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Comparative Analysis of the Properties of Synthetic and Natural Leathers: a Focus on Microfiber Synthetic Leather for Footwear Applications

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ABSTRACT:
The market for leather-like materials has grown significantly due to concerns about natural leather. Research into sustainable materials is an important part of sustainable fashion. This ever-increasing demand for leather alternatives, particularly microfibre synthetic leather, has made it necessary to understand the properties of leather and leather-like materials. Therefore, this study provides a comparative analysis of the properties of natural leather, PU leather and microfibre synthetic leather. The results show that microfibre synthetic leather is the most robust of the three, with adequate seam strength. On the other hand, PU leather has exceptional seam strength and adequate durability compared to natural leather. In addition, further tests were carried out to assess the performance and potential of microfibre synthetic leather for use in footwear. The results demonstrated the resilience of the material and its potential to improve product durability and sustainability. Considering the test results, it is thought that microfibers will contribute to the concept of environmentally friendly fashion with a longer lifetime and therefore less consumption. It is also thought that both long usage and low structural deformation will increase the intensity of use of these structures in the fashion industry.

Keywords: synthetic leather, natural leather, footwear

1. Introduction

Leather has been used for its durability since the dawn of time (Meyer *et al.*, 2021). However, due to limited resources, high cost, ethical concerns, and advancements in material sciences, the need for an alternative has increased tenfold (Qiang *et al.*, 2018; Chen *et al.*, 2007). Polyurethane (PU) or polyvinyl chloride (PVC) synthetic leather were introduced to address these concerns (Rahimi *et al.*, 2020). The use of synthetic polymers allowed for the customization of the performance of the material (Meyer *et al.*, 2021). Even though this inexpensive material gained immense popularity, it lacked the robustness and feel of natural leather. Subsequently, improved properties of materials were made possible with the advancement of technology. For instance, the ability to produce filaments is even finer than silk, such as micro and ultra-microfibers (Mukhopadhyay, 2002).

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Microfibers are defined by the length, weight, or diameter of the filament. Therefore, fibers ranging from 0.1 to 1.0 dtex are termed microfibers (Mukhopadhyay, 2002). These microfibers can be produced by using synthetic polymers and various spinning methods such as direct or bicomponent spinning (Fu *et al.*, 2024) . However, the bicomponent spun sea island fibers are most used. The non-woven microfiber material is then treated with PU to create a leather alternative (Lei *et al.*, 2022). While the use of a microfiber base enhances some properties such as strength, uniformity, and dimensional stability, it reduces others, such as dye fastness, water vapor permeability, moisture absorption, etc (Xu *et al.*, 2021; Cai *et al.*, 2022; Zhao *et al.*, 2019; Duo *et al.*, 2019). Numerous studies are underway to address these limitations and improve the properties of microfiber synthetic leather (Ren *et al.*, 2014).

Microfiber synthetic leather is deemed the ideal substitute for natural leather. It is also termed sustainable as its durability, permeability, dimensional stability, and mildew resistance, etc., is said to outperform natural leather, consequently increasing the lifespan of microfiber synthetic leather products. Furthermore, the small denier of the fibers, the high fiber coverage, and the large surface area of the fibers offer flexibility, smoothness, and uniformity to the material (Fu *et al.*, 2024). In instances where the use of synthetic materials is deemed unavoidable—due to functional, economic, or design-related constraints—material selection has been guided by principles aimed at minimizing environmental impact and maximizing the lifespan of the product. This approach reflects a pragmatic balance between performance requirements and sustainability goals. However, it is important to emphasize that the adoption of micro synthetic materials in such contexts does not imply that they are environmentally superior to natural alternatives. Rather, their use is a conditional compromise, informed by the intent to reduce harm within the constraints of current material technologies and industry practices. Microfiber synthetic leather has the internal structure that mimics genuine leather (Zhao *et al.*, 2024; Qiang *et al.*, 2015; Zhao *et al.*, 2019). For instance, the microfibers are comparable to 4 μm diameter collagen fibers found in leather (Othman *et al.*, 2024) . Additionally, the nonwoven base of the microfiber synthetic leather mimics the 3D net structure present in natural leather (Zhao *et al.*, 2018; Zhao *et al.*, 2019) . Due to its remarkable resemblance to natural leather, it has been adopted by the apparel and upholstery industries, among others (Wang *et al.*, 2018; Hassan *et al.*, 2021) . Similarly, more than 90% of the high-end shoes are made of microfiber synthetic leather (Wang *et al.*, 2015) . For instance, the Japanese company Kuararay has been developing artificial leather such as Clarino since 1964. Amaretta by Kuararay has also been popular in high-end leather shoes, bags, and jackets (Fu *et al.*, 2024).

The use of microfiber synthetic leather in footwear can be seen as a step towards sustainability even if made with synthetic materials. Footwear can have both aesthetic and functional value in one's life, however, 95% of the shoes manufactured in a year end up in a landfill. It is simply not designed to last or to be recycled due to its heterogenous nature. Therefore, it is necessary to use materials that can at the least increase the lifespan of footwear and decrease the 700 metric tons of CO2 produced annually by the footwear industry (Su, 2022).

The growing demand for microfiber synthetic leather has intensified the need to understand its properties in comparison to similar materials. Therefore, this study provides a comparative analysis of the properties of microfiber synthetic leather, PU leather, and natural leather. Furthermore, with microfiber synthetic leather's popularity in footwear, it is necessary to conduct a performance evaluation to quantify its viability for footwear applications. Microfiber leather is a synthetic material composed of ultra-fine fibers, typically finer than one denier, which are densely woven or bonded to create a durable and flexible surface that mimics natural leather. Its unique fiber structure provides enhanced strength, breathability, and resistance to wear compared to conventional synthetic leathers. Due to these properties, microfiber leather is increasingly explored as a sustainable alternative in footwear and apparel industries, offering potential advantages in durability and resource efficiency. However, comprehensive evaluations, including environmental impact assessments and sensory qualities—are essential to fully understand its suitability and performance relative to traditional materials.

2. Materials and Methods

2.1 Materials

Natural leather, PU leather, and microfiber synthetic leather were used in this study. Natural leather was sourced from Turkish Leather Market, while PU leather was provided by FLO Ltd. İstanbul, Türkiye. The microfiber synthetic leather used in this study was sourced from China and used as received.

2.2 Methods

A total of five tests were performed on three materials under standard test conditions of 23±2 °C and 50±5% RH. The samples were prepared in accordance with the ISO standards. These tests are suitable for providing a comprehensive and comparative understanding of the properties of leather and leather-like materials. Additionally, four tests were conducted for the performance evaluation of microfiber synthetic leather for use in footwear applications.

2.2.1. Determination of Distension and Strength of Surface

The strength and distention of the leather surface were determined by following the ISO 3379:2024 ball burst method. The test was performed by clamping the samples into the leather lastometer as shown in Figure 1. Subsequently, distention was applied until the material cracked or burst (ISO 3379, 2024). This test is crucial to determine the structural integrity of the materials and its resistance to cracking or bursting.

Figure 1: Digital Leather Lastometer

2.2.2 Determination of Tensile Strength and Percentage Elongation

This study determined the tensile strength and percentage elongation by following ISO 3376:2020. The tests were conducted using a tensile testing machine under standard conditions as shown in Figure 2 (ISO 3376, 2020). The mechanical behavior of the material was observed to analyze the robustness and elasticity of the materials.

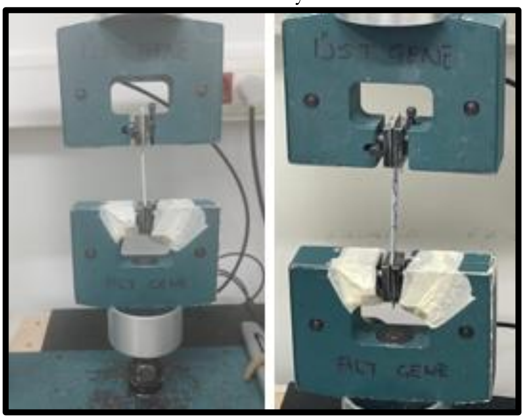

Figure 2: Determination of Tensile Strength and Elongation using Tensile Tester

2.2.3 Determination of Tear Strength

The material's resistance to tearing was determined using the double-edge tear method specified in ISO 3377-2. As shown in Figure 3, the tear strength test was performed using a tensile testing machine to assess the durability of the materials (ISO 3377-2, 2016).

Figure 3: Determination of Tear Strength using Tensile Testing Machine

2.2.4 Determination of Seam Strength

An adequate seam strength guarantees the overall quality of any product. Therefore, to determine the seam strength, method B of EN 13572 was performed with a tensile testing machine as demonstrated in Figure 4 (ISO 13572, 2001). This test is important for materials being used in stitched applications.

Figure 4: Determination of Seam strength using Tensile Testing Machine

2.2.5 Determination of Flex Resistance

The flex resistance was determined by following the flexometer method as defined by ISO 5402-1 (ISO 5402-1, 2022). As shown in Figure 5, this test simulates regular wear through the bending and flexing of the material, which helps in understanding the properties of the materials under dynamic conditions.

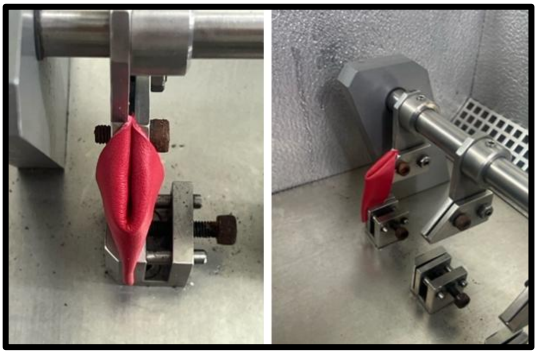

Figure 5: Determination of Flex Resistance using Flexometer Method

2.2.6 Physical and Mechanical Performance of Microfiber Synthetic Leather

To understand the physical and mechanical performance of microfiber synthetic leather for its use in footwear, several tests were performed. The first was the flex resistance test, which was conducted to test the material's ability to be used long term and its resistance to bending or flexing. The testing was performed as per ISO 17694:2016 for dry, wet, and cold conditions (ISO 17694, 2016). The dry samples were subjected to 80,000 cycles while the wet and cold samples were subjected to 20,000 cycles. The cold sample was tested at -5 °C while the dry and wet samples were tested at standard conditions of 23±2 °C. The wet and cold samples are subjected to lower cycles as moisture can make the material prone to damage. Two samples were taken from the edge of the shoe, as the area contains stitched seams or adhesives making it necessary to be tested for flex resistance. Similarly, two samples were taken from the upper part or vamp of the shoe as it suffers from bending the most during use.

Secondly, the robustness of the material was evaluated using a tearing strength test in accordance with ISO 17696:2004 (ISO 17696, 2004). The test was conducted under standard conditions using a tensile testing machine. The abrasion resistance test was also performed to check its resistance to rubbing and friction in accordance with ISO 17704:2004 (ISO 17704, 2004). The test ran for 12,800 cycles in dry conditions, while 6,400 cycles only in wet conditions. The abrasive material used was a sandpaper cloth with a pressure of 12kPa.

Lastly, a colorfastness to rubbing test was conducted to measure the material's aesthetic potential by following method A of ISO 17700:2019 (ISO 17700, 2019). The samples were subjected to 12,800 cycles in dry state, and 50 cycles in wet and sweat conditions. The results were displayed in the form of a pass or fail rating as per the set requirements.

3. Results and Discussions

3.1 Determination of Distension and Strength of Surface

Exceptional resistance to localized stress was observed in microfiber synthetic leather during the distention and strength of the surface test. The highest burst force of 373.73N and distention of 20.7mm were observed, making it the material with the most resilient surface. The resilience of this material may be attributed to the large surface area of microfibers used in the material. PU leather and natural leather also displayed adequate distention and surface strength as illustrated in Figure 6. The burst force of PU was observed at 243.99 N while it was 225.89 N for natural leather. Similarly, the distention for PU was observed to be 16.69mm while it was 17.23mm for natural leather. Despite these promising results, numerous studies are ongoing to address existing limitations and further enhance the properties of microfiber synthetic leather, aiming to optimize its performance and broaden its applicability. This study aims to strengthen the existing literature by conducting more comprehensive mechanical and physical tests to provide clearer and more robust data on the material's performance characteristics. Such an approach is necessitated by the variations in standards, material types, and application areas, which underscore the need for further systematic investigation within the literature.

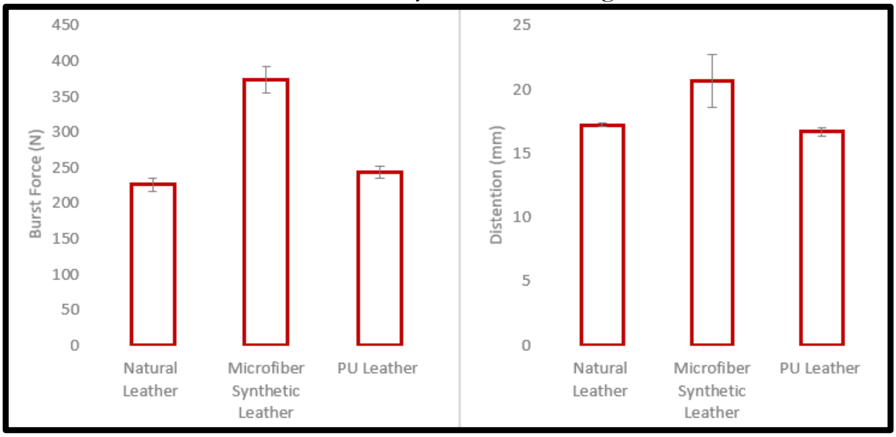

Figure 6: Distention and Strength of Surface Test

3.2 Determination of Tensile Strength and Percentage Elongation

The tensile strength and percentage elongation test revealed that microfiber synthetic leather is highly superior in terms of robustness and flexibility compared to natural leather and PU leather with tensile strength and elongation of 12.06 N/mm2 and 114.6% respectively. It can be concluded from the test results that the microfiber synthetic leather outperforms natural leather and PU leather, making it the most durable option among the three. As displayed in Figure 7, it is important to note that PU leather had the lowest tensile strength of 9.6 N/mm2 compared to natural leather's 11.4 N/mm2 strength, deeming it undesirable for high-value applications. On the other hand, the percentage elongation of PU leather was 55.1% while it was 48.5% for natural leather.

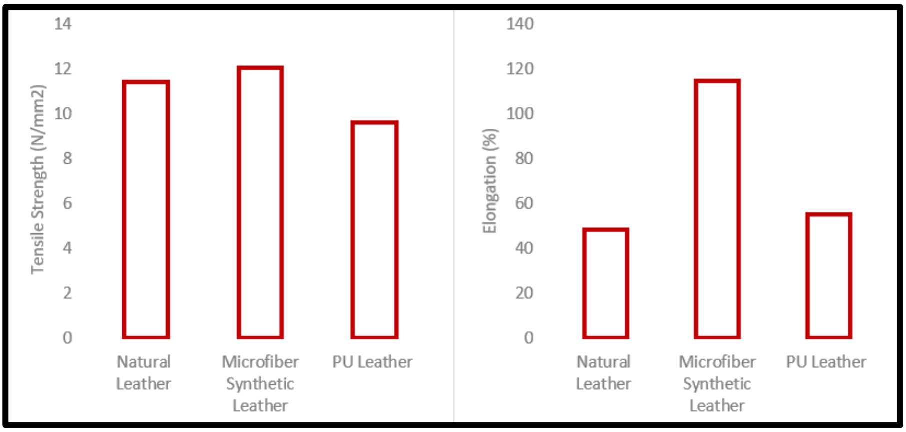

Figure 7: Tensile Strength and Elongation Test

3.3 Determination of Tear Strength

As displayed in Figure 8, microfiber synthetic leather showed a significantly high tear resistance of 139.2 N, revealing its high resistance to tearing. This test further proves the exceptional durability of microfiber leather. On the other hand, PU leather has a tear strength of 95N while it is only 40.8N for natural leather.

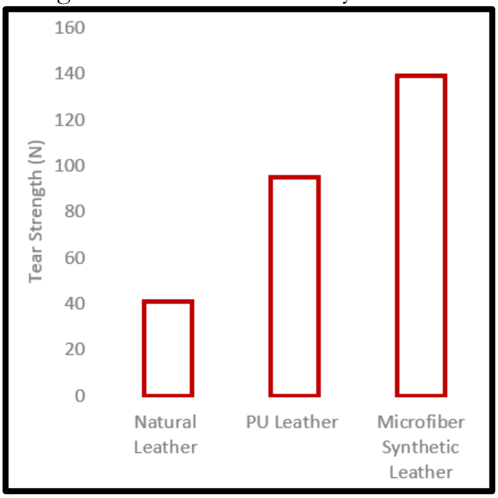

Figure 8: Tear Strength

3.4 Determination of Seam Strength

From the seam strength test results shown in Figure 9, we can conclude that PU leather has the highest seam strength of 11.7 N/mm, making it the most suitable option for stitched products. Natural leather has a seam strength of 8.1N/mm which is sufficient for stitched applications. On the other hand, microfiber synthetic leather has the lowest seam strength of 3.6 N/mm. This suggests that additional reinforcement may be required when using microfiber synthetic leather for stitching-related applications.

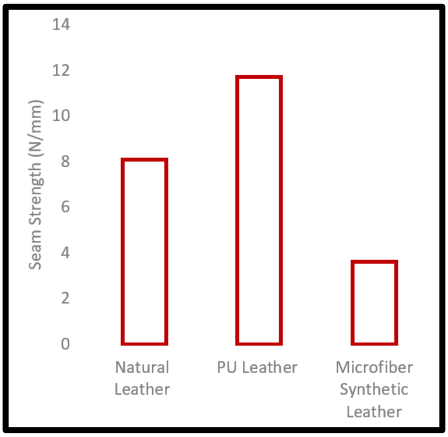

Figure 9: Seam Strength Test

3.5 Determination of Flex Resistance

The Flex resistance test results shown in Table 1, revealed that all three samples performed well with no visible damage after running for 100,000 cycles. This shows their capacity to withstand repetitive stress and use, making them suitable for everyday products.

Table 1: Flex Resistance Test

Sample	Flex Resistance (100,000 Cycles)
Natural Leather	**No damage**
PU Leather	**No damage**
Microfiber Synthetic Leather	**No damage**

3.6 Physical and Mechanical Performance of Microfiber Synthetic Leather

Flex resistance, tearing strength, abrasion resistance, and colorfastness to rubbing test were conducted to understand the physical performance and mechanical durability of microfiber synthetic leather for use in footwear. As shown in Table 2, microfiber synthetic leather achieved the required values to be used in footwear applications.

Table 2: Physical and Mechanical Performance of Microfiber Synthetic Leather

Test	Evaluation
Flex Resistance	**Pass**
Tearing strength	**Pass**
Abrasion Resistance	**Pass**
Colorfastness to Rubbing	**Pass**

3.6.1 Flex Resistance Test for Shoe Uppers and Edge

The Flex resistance test for shoe uppers and edge was conducted in dry, wet, and cold conditions. The test results can be seen in Table 3. The material passes the test as no visible cracks appear after running for 80,000 cycles in dry condition, simulating regular wear. Similarly, the material passes the test in wet and cold conditions as no visible cracks occurred after 20,000 cycles. This evaluation ensures that the material is flexible and no premature cracking will occur, making it a durable material to be used in footwear.

Table 3: Flex Resistance in Dry, Wet and Cold Conditions

Sample	Condition	Requirement	Evaluation	Rating
Sample 1 (Edge)	**Dry**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 2 (Edge)	**Dry**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 1 (Vamp)	**Dry**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 2 (Vamp)	**Dry**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 1 (Edge)	**Wet**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 2 (Edge)	**Wet**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 1 (Vamp)	**Wet**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 2 (Vamp)	**Wet**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 1 (Edge)	**Cold**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 2 (Edge)	**Cold**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 1 (Vamp)	**Cold**	**No Visible Cracks**	**Slight Creasing**	**Pass**
Sample 2 (Vamp)	**Cold**	**No Visible Cracks**	**Slight Creasing**	**Pass**

3.6.2 Tear Strength Test for Shoe Uppers

The test results of the tear strength test revealed that the microfiber synthetic leather material is suitable for use in footwear as it passes the tear strength test. As shown in Table 4, the minimum required tearing strength was 40N and the average achieved was higher than that of the requirement.

Table 4: Tear strength test for Footwear Applications

Parameter	Requirement (N)	Evaluation (N)	Rating
Average Tear Strength	**40**	**48.3**	**Pass**

3.6.3 Abrasion Resistance for Footwear Applications

The abrasion resistance test once again proved the durability and longevity of microfiber synthetic leather. Only minor changes were observed after running for 12,800 and 6,400 cycles in dry and wet conditions, respectively. As shown in Table 5, no major damage was observed that may affect the material's performance.

Table 5: Abrasion Resistance for Footwear Applications

Sample	Condition	Requirement	Evaluation	Rating
Sample 1	**Dry**	**No Severe Damage**	**Slight Damage**	**Pass**
Sample 2	**Dry**	**No Severe Damage**	**Slight Damage**	**Pass**
Sample 1	**Wet**	**No Severe Damage**	**Slight Damage**	**Pass**
Sample 2	**Wet**	**No Severe Damage**	**Slight Damage**	**Pass**

3.6.4 Colorfastness to Rubbing for Shoe Uppers

The color fastness test made it evident that the material will not result in color change and staining of adjacent fabrics. This not only adds to the longevity of the material but also opens doors for aesthetic experimentation in footwear. The results in Table 6 demonstrate that the samples received an excellent gray scale rating of 4-5 for color change and staining. It can be concluded that this material will not change color or cause staining of the adjacent fabrics in the long run, making it an excellent choice for footwear.

Table 6: Colorfastness to Rubbing for Shoe Uppers

Parameter	Condition	Requirement	Evaluation	Rating
Color Change	Dry	≥3	4-5	Pass
Staining	Dry	≥3	4-5	Pass
Color Change	Wet	≥3	4-5	Pass
Staining	Wet	≥3	4-5	Pass
Color Change	Sweat	≥2-3	4-5	Pass
Staining	Sweat	≥2-3	4-5	Pass

4. Conclusion

In this study, natural leather, PU leather, and microfiber synthetic leathers were tested for distention and strength of surface along with tensile strength, tear load, seam strength, and flex resistance. Microfiber synthetic leather significantly outperformed the other two materials, proving to be more durable and robust than natural and PU leather. However, the microfiber synthetic leather was found to have low seam strength, suggesting the need for additional reinforcement in stitched applications. Future work will systematically address the identified seam strength limitation by exploring different stitching techniques and thread materials, with the goal of optimizing seam durability and improving the performance of microfiber synthetic leather in applied contexts.PU leather performed adequately compared to natural leather. However, it has the lowest tensile strength and highest seam strength, making it useful for niche applications. Furthermore, additional tests were performed on microfiber synthetic leather to assess its appropriateness to be used in footwear. The material was subjected to tearing strength test, color fastness to rubbing test, flex and abrasion resistance tests in different conditions to simulate regular wear. The material displayed great resilience and met the requirements to be used in footwear applications.

The conclusion effectively highlights the superior durability of microfiber synthetic leather compared to natural and PU leather, underscoring its potential for footwear applications. Incorporating evaluations of aesthetic and tactile properties—such as appearance, texture, and comfort—would further enhance the understanding of the material's overall suitability. Given the importance of these sensory attributes in high-end applications, their consideration could provide valuable insights into the broader adoption and acceptance of microfiber synthetic leather in premium markets. Thus, future research integrating both functional and sensory assessments would contribute to a more comprehensive evaluation of this material's potential.

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