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Sensorial comfort characterisation of cut protective workwear made from metallic core covered yarn

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The aim of this study is to investigate the influence of metallic core-covered yarn fabrics on the sensorial comfort of cut-protective clothing. Here, a 6-end satin weave is selected owing to its tight structure and reduced number of interlacings, which are advantageous for both cut protection and tactile comfort. Metallic core covered yarns with linear densities of 15, 10, and 8 Ne are produced using stainless steel filament as the core, high-performance polyethylene as the outer sheath, and polyester as the inner sheath. Nine hybrid woven fabric samples are then developed using these yarns in a 6-end satin design at three different areal weights: 150, 200, and 250 g/m², woven on a rapier loom. The low-stress mechanical properties of the samples, including tensile, shear, bending, compression, surface friction, and surface roughness, are assessed using the Kawabata Evaluation System to determine their sensory comfort characteristics. The results indicate that areal weight and bulk density exert a significant influence on the tactile properties of metallic core covered yarn fabrics used in cut-protective applications.

Keywords: Bulk density, Cut-resistant fabric, Core-covered yarn, 6-end satin, Sensory comfort

1 Introduction

The development of protective clothing for industrial and occupational environments has traditionally prioritised durability, resistance, and functionality, as safety remains paramount. With the growing demand for protective garments, increasing attention is now directed towards enhancing wearer comfort without compromising safety performance. As individuals place greater emphasis on well-being, security, and quality of life, the clothing industry recognises the need to integrate comfort with effective protection. Protective clothing intended for occupational and environmental hazards must therefore ensure both safety and comfort[1-3]. Such garments play a crucial role in reducing occupational injuries and health risks, and awareness of the need for comfortable, protective apparel continues to rise alongside improvements in social and economic conditions[4,5].

In response to end-user expectations and evolving professional standards, protective gear is increasingly designed to provide enhanced resistance against cut, slash, chemical, heat, and cold hazards, while also improving thermal and tactile comfort[6]. However, existing cut-resistant fabrics often present drawbacks, particularly poor thermal and tactile comfort, as well as complex donning processes. As thermal and tactile comfort directly influence human well-being, their optimisation is essential. Tactile comfort refers to the sensations a fabric produces on the skin—such as prickliness, stiffness, smoothness, or softness—and surface roughness is recognised as a key determinant of how fabric feels to the touch[7]. Sensory comfort is closely linked to fabric surface structure, which governs perceptions such as smoothness, clamminess, prickliness, or coolness. These sensations correspond to measurable properties including the number of contact points, surface fibres, bending stiffness, tensile and shear resistance, surface friction, absorptivity, and moisture behaviour[8]. Sensory perceptions may be pleasant, such as softness or pliability, or unpleasant, such as stiffness, irritation, or scratchiness[9].

Fundamental material characteristics—raw fibre type, yarn structure, fabric construction, and chemical treatments—strongly influence sensory comfort[10-13]. Discomfort in next-to-skin fabrics typically arises

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from either (i) prickling, itching, or tingling sensations, or (ii) wet clinginess when the fabric becomes damp[14,15]. High surface roughness in cut-protective workwear frequently leads to irritation, while inadequate moisture management may result in excessive dampness and stickiness. Since sensory comfort differs between dry and wet states, moisture management plays a crucial role in mitigating discomfort[12]. Numerous studies have examined the relationship between fabric properties—such as fibre protrusion, yarn fineness, fabric thickness, stiffness, and density—and the tactile sensations experienced on the skin[16-20]. Prior work by Cay and Vassiliadis demonstrates that woven fabric density has a significant impact on handle attributes[21] Yan reported that chemically pretreated fabrics exhibit rougher surfaces and reduced comfort compared with untreated fabrics[22]. Ozguney demonstrated that fabrics produced with higher linear density yarns outperform those with lower-density yarns in terms of bending and compression behaviour[23]. Fabrics with smoother, finer fibres typically offer improved flexibility, reduced surface resistance, and better drape[24]. Fibre morphology, particularly in animal fibres, also influences yarn and fabric surface behaviour[25]. Consequently, fibre composition, yarn linear density, yarn structure, and fabric construction are essential parameters for determining cut-protection performance. Improving the sensory comfort of cut-protective fabrics remains a significant challenge that depends on the appropriate selection of raw materials, yarn structures, and fabric designs. Although extensive efforts have been made, fully addressing the sensory comfort of protective fabrics is still an ongoing research need[13,26].

Metallic core covered yarns represent a noteworthy advancement in the fabrication of cut-protective textiles. This approach combines the robustness and cut resistance of metallic fibres with the flexibility and comfort of conventional textile materials. Fabrics made from such yarns offer a unique balance of protection and sensory comfort, addressing both safety requirements and wearer expectations. However, the conductive nature of metallic fibres introduces additional concerns for comfort and safety. While metallic yarns enhance cut resistance, their conductivity may cause discomfort or pose potential risks if not appropriately managed. Hence, strategies to mitigate conductivity-related issues must be considered alongside protective performance in order to effectively assess sensorial comfort. Given these considerations, the aim of this study is to thoroughly characterise the sensory comfort of cut-protective fabrics manufactured using metallic core covered yarns.

2 Materials and Methods

2.1 Materials

2.1.1 Preparation of Core-Covered Yarn

Three types of metallic core-covered yarns were produced using an HKV141 hollow spindle wrapping machine with a constant twist level of 400 m^{-1}. Stainless steel (SS) filament (30–50 μm), polyester (PET; 100D), and high-performance polyethylene (HPPE) filament fibres (200–400D) were selected as raw materials, and their specifications are summarised in Tables 1 and 2. Core-covered yarns are typically constructed by combining two or more fibre threads in a core–wrap structure to achieve the desired functional performance[27].

In this study, SS filament served as the core material owing to its superior cut-resistant characteristics, while PET and HPPE were employed as the inner and outer wrapping layers, respectively. A microscopic image of the metallic core-covered yarn is shown in Fig. 1.

2.1.2 Preparation of Fabrics from Core-Covered Yarn

Nine woven fabric samples (P1–P9) were prepared using the three core-covered yarn types (15 Ne, 10 Ne, and 8 Ne) as both warp and weft yarns. The fabrics were produced on a rapier loom using a 6-end

Table 1— Specifications of high-performance fibres

Filament type	Linear density	Diameter of individual fibre	Number of filaments
SS	85-132D	30-50 μm	1
HPPE	200-400D	20-30 μm	90-180
PET	100D	20 μm	36

Table 2 — Particulars of metallic core-covered yarns

Sample code	Core	Inner layer	Outer layer	Yarn count	Twist direction	Twist, m^{-1}
Y1	SS (30 μm)	PET (100D)	HPPE (200D)	15 Ne	S and Z	400
Y2	SS (40 μm)	PET (100D)	HPPE (300D)	10 Ne	S and Z	
Y3	SS (50 μm)	PET (100D)	HPPE (400D)	8 Ne	S and Z	

satin weave, chosen for its tight structure and minimal interlacements, which enhance cut resistance by limiting blade penetration compared to plain or twill weaves. The weaving design is shown in Fig. 2[28] . The full specifications of the nine fabric samples, including warp and weft yarn counts and thread densities, are given in Table 3.

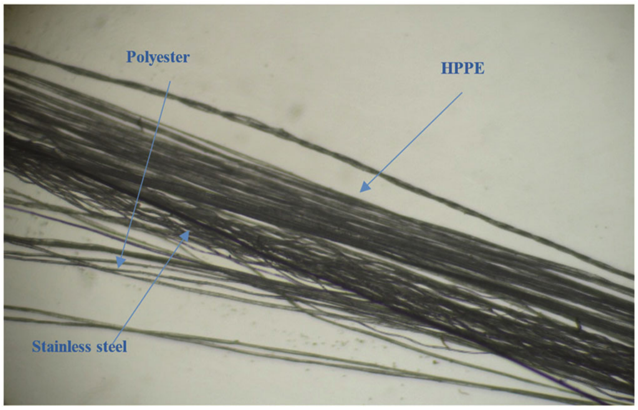

Fig. 1 — Microscopic image of metallic core-covered yarn

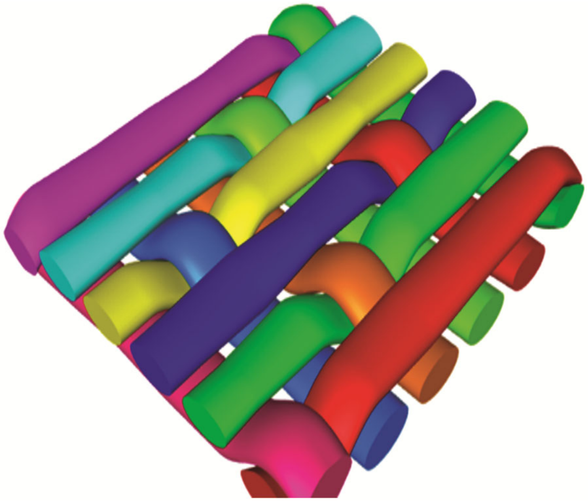

Fig. 2 — Weave design of 6-end satin fabric

2.2 Methods

2.2.1 Physical Properties

The physical properties of each fabric sample were evaluated in accordance with relevant ASTM standards[29,30]. Thread density was measured using a pick glass, and areal density (g/m²) was determined by weighing the samples. Fabric thickness was measured using a digital thickness gauge. Bulk density was calculated from the ratio of areal density to thickness. Porosity was calculated using Eq. 1:

$$\text{Porosity} = 1 - \frac{\text{Fabric density}}{\text{Fibre density}} \quad \ldots (1)$$

Cut resistance was assessed using a Tono-dynamometer (IRSST, Germany) equipped with a straight blade[31]. The test results were interpreted in accordance with the EN 388:2016 + A1:2018 standard, using the ISO 13997 method, as outlined in Table 4.

2.2.2 Sensorial Comfort Properties of the Fabric

Sensorial comfort parameters—including tensile, shear, bending, compression, surface friction, and surface roughness—were evaluated using four modules of the Kawabata Evaluation System for Fabrics (KES-F1, KES-F2, KES-F3, and KES-F4)[32]. Before the evaluation, all specimens (20 cm × 20 cm) were conditioned for 24 h at 25 °C and 70% RH.

2.2.2.1 Tensile and Shear Properties

Tensile and shear properties were measured using the KES-FB1 tester. Tensile behaviour was recorded by applying forces from 0 to 500 gf/cm on specimens of 50 mm × 200 mm. Force–extension and recovery

Table 4 — Cut resistance grading as per ISO 13997 method (EN 388:2016)

Grading	A	B	C	D	E	F
Cut resistance, N	≥2	≥5	≥10	≥15	≥22	≥30

Table 3 — Specifications of core-covered yarn fabrics

Sample code	Yarn material	Warp yarn count, Ne	Weft yarn count, Ne	Warp thread density (ends), inch^{-1}	Warp thread density (picks), inch^{-1}
P1	HPPE/PET/SS	15	15	60	30
P2	HPPE/PET/SS	15	15	60	60
P3	HPPE/PET/SS	15	15	60	90
P4	HPPE/PET/SS	10	10	40	20
P5	HPPE/PET/SS	10	10	40	40
P6	HPPE/PET/SS	10	10	40	60
P7	HPPE/PET/SS	8	8	30	20
P8	HPPE/PET/SS	8	8	30	35
P9	HPPE/PET/SS	8	8	30	50

curves were obtained for both warp and weft directions. Shear properties were evaluated at a shear angle of 8° under rotational deformation. Since garments undergo frequent shear deformation during body movement, these measurements provided insight into fabric performance during wear. Twenty replicates were tested for each specimen, and mean values were reported.

2.2.2.2 Bending Properties

Bending behaviour was assessed using the KES-FB2 tester. Bending rigidity (B) and bending hysteresis (2HB) were measured to determine the fabric's resistance to bending and its recovery ability. Specimens measuring 200 mm × 10 mm were subjected to rotational bending deformation within ±2.5 cm^{-1} curvature. The test provided pair-convex bending characteristics, and the recorded data reflected the ease with which the fabric bent under applied loads.

2.2.2.3 Compression Properties

Compression properties, including compressional resilience, work of compression, and thickness under load, were measured using the KES-FB3 tester. A pressure of 50 gf/cm^2 (4.9 kPa) was applied through a pressure plate acting as the probe. Twenty measurements were performed for each sample, and average values were calculated.

2.2.2.4 Surface Friction and Roughness Properties

Surface friction and roughness were assessed using the KES-FB4 surface tester. Measurements were taken at three different locations on each specimen. The coefficient of friction (MIU) was computed by averaging the values obtained over a 0–20 mm range using an integrator. In the second mode of operation, a 10 gf-loaded probe traversed the fabric surface to record vertical displacement, representing surface roughness. Measurements were taken in both warp and weft directions, and values for friction and roughness were recorded separately.

3 Results and Discussion

3.1 Physical Properties

The physical characteristics of the woven fabric samples are presented in Table 5, while the corresponding thread densities in the warp and weft directions are given in Table 3. Among the samples, P4 and P7 exhibit the highest porosity, whereas P3 displays the lowest. This trend is closely associated with bulk density. A lower bulk density indicates a greater proportion of voids within the fabric structure, resulting from the reduced mass per unit volume. Larger inter-fibre or inter-yarn gaps allow more air to be entrapped, resulting in higher porosity. Conversely, porosity decreases as bulk density increases, confirming earlier reports that greater bulk density is associated with reduced porosity[33,34].

Higher porosity also affects tactile comfort, influencing softness, drape and skin interactions. Fabrics with greater porosity generally feel softer because the entrapped air provides a cushioning effect, reducing perceived stiffness. Porosity additionally improves drape behaviour by enabling the fabric to conform more naturally to body contours. Such fabrics may also be more suitable for individuals with sensitive skin, owing to the reduced friction compared with denser materials.

According to the EN 388:2016 standard, samples P5, P6, P8, and P9 achieve a cut resistance level of E; P4 and P7 achieve a Level of D; and P1, P2, and P3 exhibit a Level of C. This distribution can be explained by areal density and thickness. Fabrics with higher areal density incorporate more yarn per unit area, enhancing structural integrity. These fabrics also tend to be thicker and denser, creating additional layers that hinder blade penetration. As demonstrated

Table 5 — Physical properties of woven fabric samples

Sample code	Areal density, g/m^2	Cut-resistance grade	Thickness, mm	Bulk density, kg/m^3	Porosity
P1	150	C	0.57	263.16	0.974
P2	200	C	0.58	344.83	0.966
P3	250	C	0.56	446.43	0.956
P4	150	D	0.71	211.27	0.979
P5	200	E	0.78	256.41	0.975
P6	250	E	0.73	342.47	0.966
P7	150	D	0.70	214.29	0.979
P8	200	E	0.77	259.74	0.975
P9	250	E	0.87	287.36	0.972

previously, increased areal mass and thickness typically improve cut resistance[35].

3.2 Sensorial Comfort Properties of Cut protective Fabric

3.2.1 Tensile Properties

Cut-resistant performance in protective clothing can be improved by enhancing tensile behaviour, enabling the fabric to absorb external impact energy. Tensile characteristics are therefore vital in determining fabric response under low-stress conditions[36]. The tensile strain (EM), which denotes low-stress extensibility, is consistently higher in the warp direction than in the weft for all samples [Fig. 3(a)]. This arises from yarn orientation during weaving, where warp yarns are subjected to greater tension, resulting in straighter, more aligned yarns that elongate more readily when stretched. Among the samples, P4 exhibits the highest EM, while P3 shows the lowest. Higher EM values indicate increased wear comfort and are influenced by bulk density. P3, having the highest bulk density, demonstrates reduced extensibility due to its compact structure, while P4, with lower bulk density, exhibits greater strain.

The linearity of tensile behaviour (LT), an indicator of fabric extensibility in the initial strain region, is higher for sample P3 owing to its compact structure [Fig. 3(b)]. Fabrics with higher bulk density contain more uniformly distributed fibres, which promote linear deformation due to reduced structural irregularity. LT, WT (tensile energy), and RT (tensile resilience) are all higher in the warp direction [Fig. 3 (c)–(d)], again due to the pre-tensioned and structurally stabilised warp yarns. Samples with higher bulk density show greater tensile strength and resilience, suggesting enhanced strength and durability.

3.2.2 Shear Properties

Shear deformation occurs routinely during garment use as fabric adapts to complex body movements. The ability to undergo such deformation without loss of integrity is therefore essential.

Samples with higher bulk density demonstrate greater shear rigidity [Fig. 4(a)] due to increased fibre packing, which restricts movement and enhances stiffness. The warp and weft yarn flexibility, together

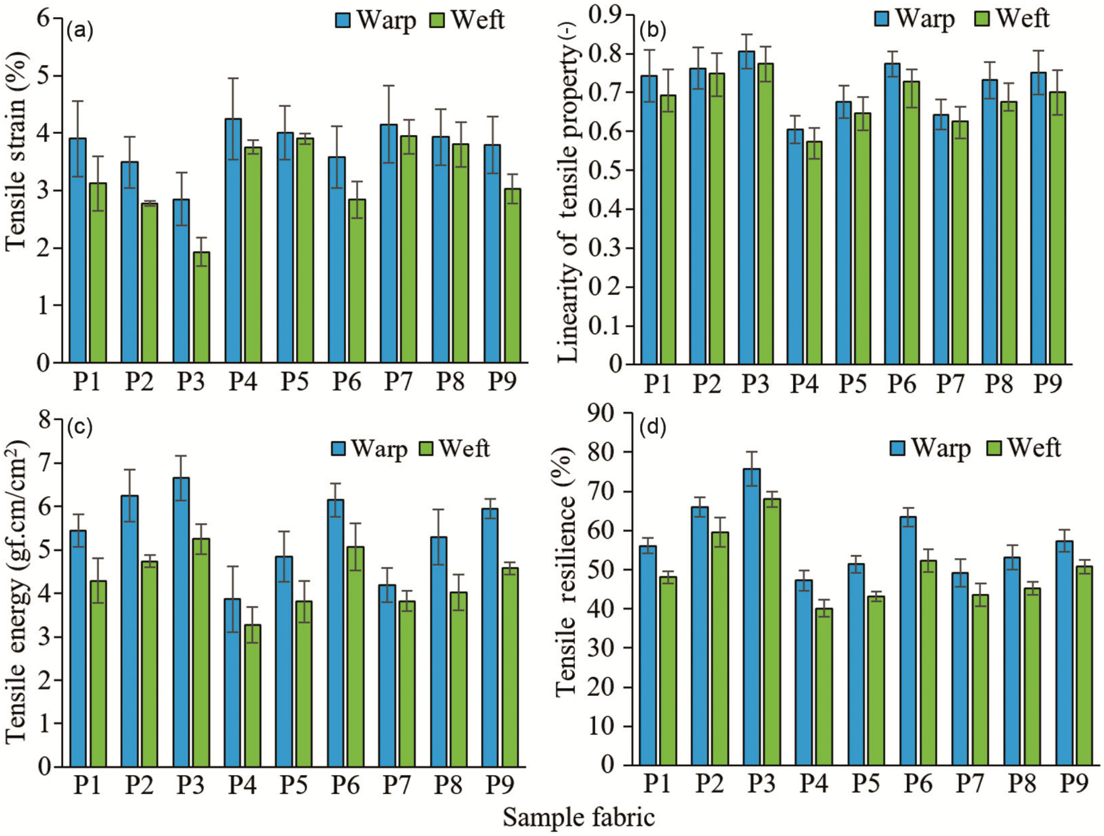

Fig. 3 — Tensile properties of cut protective fabrics (a) tensile strain, (b) linearity of tensile property, (c) tensile energy and (d) tensile resilience

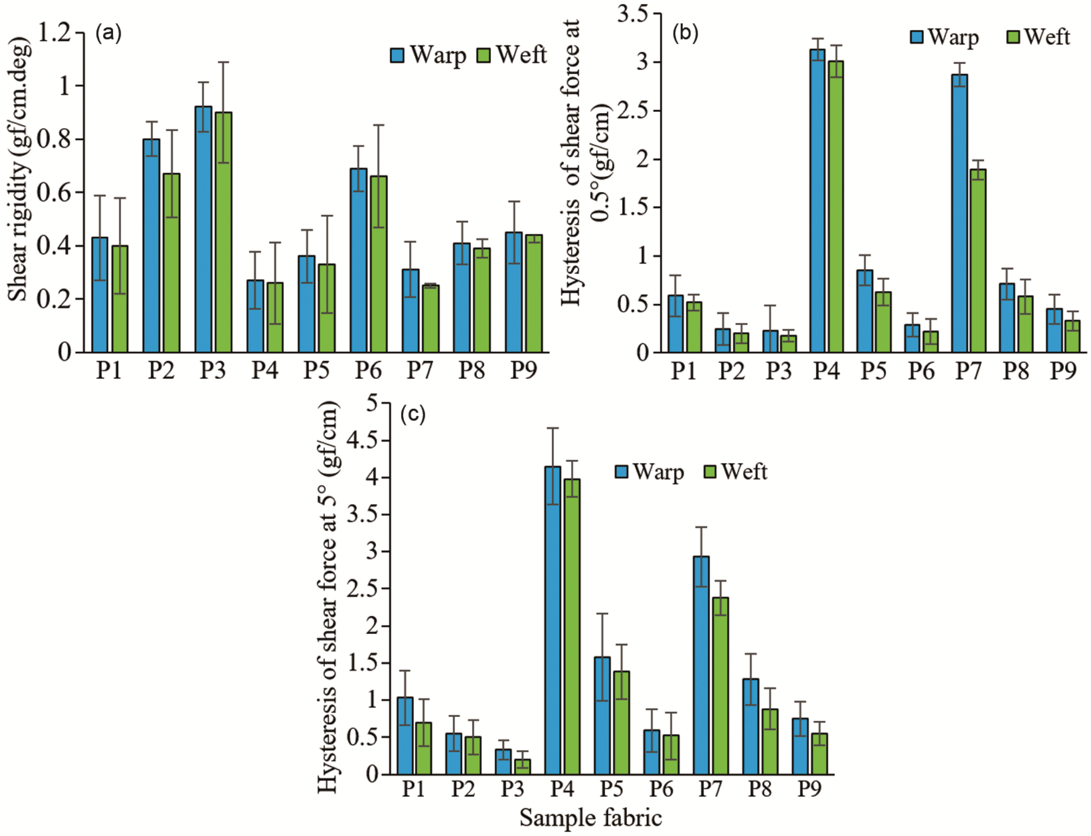

Fig. 4 — Shear properties of cut protective fabrics (a) shear rigidity, (b) shear hysteresis at 0.5° and (c) shear hysteresis at 5°

with yarn density, also significantly influence shear rigidity[37]. Sample P3, with the highest bulk density and closely packed yarns, demonstrates the highest G value.

The shear hysteresis values (2HG and 2HG5) represent energy losses during deformation [Fig. 4(b) and 4(c)]. These values are highest for P4, which has a lower bulk density and a more open structure. Fabrics with greater inter-fibre spacing deform more readily and thus exhibit higher hysteresis. All samples show greater G, 2HG and 2HG5 in the warp direction, attributed to the higher tension and structural stability of warp yarns.

3.2.3 Bending Properties

Bending behaviour plays a significant role in determining the comfort and performance of cut-protective clothing. The bending rigidity (B) reflects the perceived stiffness of a fabric; higher values indicate a stiffer material, whereas lower values correspond to a softer and more flexible structure. The bending moment hysteresis (2HB) represents the fabric's ability to recover from bending deformation.

The bending properties are strongly influenced by bulk density. Fabrics with higher bulk density generally exhibit greater thickness and structural compactness, which increases their resistance to bending. The tightly packed fibres or yarns in such fabrics contribute to increased internal friction during deformation. This higher internal friction leads to enhanced energy dissipation when the fabric is bent, resulting in greater bending hysteresis. Moreover, a higher content of stainless-steel yarns per unit area—associated with increased bulk density—further contributes to both bending rigidity and bending hysteresis.

As shown in Fig. 5(a) and 5(b), sample P3, which possesses the highest bulk density, exhibits the greatest values of B and 2HB. This confirms that denser fabrics are stiffer and display greater resistance to bending deformation compared with less compact structures.

For all samples, the values of bending rigidity and bending hysteresis are higher in the warp direction than in the weft direction. This directional difference arises because warp yarns are held under greater

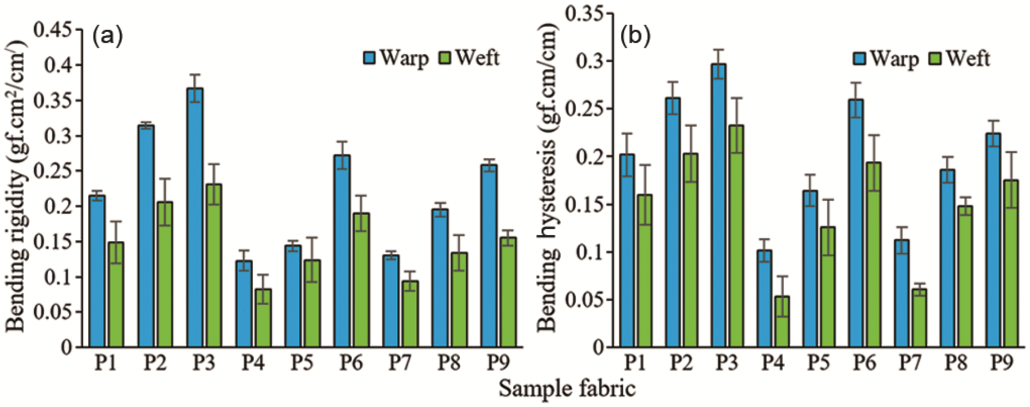

Fig. 5 — Bending properties of cut protective fabrics (a) bending rigidity and (b) bending hysteresis

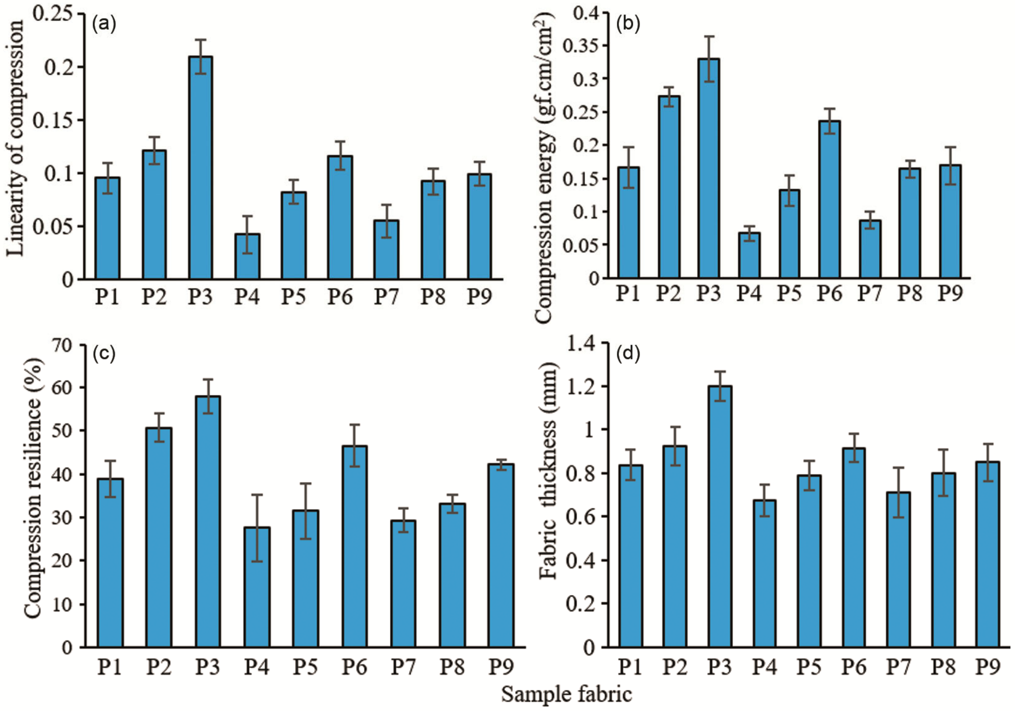

Fig. 6 — Compression properties of cut protective fabrics (a) linearity of compression, (b) compression energy, (c) compression resilience and (d) fabric thickness

tension during weaving, anchoring them more firmly within the structure. Consequently, they offer more resistance to bending and exhibit greater energy loss during recovery.

3.2.4 Compressional Characteristics

The compressional behaviour of a fabric is governed by its structural configuration and the compressional response of the warp and weft yarns. Fabric thickness is one of the most significant parameters because it reflects the extent of compression, thermal insulation potential, weight, and stiffness during use. The fabric's density and the compressional properties of the constituent yarns strongly influence the linearity of compression (LC)[38]. The combination of LC and total compression determines the compressional energy (WC).

As shown in Fig. 6(a) and 6(b), sample P3, which exhibits the highest bulk density, demonstrates the greatest values of LC and WC. Fabrics with higher bulk density typically show lower compressibility because the fibres and filaments are more tightly packed. This compact structure restricts fibre mobility under pressure, resulting in a more linear compression response. Conversely, fabrics with lower bulk density offer greater freedom for fibre movement and rearrangement, producing a more non-linear compression behaviour.

WC is similarly influenced by bulk density. Dense fabrics contain fewer voids and therefore resist deformation more strongly, requiring greater energy to achieve a given level of compression. This trend is also reflected in compression resilience (RC), as shown in Fig. 6(c), where sample P3 again displays the highest values. A higher density corresponds to a greater number of fibres within a given area, enhancing structural resistance to compression and improving recovery after load removal.

Fabric thickness (T), illustrated in Fig. 6 (d), is also greatest for sample P3. The tighter weave and reduced inter-fibre spacing associated with higher density contribute to increased structural solidity, resulting in thicker overall fabric.

3.2.5 Surface Characteristics

Surface characteristics play a pivotal role in determining the sensory response of the human body to textile materials. Attributes such as comfort, handle, and appearance are closely associated with surface properties. The coefficient of friction (MIU) indicates the perceived smoothness or roughness when the fabric surface is touched; its value ranges from 0 (completely smooth) to 1 (extremely rough). The degree of fluctuation in friction (MMD) and the surface geometrical roughness (SMD) further describe the tactile interaction between fabric and skin. These parameters are influenced by structural factors such as yarn type, fabric construction, and applied chemical treatments[39].

As shown in Fig. 7 (a) and 7(b), fabrics with higher bulk density exhibit higher values of MIU and MMD. Dense fabrics possess a reduced surface area per unit mass, increasing the effective contact area between the fabric and another surface. This increase in contact area typically leads to higher frictional forces, resulting in elevated MIU values. Similarly, the increased rigidity associated with higher density may produce more consistent frictional contact, contributing to higher MMD values.

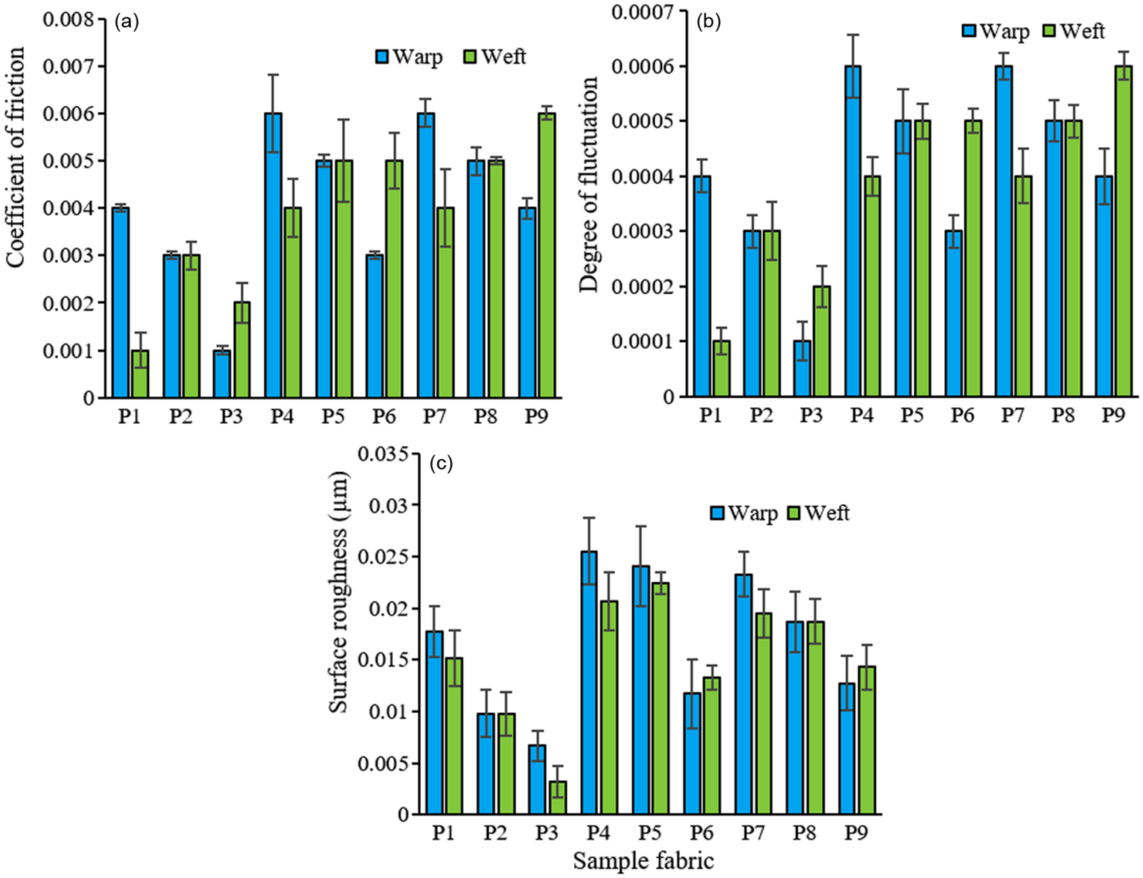

Fig. 7 — Surface properties of cut protective clothing (a) coefficient of friction, (b) degree of fluctuation in friction and (c) surface roughness

Surface roughness (SMD) behaves differently. The geometrical surface irregularities are lower in fabrics with greater bulk density, as shown in Fig. 7(c). The more compact weave reduces the presence of gaps or protruding fibres, creating a smoother and more uniform surface. Consequently, higher-density fabrics have reduced SMD values, indicating lower physical roughness. This trend is consistent in sample P3, which shows lower MIU, MMD, and SMD values in the weft direction compared with the warp. This directional variation can be attributed to differences in yarn tension during the weaving process. Higher bulk density fabrics, therefore, tend to exhibit smoother surfaces and reduced friction, owing to their compact structure and diminished void spaces.

4 Conclusion

This study characterises the sensory comfort and mechanical behaviour of cut-protective woven fabrics developed using metallic core-covered yarns. The findings demonstrate that bulk density plays a decisive role in governing the physical, mechanical, and surface properties of the fabrics. Fabrics with higher bulk density exhibit lower porosity, greater structural compactness, and enhanced cut resistance, while also showing increased rigidity and reduced compressibility. These attributes contribute to superior mechanical stability but may influence tactile comfort due to increased thickness and stiffness. The low-stress mechanical analyses reveal that higher bulk density fabrics possess greater tensile, shear, bending, and compressional resistance, resulting from the closer packing of fibres and higher metal content within the structure. Conversely, fabrics with lower bulk density present improved extensibility and reduced resistance to deformation, which may enhance wearer comfort during movement. Surface evaluations indicate that denser fabrics tend to exhibit smoother surfaces with reduced geometric roughness, although their frictional properties may vary depending on yarn orientation. These insights support the rational design and optimisation of protective clothing that balances cut resistance with wearer comfort, addressing the evolving needs of occupational users.

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References

1 Holmer I, *Ind Health*, 44 (2006) 413.
2 Gagge A P & Gonzalez R R, *Environ Res*, 7 (1974) 242.
3 Hatch K L, Woo S S, Barker R L, Radhakrishnaiah P, Markee N L & Maibach H I, *Text Res J*, 60 (1990) 412.
4 Mao L, Yu H, Yao L, Shen Y, Yan X & Ma Y, *Material Des*, 237 (2024) 13.
5 Tian L, Shi J, Chen H, Huang X & Cao H, *J Text Ins*, 113 (2022) 1467.
6 Rajput B, Mahesh N, Rathour R, Das T, Ray B, Das A & Talukdar P, *J Text Ins*, 115 (2022) 227.
7 Kamalha E, Zeng Y, Mwasiagi J I & Kyatuheire S, *J Sen Studies*, 28 (2013) 444.
8 Umbach K H, *Environmental Ergonomics*, *Taylor & Francis*, (1988)138.
9 Demiryurek O & Uysaltruk D, *Text Res J*, 83 (2013) 1753.
10 Das A, Kothari V K & Balaji M, *J Text Ins*, 98 (2007) 376.
11 Nawaz N, Troynikov O & Watson C, *Phys Proceed*, 22 (2011) 486.
12 Özdemir H, *Autex Res J*, 17 (2017) 141.
13 Subham, Rathour R, Das A & Alagirusamy R, *J Text Ins*, 115 (2023) 812.
14 Mattila H, *Woodhead Publishing*, (2006).
15 Wang Y, Zhang Z & Li J, *J Text Ins*, 104 (2013) 540.
16 Bensaid S, Osselin J F, Schacher L & Adolphe D, *J Text Ins*, 97 (2006) 145.
17 Bishop D P, *Text Topics*, 26 (1996) 62.
18 Du Z & Yu W, *Measurement Sci Tech*, 18 (2007) 3554.
19 Jeguirim S E G, Dhouib A B, Sahnoun M, Cheikhrouhou M, Njeugna N, Schacher L & Adolphe D, *J Sens Studies*, 25 (2010) 215.
20 Kayseri G Ö, Özdil N & Mengüç G S, *Intech Open*, (2012).
21 Cay A & Vassiliadis S, *Inter Sympos Novel Text*, (2006) 1.
22 Yan K, Höcker H & Schäfer K, *Text Res J*, 70 (2000) 738.
23 Ozguney A T, Özçelik G, Unal P G & Ozerdem A, *Teks ve Konf*, 19 (2009) 113.
24 Behera B K & Mishra R, *Indian J Fibre Text Res*, 32 (2007) 79.
25 Supuren G, Ozdil N, Leskovsek M & Demsar A, *Fibre Society Spring Conference*, (2010).
26 Sular V & Okur A, *J Sens Studies*, 22 (2007) 16.
27 Elmogahzy Y, *Indian J Fibre Text Res*, 31 (2006) 159.
28 Limeneh D Y, Ayele M, Tesfaye T, Liyew E Z & Tesema A F, *J Nat Fibre*, 19 (2022) 4855.
29 Rathour R, Das A & Alagirusamy R, *J Text Ins*, 114 (2022) 1346.
30 Rathour R, Krishnasamy J, Das A & Alagirusamy R, 53 (2023) 20.
31 EN ISO 13997:1999 -Protective clothing-mechanical properties-determination of resistance to cutting by sharp objects.
32 Kawabata S & Niwa M, *J Text Ins*, 80 (1989) 50.
33 Das A, Alagirusamy R & Kumar K P, *Autex Res J*, 11 (2011) 60.
34 Houshya S, Padhye R & Nayak R, *Fibre Polym*, 18 (2017) 389.
35 Ertekin M & Ertekin G, *J Text Ins*, 111 (2020) 163.
36 Xuhong M, Xiangyong K & Gaoming J, *J Ind Text*, 43 (2013) 301.
37 Nayak R, Nayak R K, Punj S K & Chatterjee K N, *Indian J Fibre Text Res*, 34 (2009) 128.
38 Mukhopadhyay A, Dash A K & Kothari V K, *Int J Cloth Sci Tech*, 14 (2002) 99.
39 Ajayi J O, *Text Res J*, 62 (1992) 93.