



Mechanical Properties of textile fabrics for shoe - internal applications in footwear

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This study investigates the suitability of textile materials as replaceable shoe-internal linings in footwear, focusing on the concept of "Innovation on Replaceable Concepts". The shoe-internal lining component is designed to be removable for enhanced convenience and hygiene. Various textile materials, including canvas, cotton, denim or terry cot are evaluated for mechanical strengths such as tensile, tear, water vapour permeability and abrasion resistance to ensure foot comfort. Denim, followed by canvas, exhibits higher tensile and tear strength but the lowest coefficient of variance, indicating superior durability after repeated washing. All tested fabric samples possess good abrasion resistance in dry and wet conditions, and flexing tests confirm their suitability as inner linings. However, canvas fabrics show higher compressive load values. Considering functional characteristics of the shoe's internal component, properties such as flexibility, puncture resistance and impact resistance are evaluated, and results confirm that denim and canvas possess superior values on all parameters across washing cycles. Finally, canvas fabric is recommended as the optimal choice for shoe-internal linings due to its superior flexing properties, puncture resistance, and overall mechanical performance, making it an ideal choice for shoe-internal component footwear.

Keywords: Abrasion resistance, Canvas footwear, Foot comfort, Mechanical properties, Replaceable lining, Shoe inner lining

1 Introduction

The footwear industry in India is experiencing remarkable growth, emerging as a key sector for earning foreign exchange through global exports. Traditionally, footwear comprises an upper material, usually leather, and a sole, with a lining beneath the upper to protect the skin from abrasion and friction. While leather remains a popular choice for linings due to its comfort, it is prone to fungal deposition when in contact with skin under sweaty and moist conditions. This challenge, coupled with the high cost and limited availability of leather, has driven the search for alternative materials. Globally, the footwear industry is exploring innovative solutions to reduce production costs and enhance product performance, such as replacing leather with synthetic materials, fabrics, and composites^{1,2}. Textile-based linings, particularly those made of cotton, polyester, denim, and blended fabrics, are gaining prominence due to their desirable properties such as moisture absorption, breathability, lightweight, thermal insulation, and durability^{3,4}. Additionally, textiles provide thermal comfort by

facilitating heat dissipation and maintaining foot hygiene, making them viable alternatives for shoe-internal components^{5,6}.

Textile materials offer versatile applications in footwear due to advancements in fabric structures, including woven, knitted, and nonwoven textiles⁷. Woven fabrics, in particular, exhibit superior tensile strength, abrasion resistance, and flexibility, making them suitable for shoe linings^{8,9}. Further, innovative design approaches like "design for disassembly" have introduced replaceable lining systems in footwear, enabling easy replacement of worn-out components. This not only extends product life but also enhances comfort, hygiene, and sustainability¹⁰.

Denim, a globally favored textile material, stands out for its moisture absorption and air permeability, which contribute to a comfortable and healthy environment inside the shoe¹¹. However, repetitive washing can affect its mechanical properties, such as tensile strength and elongation, requiring careful consideration of washing conditions¹². Cotton lining materials are also commonly used due to their breathability and comfort, with studies highlighting the impact of fabric construction and finishing treatments on moisture management properties¹³.

Despite the widespread adoption of textile-based linings, there is a critical need to systematically

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evaluate their mechanical and functional properties for shoe-internal applications. This study aims to address this gap by investigating the properties of selected textile materials—canvas, cotton, denim, and terry-cotton—for their suitability as replaceable shoe linings. Key mechanical characteristics, including tensile and tear strengths, flexing endurance, puncture resistance, and moisture management, are assessed to identify materials that fulfil the dual objectives of foot hygiene and user comfort.

2 Materials and Methods

2.1 Materials

In this study, textile materials, namely canvas, cotton, denim, and terrycot were chosen for internal applications in footwear. These materials were procured from the local market, and their weaving patterns and physical properties were evaluated using standardized procedures.

The canvas fabric was made using a 2/2 mat weave pattern with fewer interlacing points between warp and weft directions. This weave pattern possesses minimal thermal resistance and is ideal for hot climatic conditions. Additionally, canvas exhibits ease of flexibility, wrinkle resistance and tear resistance.

The cotton fabric was constructed in a 2/2 twill weave pattern, which produced a diagonal striped appearance. It possesses higher tearing strength but faster abrasion compared to plain weave.

In Denim fabric, the weave pattern of ½ twill was adopted with the diagonal lines running along the width of the fabric.

The Terrycot fabric is a blended fabric made from cotton and polyester fibres. The fabric has loops on both sides, creating a plush and fluffy texture for higher absorbency parameters and can withstand frequent use and washing. Representative weave patterns of the fabrics are presented in the Fig. 1.

2.2 Methods

The selected fabrics underwent testing across four washing cycles. Physical properties such as tensile strength, tear strength, water vapour permeability, and abrasion resistance were evaluated sequentially after each washing cycle.

The tensile strength was measured as per the ISO 3376 standard, which involved clamping fabric specimens in a tensile testing apparatus and recording the maximum force (F) before breakage. Tensile strength (T_n) was calculated using the following formula:

$$T_n = F / w \times t \quad \dots (1)$$

where F is the maximum force (N); w, specimen width (mm); and t, thickness (mm).

The tear strength of the fabrics was evaluated using the ISO 3377 test method. This method involves a rectangular test specimen with a partial slit at one short edge. The specimen was pulled to propagate a tear from the end of the slit, and the mean force exerted during the tear propagation was recorded. The tensile testing machine was set with clamps at an appropriate distance to hold the test piece securely. One leg of the specimen was fixed in one jaw of the machine, while the other leg was positioned through a 180° rotation in the opposite jaw. The machine was operated until the specimen tore completely, and the force required was recorded.

Water vapour permeability was assessed by the ISO 14268 standard. The test piece was clamped over the opening of a container containing a solid desiccant. This set-up was placed in a strong current of air in a standard atmosphere. The air inside the container was constantly agitated by the desiccant, which was kept in motion by the container's rotation. The mass of absorbed moisture was determined by weighing the containers before and after the test.

The abrasion resistance of the fabrics was determined using the Martindale method, as specified in SATRA TM 31. The circular specimens were subjected to multi-directional rubbing under constant pressure. Both dry and wet abrasion tests were performed, and the damage to the fabric was assessed after a specified number of revolutions.

3 Results and Discussion

3.1 Tensile Strength

The mechanical characteristics of textile fabrics play an immense role in the suitability of shoe-internal applications in footwear. The present study evaluates the tensile strength of four fabric types—Canvas, Cotton, Denim, and Terrycot—across different washing cycles to understand their durability and functional suitability. Tensile strength is

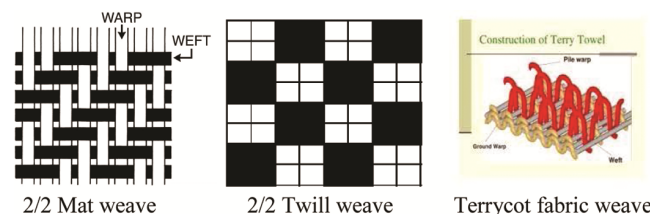


Fig. 1 — Weave patterns of textile fabric samples¹

Table 1 — Tensile strength of fabrics across washing cycles

Fabric	0 wash	1 wash	2 wash	3 wash	4 wash	Mean	SD	CV, %
Canvas	14.69	13.60	13.38	14.80	12.93	13.88	0.74	5.72
Cotton	14.93	12.39	8.83	10.72	9.13	11.20	2.26	24.72
Denim	15.89	16.14	15.35	15.51	15.12	15.60	0.37	2.43
Terrycot	10.18	10.90	8.45	8.76	9.36	9.53	0.90	9.67

Table 2 — Tear strength of fabrics across washing cycles

Fabric	0 wash	1 wash	2 wash	3 wash	4 wash	Mean	SD	CV, %
Canvas	36.8	30.0	32.6	30.8	33.0	32.69	2.35	7.11
Cotton	11.1	10.3	10.7	10.8	11.5	10.93	0.40	3.48
Denim	51.5	49.7	53.6	50.3	52.4	51.54	1.40	2.67
Terrycot	46.3	52.7	47.9	44.3	31.2	44.54	7.19	23.0

measured using the ISO 3376 standard after 0, 1, 2, 3, and 4 washing cycles. The results are presented in Table 1.

Initially (0 wash), Denim exhibits the highest tensile strength of 15.89 N/mm², followed by Cotton (14.93 N/mm²), Canvas (14.69 N/mm²), and Terrycot (10.18 N/mm²). After the fourth washing cycle, Denim retains its superior tensile strength at 15.12 N/mm², with Canvas at 12.93 N/mm², Cotton at 9.13 N/mm², and Terrycot at 9.36 N/mm². Denim's consistent performance is attributed to its high-density twill weave, where closely packed fibres enhance durability and resistance to tensile forces. The diagonal ribbing in Denim's weave, formed by alternating warp and weft yarns, also contributes to its high tensile strength¹⁴.

Canvas, ranking second in tensile strength, owes its performance to its closely woven fabric pattern, made with single or plied yarns in both warp and weft directions. This structure enhances its durability through repeated washes. The coefficient of variation (CV) of Denim remains the lowest (2.43%), indicating the minimal impact of washing on its tensile strength. In contrast, Cotton shows the highest CV (24.72%), reflecting its greater susceptibility to strength degradation. Terrycot, although above the minimum standard tensile strength, had a CV of 9.67%, suggesting moderate variability and lower durability compared to Canvas and Denim.

3.2 Tear Strength

The tear strength of fabrics is assessed across washing cycles, as presented in Table 2. Denim exhibits the highest tear strength, starting at 51.5 N and slightly increasing to 52.4 N after the fourth wash. Canvas follows, with tear strength decreasing from 36.8 N to 33 N, while Terrycot and Cotton demonstrate lower tear strengths, ending at 31.2 N and 11.5 N, respectively.

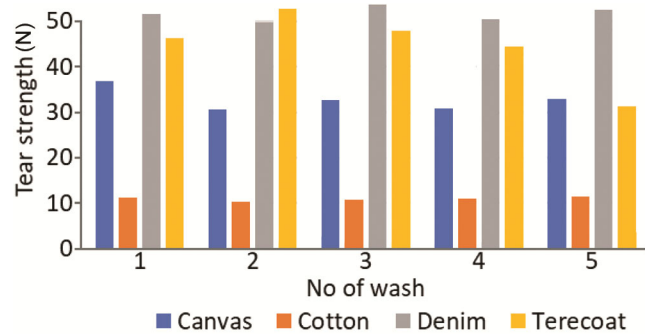


Fig. 2 — Tear strength of fabrics vs number of washing Cycles

The CV for tear strength is lowest for Denim (2.67%), emphasizing its stability under repetitive washing. Cotton and Terrycot display higher variability, with CV values of 3.48% and 23.0%, respectively, indicating their greater susceptibility to wear and tear during washing cycles.

Denim's superior tear strength results from its robust twill weave, which enhances yarn interaction and structural integrity (Fig. 2). The closely packed fibres and the mobility of yarns within the fabric matrix contribute to its high resistance against tearing forces. Although less durable than Denim, Canvas still shows moderate tear strength due to its tightly woven structure¹⁵. Conversely, Cotton, with its looser weave, exhibits the lowest tear strength, rendering it unsuitable for applications requiring high durability. Terrycot fabric demonstrates moderate tear strength but has the highest coefficient of variation, indicating significant susceptibility to degradation under repetitive washing. Consequently, this material may not be suitable for shoe interiors, where durability and consistent performance are critical¹⁶.

The textile fabrics in terms of tear and tensile strength are graded as cotton < terrycot < canvas < denim which came out based on the results obtained

from the evaluation test conducted on washing cycles of textile fabrics in the study. The denim fabric possesses superior character, followed by canvas and terrycot, and finally, cotton stands to be of low quality amongst the other fabrics.

Cotton fabric, procured locally, is composed of cellulose fibres joined by polymeric chains and hydrogen bonds. Its natural moisture-absorbing properties result in slow drying and wrinkling. The experimental results reveal low tearing and tensile strength, limiting its use in applications demanding durability.

The Terrycot sample, a blend of 65% cotton and 35% terylene, exhibits greater tear and tensile strength than Cotton alone. This is attributed to the inclusion of terylene, which enhances its stretchability and structural strength.

Canvas fabric demonstrates high tear and tensile strength, second only to Denim. Its open weave structure provides breathability and strength. The robust interlacing of warp and weft yarns through cohesion forces contributes to its durability and resistance to tearing.

Denim stands out with its exceptional tear and tensile strength, attributed to its twill weave and compact structure. This makes it ideal for applications requiring high durability, such as footwear, ensuring product longevity and consumer satisfaction.

In summary, the tensile strength of Denim fabric is superior to all other fabrics used in the present experiments. This is mainly due to factors such as fibre type, yarn construction, and fabric thickness. Denim fabrics of higher tensile strength are desired and necessary for application in footwear as the product is continuously subjected to external forces during the entire life cycle of the usage period.

3.3 Water Vapour Permeability

Water vapour permeability is crucial for shoe-internal application for the wearers. Table 3 summarizes the water vapour permeability of fabrics across washing cycles. At the 0 wash, Terrycot shows the highest permeability (24.11 mg/cm²/h), followed by Canvas (16.99 mg/cm²/h), Denim (14.66 mg/cm²/h),

and Cotton (12.20 mg/cm²/h). After four washes, Terrycot (19.83 mg/cm²/h) and Cotton (19.83 mg/cm²/h) retain relatively high permeability, while Denim (14.45 mg/cm²/h) and Canvas (15.07 mg/cm²/h) exhibit stable performance.

Denim's low CV of 4.37% highlights its stability in maintaining permeability across washing cycles. Its superior breathability and moisture-wicking abilities make it ideal for reducing skin humidity and enhancing comfort in footwear. Canvas demonstrates comparable performance but shows higher variability (11.63%). Cotton, despite being a natural fibre with high hygroscopicity, shows a greater CV (12.59%), indicating reduced stability under washing stress. Terrycot exhibits the highest initial permeability but lacks consistency, with a CV of 11.15%, suggesting its limited suitability for long-term applications. The results are at par with the findings of many researchers^{2,8,13,17}.

3.4 Abrasion Resistance

The abrasion resistance of the fabrics is evaluated using the SATRA TM 31 test. Results show (Table 4) that all fabrics demonstrate good abrasion resistance in dry and wet conditions. When subjected to abrasion under both conditions, all fabric materials maintain a consistent B scale rating, especially after 1600 cycles, as well as after 3200, 6400, and 12800 cycles. It indicates that there are no significant changes in the surface characteristics of the fabrics due to the mechanical friction of the abraders used in the testing.

3.5 Flexibility

Flexibility refers to the material's ability to bend or move with the foot while providing comfort and ease. In sports footwear, flexible materials such as synthetic polyester, leather, and mesh are commonly used². Among the textile fabrics evaluated in this study, Denim and Canvas exhibit desirable properties such as tensile strength, tear strength, water vapour permeability, and abrasion resistance, demonstrating benefits after multiple washing cycles. The flexible properties of the upper materials, along with the shoe's internal materials, determine the degree of foot comfort. The textile fabrics Terrycot, Canvas, Cotton

Table 3 — Water vapour permeability of fabrics across washing cycles

Fabric		0 Wash	1 wash	2 wash	3 wash	4 wash	Mean	SD	CV, %
Canvas	Min 2.0	16.99	17.48	14.01	12.84	15.07	15.28	1.75	11.63
Cotton	Min 2.0	12.20	17.30	16.57	15.39	19.83	16.26	2.50	12.59
Denim	Min 2.0	14.66	15.92	15.74	15.82	14.45	15.32	0.63	4.37
Terrycot	Min 2.0	24.11	23.62	21.92	26.43	19.83	23.18	2.21	11.15

Table 4 — Abrasion resistance of fabrics across washing cycles

Fabric	Cycles	Number of washes									
		0	0	1	1	2	2	3	3	4	4
		Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet	Dry	Wet
Canvas	1600	A	A	A	A	A	A	A	A	A	A
	3200	B	B	B	B	B	B	B	B	B	B
	6400	B	B	B	B	B	B	B	B	B	B
	12800	B	-	B	-	B	-	B	-	B	-
	Rem.	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
Cotton	1600	A	A	A	A	A	A	A	A	A	A
	3200	B	B	B	B	B	B	B	B	B	B
	6400	B	B	B	B	B	B	B	B	B	B
	12800	B	-	B	-	B	-	B	-	B	-
	Rem.	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
Denim	1600	A	A	A	A	A	A	A	A	A	A
	3200	B	B	B	B	B	B	B	B	B	B
	6400	B	B	B	B	B	B	B	B	B	B
	12800	B	-	B	-	B	-	B	-	B	-
	Rem.	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH
Terrycot	1600	A	A	A	A	A	A	A	A	A	A
	3200	B	B	B	B	B	B	B	B	B	B
	6400	B	B	B	B	B	B	B	B	B	B
	12800	B	-	B	-	B	-	B	-	B	-
	Rem.	NH	NH	NH	NH	NH	NH	NH	NH	NH	NH

A- none, B- very slight, C- slight, D- moderate, E- severe, F- almost complete, G- complete, H- hole formed, and NH- no hole formed.

Table 5 — Flexing properties of fabric materials

Cycles	Canvas		Terrycot		Cotton		Denim	
	Along-dry	Along-wet	Along-dry	Along-wet	Along-dry	Along-wet	Along-dry	Along-wet
10000	A	A	A	A	A	A	A	A
20000	A	B	A	B	A	B	A	B
30000	A		A		A		A	
40000	B		B		B		B	
50000	B		B		B		B	
60000	B		B		B		B	
70000	B		B		C		B	
80000	C		C		C		C	
90000	C		C		D		C	
100000	C		D		E		C	

A- no effect, B- slight creasing, C- slight pipiness, D- marked creasing, E- severe creasing, F- severe pipiness, G- slight crack, H- marked crack, I- severe crack, and J- complete failure.

and Denim are evaluated using the Bally Method under two conditions: Along-dry and Along-wet. Visual observations of materials' failures over a series of cycles, ranging from 10000 to 150000 cycles, are detailed in Table 5.

The results show that no material failures occur up to 100,000 cycles under both Along-dry and Along-wet conditions, indicating that all tested fabrics possess suitable flexing properties for shoe applications. However, Terrycot, while meeting minimal requirements for replaceable purposes, is less durable than Denim and Canvas, which are more stable in the face of repeated washing cycles.

3.6 Puncture Resistance

Puncture resistance is essential for protective footwear, especially for workers exposed to sharp objects. While puncture resistance is not as critical for everyday footwear, it is a key feature in safety shoes designed for industrial environments². Insoles, whether metal or textile, are incorporated into footwear for added puncture resistance¹⁸. The puncture resistance of textile materials is evaluated using the ISO 20344 method (Table 6).

The results of the puncture test conducted on the textile material samples are shown in Fig. 3. The test includes four types of fabrics: cotton, terrycot, canvas

Table 6 — Puncture resistance of fabric materials

Fabric	Compressive load, N	Compressive extension, mm	Compressive strain, mm/mm	Compressive stress, MPa
Terrycot	44.95	5.42	0.055	0.57
Canvas	73.09	6.47	0.065	0.93
Denim	23.92	6.35	0.065	0.30
Cotton	49.31	6.76	0.065	0.63

and denim. Two samples of each fabric type are tested, resulting in a total of eight specimens. The load versus extension values for these specimens are plotted and presented in Fig. 3

The data shows that Denim has the lowest compressive load (23.92 N), indicating a weaker puncture resistance than other fabrics. Terrycot and Cotton exhibit medium-range values for compressive load 44.95 N and 49.31 N, respectively. Canvas fabrics have the highest compressive load, 73.09 N, demonstrating superior puncture resistance. The greater compressive extension of Canvas is beneficial for use as a shoe internal lining, enhancing durability and providing better foot comfort.

3.7 Impact Strength

Impact resistance or strength refers to the material's ability to withstand sudden or intense force or shock. Foot and leg injuries can result from impacts from falling or rolling objects, crushing force, penetrating materials and various other hazards⁵. The impact resistance components used in footwear should provide the desired level of shielding, especially on the toe and metatarsal regions of the foot of wearers¹⁹. The impact tester equipped with a mass of about 10 kg is allowed to fall freely from a height of 0.8-1.0 m to test the strength of textile material, mainly on the toe cap. The impact energy recorded is about 100 J. Though this test may not be necessary for common-purpose shoes, it is needed to test the impact on textile materials for safety shoes. Hence, impact resistance is a key property essential for safety and protective footwear.

4 Conclusion

This study evaluates the mechanical characteristics of textile fabrics like denim, canvas, cotton and terrycot for their suitability in footwear applications. Among the materials tested, denim and canvas possess superior tensile strength, tear strength, water vapour permeability, and abrasion resistance, especially under repetitive washing cycles. Canvas fabric, in particular, emerges as the ideal choice for shoe-internal applications due to its outstanding

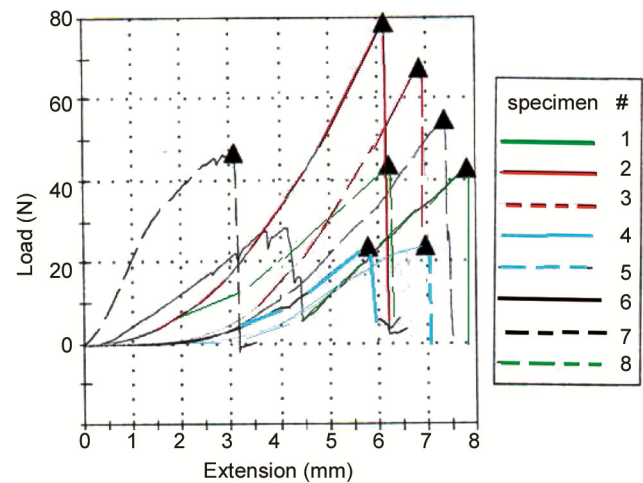


Fig. 3 — Puncture tests for different fabrics [1,8 – Terrycot, 2,3 – canvas, 4,5 – denim, 6,7 – cotton]

physical properties, including superior flexibility, high puncture resistance, and exceptional durability. This study introduces and highlights the concept of replace ability, akin to shoe socks, for day-to-day usage. This innovative approach offers significant benefits to end-users by enhancing foot hygiene and comfort, primarily attributed to the remarkable mechanical properties of Canvas fabric. These findings underscore the potential of Canvas fabric as a game-changing material in developing comfortable, hygienic, and durable footwear solutions.

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