex processing techniques, including tanning, finishing and treatment, which not only add to production costs but also raise concerns regarding environmental impact and resource consumption [6-7].

With increasing environmental awareness, the demand for sustainable and cost-effective alternatives has led to a shift towards synthetic materials, particularly polyester non-woven textiles [7-9]. These materials offer several advantages over traditional leather, such as consistent quality, improved water resistance, recyclability, and ease of manufacturing. Polyester non-woven materials are increasingly being incorporated into sports and casual footwear designs, as they exhibit high durability, resistance to abrasion and better shape retention compared to some natural leathers. Moreover, synthetic materials are often more affordable and easier to process in large-scale production. While natural leather and polyester non-woven materials have their respective benefits, it is essential to perform a comprehensive comparison of their properties to determine their suitability for different footwear applications [10-13]. This study aims to evaluate and compare the structural, chemical, and mechanical properties of cow, goat, and sheep leather with polyester non-woven materials, focusing on their performance in sports footwear applications. The research utilizes empirical testing methods and standardized assessment techniques to analyze the materials based on strength, flexibility, moisture resistance and long-term durability. As sports footwear is subjected to intensive mechanical stress, environmental exposure, and extreme usage conditions, selecting the right material is crucial for ensuring product longevity and consumer satisfaction. Therefore, a scientific approach is necessary to determine whether natural leathers or polyester non-woven materials provide a more viable solution for modern sports footwear manufacturing.

1.1 Research Objectives

To establish a clear framework for evaluating the materials under study, this research is guided by the following objectives:

1.1.1 Structural and Chemical Analysis of Leather and Polyester Non-Woven Materials

One of the primary objectives of this study is to analyze the anatomical and chemical structures of different leather types and polyester non-woven materials. Each type of leather—cow, goat and sheep has a distinct structural composition that influences its physical properties.

- Cow leather is characterized by dense, tightly packed fibers, making it highly durable and resistant to wear and tear. It is often preferred for high-performance footwear due to its tensile strength and longevity.
- Goat leather, while slightly less durable than cow leather, possesses higher elasticity and softness, making it suitable for footwear that requires flexibility and comfort.
- Sheep leather is the lightest and softest among the three, offering exceptional comfort and a smooth texture but lacking the durability required for sports footwear.
- Polyester non-woven materials, on the other hand, consist of synthetic fibers that are thermally bonded or mechanically entangled, creating a structure that offers high tensile strength, water resistance, and uniform consistency.

Understanding these structural differences is crucial for selecting the appropriate material based on footwear performance requirements.

1.1.2 Mechanical Performance Evaluation

The second objective of this study is to assess the mechanical properties of both leather and polyester non-woven materials through standardized testing methods. Mechanical properties play a vital role in determining the durability, comfort, and performance of footwear materials. Key mechanical properties under evaluation include:

- Tensile Strength: Measures the ability of the material to withstand pulling forces, which is crucial for ensuring the durability of sports footwear.
- Abrasion Resistance: Determines how well the material resists wear and tear caused by friction and repeated use.
- Shape Retention: Evaluates the ability of the material to maintain its structure and prevent deformation under mechanical stress.
- Collapsing Load: Assesses the material's resistance to compression and impact forces, a critical factor for shock absorption in sports footwear.
- Flexibility and Elasticity: Determines how well the material can bend and flex without cracking, which is essential for comfort and movement.

By systematically comparing these properties, this study aims to identify which material is best suited for sports footwear, considering both durability and performance factors.

1.1.3 Sustainability and Environmental Impact Assessment

In recent years, sustainability has become a major concern in the footwear industry, influencing material selection and manufacturing processes. Traditional leather production involves environmentally hazardous practices, particularly chrome tanning, which generates toxic waste and contributes to water pollution. Additionally, leather processing requires significant water and energy consumption, further raising sustainability concerns.

Polyester non-woven materials, while synthetic, offer several environmental advantages over natural leather:

- Recyclability: Unlike leather, which is difficult to recycle, polyester non-woven materials can be repurposed and reused in various applications.
- Lower Water Consumption: The production of synthetic materials generally requires less water compared to the extensive water usage in leather tanning.
- Reduced Chemical Waste: Polyester non-woven materials do not require the same level of chemical treatment as leather, resulting in lower environmental impact.

However, synthetic materials also have their drawbacks, particularly in terms of microplastic pollution and biodegradability issues. Therefore, this research aims to analyze and compare the long-term environmental impact of both material categories to determine which option offers the best balance between performance and sustainability.

1.1.4 Suitability for Sports Footwear Applications

The final objective of this study is to determine the practical suitability of leather and polyester non-woven materials for sports footwear manufacturing. Sports footwear is subjected to rigorous movement, stress, and exposure to various environmental conditions, including humidity, temperature fluctuations, and impact forces. Thus, material selection must consider:

- Breathability: Ensuring proper air circulation to maintain foot comfort.
- Weight Considerations: Lighter materials contribute to better agility and reduced fatigue.
- Water Resistance: Preventing moisture absorption to enhance durability in outdoor sports environments.
- Longevity and Performance: Ensuring the material can withstand prolonged use without significant degradation.

By evaluating these parameters, the study aims to provide scientific recommendations for footwear manufacturers regarding the most suitable materials for sports footwear applications.

1.2 Significance of the Study

The findings of this research are expected to benefit multiple stakeholders in the footwear industry, including manufacturers, material scientists, and sustainability advocates.

1. For Footwear Manufacturers: The study provides data-driven insights to help manufacturers select the most suitable material for different types of sports footwear.

2. For Material Researchers: The study contributes to the understanding of material behavior and performance under real-world conditions, guiding future innovations in hybrid materials that combine the best features of leather and synthetics.
3. For Sustainability Advocates: The study assesses the environmental impact of traditional and synthetic materials, contributing to the global effort toward eco-friendly production practices.

As the footwear industry continues to evolve, material innovation remains a critical aspect of product development. Natural leathers have long been the preferred choice due to their superior properties, but polyester non-woven materials present a viable alternative with enhanced durability, moisture resistance, and cost efficiency. This study aims to provide a comprehensive scientific analysis to support informed decision-making in the selection of footwear materials, ultimately contributing to the advancement of high-performance and sustainable sports footwear solutions.

2. Materials and Methodology

2.1 Materials Analyzed

The study examines the following materials:

- Cow Leather: Known for its high tensile strength, flexibility, and durability.
- Goat Leather: Offers excellent softness and elasticity but moderate tensile strength.
- Sheep Leather: Distinguished by its smooth texture and lightweight properties, but less durable than cow and goat leather.
- Polyester Non-Woven: A synthetic material with high resistance to moisture, microbial growth, and wear, commonly used as an alternative to leather in modern footwear.

2.2 Testing Standards and Methodology

To ensure the accuracy, consistency, and reliability of the research findings, this study adheres to standardized material testing protocols, incorporating SATRA and ISO methodologies. These internationally recognized testing standards provide a scientific framework for evaluating the mechanical, structural, and chemical properties of natural leathers (cow, goat, and sheep) and polyester non-woven materials. Each test was designed to assess a specific performance characteristic, ensuring that the materials meet the demands of sports footwear applications.

2.2.1 Shape Retention and Collapsing Load Testing

Objective:

The purpose of this test is to evaluate the ability of toe puff and stiffener materials to maintain their structural integrity under repeated mechanical stress. Toe puff and stiffener materials play a crucial role in footwear durability, providing reinforcement and support to maintain the shoe's form over extended use.

Methodology:

- Test Specimen Formation: The materials were cut into standard specimens and formed into a domed shape, mimicking the real-world conditions they would experience in sports footwear.
- Load Application: Each domed test specimen was subjected to a controlled compressive force, simulating repeated pressure applied during walking, running, or sports activities.
- Measurement Recording: The height of the domed specimen was measured before and after compression, assessing how well the material retained its original shape.
- Resilience and Moisture Resistance Calculation: The ability of the material to recover from deformation was quantified, along with its performance under moisture exposure, ensuring that the materials maintain their shape and durability even in humid or wet conditions.

Findings from this test help determine which materials offer better shape retention and impact resistance, two essential qualities for long-lasting sports footwear.

2.2.2 Peel Strength and Bonding Tests

Objective:

This test evaluates the adhesive bond strength between leather and polyester non-woven materials, ensuring that the layers remain intact under stress and environmental exposure. Strong adhesion is particularly important in sports footwear, where materials are frequently subjected to bending, stretching, and external forces.

Methodology:

- Tensile Testing Machine: A standardized tensile testing machine was employed to apply a controlled pulling force on bonded materials. The force required to separate the layers was recorded.
- Failure Analysis: The type of failure was classified as either:
  - Adhesive failure (if the bond between the layers failed).
  - Cohesive failure (if the material itself tore, indicating a strong bond).

By analyzing the peel strength, researchers can determine whether natural leathers or synthetic materials provide better bonding efficiency, ensuring that layered footwear components remain durable over time.

2.2.3 Tanning Process Analysis

Objective:

This test examines the effectiveness of chrome tanning in leather processing and evaluates its impact on material durability, flexibility, and environmental sustainability. Chrome tanning is the most widely used method in the leather industry due to its efficiency, speed, and ability to enhance leather properties.

Methodology:

- Chemical Treatments: Various stages of leather processing were analyzed, including:
  - Liming: The removal of hair and impurities to prepare rawhide for tanning.
  - Bating: The softening of leather to improve flexibility.
  - Neutralization: The balancing of pH levels to stabilize leather structure.
  - Fat Liquoring: The addition of oils to enhance elasticity and moisture resistance.
  - Dyeing: The application of color to achieve the desired aesthetic properties.
- Structural Analysis: The transformation of rawhide into finished leather was examined under microscopic and mechanical tests, ensuring that the fibrous structure remained intact while improving durability and flexibility.

This analysis helps determine whether chrome-tanned leathers are structurally superior to synthetic alternatives and assesses environmental concerns associated with chemical waste disposal in the tanning process.

These standardized tests provide quantifiable insights into the physical, mechanical, and chemical performance of both natural leathers and synthetic polyester non-woven materials. By evaluating shape retention, bond strength, and tanning effectiveness, this study offers scientific recommendations for selecting the most suitable materials for high-performance sports footwear.

3. Results and Discussion

The study demonstrated significant differences in the performance of natural leathers (cow, goat, and sheep) and polyester non-woven materials when assessed for their mechanical and functional properties. Each material exhibited unique advantages and limitations, which play a crucial role in determining its suitability for sports footwear applications. The shape retention and collapsing load tests revealed that cow leather maintained its original structure more effectively than other leathers, retaining 82.7% of its shape after repeated compression. However, polyester non-woven materials outperformed all types of leather in both moisture resistance and load-bearing capacity, making them highly durable under extreme conditions. The collapsing load test, which measures the material's ability to withstand compressive forces, showed that polyester non-woven materials had the highest load-bearing capacity (105.2 N), followed by cow leather (99.99 N), goat leather (95.21 N), and sheep leather (90.35 N). These findings indicate that while natural leather remains structurally strong, synthetic alternatives such as polyester non-woven provide enhanced durability and better long-term structural integrity, especially in high-impact sports footwear. Peel strength plays a crucial role in footwear construction, particularly in bonded and multi-layered designs where strong adhesion is necessary to prevent delamination over time. The results showed that cow leather had a peel strength of 0.8 N/mm, indicating moderate bonding strength suitable for most applications. However, polyester non-woven materials exhibited superior bonding properties, with a peel strength of 1.1 N/mm, making them more resistant to delamination, especially in moist or wet conditions. This suggests that synthetic materials provide an advantage in sports footwear that requires enhanced adhesion and resistance to water exposure.

Table 1: Physical and Mechanical Performance

Material	Shape Retention (%)	Collapsing Load (N)	Peel Strength (N/mm)	Resilience (%)	Moisture Resistance (%)
Cow Leather	82.7	99.99	0.8	31.1	74.7
Goat Leather	79.3	95.21	0.7	29.8	70.2
Sheep Leather	76.8	90.35	0.6	27.5	68.5
Polyester Non-Woven	85.5	105.2	1.1	34.2	90.3

Beyond mechanical performance, the environmental impact of these materials is a critical consideration for sustainable footwear production. Chrome tanning, the most commonly used method in leather processing, is known to generate significant amounts of chemical waste, posing risks to water sources and ecosystems. Additionally, leather processing is highly resource-intensive, requiring large amounts of water and energy, contributing to higher carbon emissions. Conversely, polyester non-woven materials, despite being synthetic, offer greater recyclability and lower water consumption during production. Unlike leather, which is difficult to recycle and biodegradable over extended periods, polyester non-woven fabrics can be repurposed and reused in various applications, reducing overall waste. However, synthetic materials also present sustainability challenges, including microplastic pollution and non-biodegradability, which must be addressed through eco-friendly innovations such as bio-based polyester alternatives

The findings indicate that cow leather remains a strong candidate for premium sports footwear, offering superior flexibility, durability, and aesthetic appeal. However, polyester non-woven materials provide enhanced durability, moisture resistance, and bonding strength, making them a highly suitable alternative for modern sports footwear

applications. The decision between natural leather and synthetic alternatives should therefore be based on specific performance needs, cost considerations, and environmental sustainability goals.

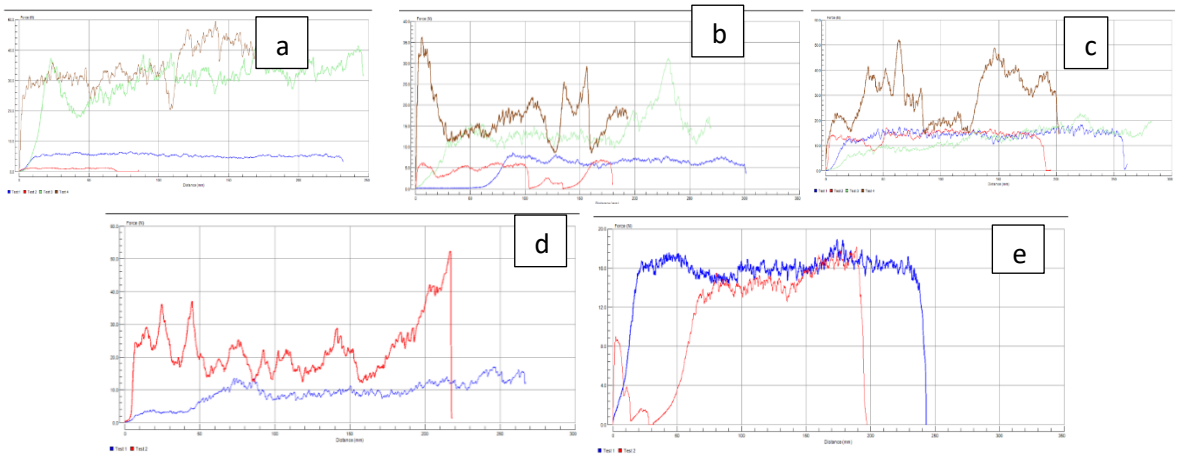

Fig: a,b,c,d & e Peel Strength and Bonding Tests

4. Conclusion

The research highlights key performance differences between natural leather and polyester non-woven materials in footwear manufacturing.

- Cow leather remains the superior choice for premium, high-end footwear due to its tensile strength and longevity.
- Goat and sheep leather are more flexible and lightweight, making them suitable for fashion and casual footwear.
- Polyester non-woven materials provide exceptional moisture resistance, durability, and shape retention, making them ideal for sports, outdoor, and industrial footwear.
- Development of bio-based synthetic alternatives to further reduce environmental impact.
- Improvement of chrome tanning processes to enhance sustainability.
- Hybrid materials research, combining the benefits of leather and synthetic fabrics for enhanced performance.

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Conflicts of Interest

No conflict of interest was reported.

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