Influence of wet thermal treatment on the performance of three-dimensional weft-knitted fabrics intended for personal protective equipment applications

DOI: 10.35530/IT.077.03.2025154

CRISTINA GROSU
MIRELA BLAGA
RODICA HARPA
DANIELA FĂRÎMĂ
MIHAI PENCIUC
ANA RAMONA CIOBANU
MIHAELA PERDEVARĂ

ABSTRACT – REZUMAT

Influence of wet thermal treatment on the performance of three-dimensional weft-knitted fabrics intended for personal protective equipment applications

This study evaluates the influence of wet thermal treatments (washing and steaming) on the structural, comfort, and functional properties of a set of twelve three-dimensional weft-knitted fabrics, all based on a sandwich configuration with identical cotton outer layers and a polyester monofilament binding yarn. The experimental design considered three machine set-up stitch cam divisions NP (13, 12, 11) corresponding to loose, medium and highly compact fabric structures and four binding ratios of the monofilament yarn (1:1; 1:3; 1:7; 1:15). Mass, thickness, and stitch density were measured before and after the wet thermal treatment, while air and water-vapour permeability, bursting strength, abrasion resistance, and dimensional behaviour were determined on the finished fabrics, according to relevant standards. Results showed that mass and stitch density increased, while thickness generally decreased after wet thermal stabilisation. For the finished fabrics, abrasion resistance and bursting strength increased with the monofilament binding ratio, reaching up to 15,000 cycles and 590 kPa, respectively, while air permeability showed an inverse trend, decreasing to approximately 1,000 L/m^2/s for the most compact variants. These findings highlight the role of the binding ratio and stitch cam division of the knitting machine in defining the trade-off between comfort and protective performance. Overall, the investigated fabrics exhibit a balanced structural and functional behaviour, indicating their suitability as constituent layers for Category II PPE, such as gloves, workwear, jackets and vests, where mechanical durability and breathability are required.

Keywords: *sandwich knitted fabrics, wet thermal treatment, structural parameters, comfort, dimensional stability, workwear, PPE applications*

Influența tratamentului de finisare umido-termic asupra performanțelor tricoturilor 3D destinate echipamentelor individuale de protecție

Acest studiu evaluează influența tratamentului de finisare umido-termic (spălare și aburire) asupra proprietăților structurale, de confort și funcționale ale unui set compus din 12 tricoturi tridimensionale (3D) din bătătură, având o configurație tip sandwich, cu straturile exterioare din bumbac, conectate între ele cu ajutorul unui fir monofilamentar din poliester. Tricoturile au fost realizate prin varierea a doi parametri tehnologici și structurali: adâncimea de buclare (NP = 13, 12, 11), corespunzătoare structurilor cu compactitate scăzută, medie, ridicată și raportul de legare al firului monofilamentar (1:1; 1:3; 1:7; 1:15). Masa, grosimea și desimea tricotului au fost măsurate înainte și după tratamentul umido-termic, în timp ce permeabilitatea la aer și la vapori de apă, rezistența la plesnire, rezistența la abraziune și stabilitatea dimensională, au fost evaluate pentru tricoturile în stare finisată. Rezultatele au evidențiat o creștere a masei și a desimii tricotului, în timp ce grosimea a prezentat o tendință generală de scădere ca urmare a aplicării tratamentului umido-termic. Rezistența la abraziune și rezistența la plesnire au crescut odată cu raportul de legare al monofilamentului, ajungând până la 15.000 de cicluri și, respectiv, 590 kPa, în timp ce permeabilitatea la aer a prezentat o tendință inversă, scăzând la aproximativ 1.000 L/m^2/s pentru structurile cele mai compacte. Aceste rezultate evidențiază rolul raportului de legare și al adâncimii de buclare în armonizarea performanțelor de protecție cu cerințele de confort. În ansamblu, tricoturile 3D investigate prezintă un comportament structural și funcțional echilibrat, confirmând aplicabilitatea lor ca materiale cu rol activ de protecție în configurația EIP de Categoria II, cum ar fi mănuși, îmbrăcăminte de lucru, jachete și veste, unde sunt necesare atât durabilitatea mecanică, cât și respirabilitatea.

Cuvinte-cheie: *tricoturi stratificate, tratament umido-termic, parametri de structură, confort, stabilitate dimensională, echipamente de lucru, echipamente individuale de protecție*

INTRODUCTION

Personal protective equipment (PPE) represents a crucial component in ensuring safety and occupational health in industrial environments. The design of PPE materials has progressively evolved from rigid, heavy, and low-comfort structures to advanced textile systems capable of providing both mechanical protection and physiological comfort. Among such textile systems, three-dimensional knitted fabrics are playing an increasingly important role due to their structural versatility, conformability, and the possibility of engineering multilayer configurations that meet diverse protection requirements. Previous studies of the authors have also explored the use of these fabrics for vibration damping and protective applications, highlighting the relationship between their structural design and functional performance [1, 2].

In recent years, sandwich or spacer knitted fabrics have been widely studied for use in PPE applications, particularly in gloves, protective garments and cushioning layers. Their three-dimensional architecture, composed of two outer knitted layers connected by monofilament or multifilament binding yarns, enables the creation of lightweight, breathable, and mechanically resilient materials [3, 4]. The ability to tune their structural parameters, such as the binding ratio and stitch cam depth setting, offers a significant advantage in controlling mass, thickness, porosity and consequently the comfort and protection levels.

While numerous studies have investigated the mechanical and comfort-related performance of technical knitted fabrics in their finished state, comparative analyses assessing fabric properties before and after wet thermal stabilisation treatments remain limited [5]; a systematic correlation between wet thermal stabilisation and structural rearrangements in three-dimensional knitted structures intended for PPE applications has not been extensively reported. Unlike conventional finishing processes, these treatments are not designed to enhance surface appearance or handle, but to stabilise the knitted structure by releasing the residual stresses generated during knitting. Understanding how technological parameters such as the binding ratio and stitch cam depth setting affect the properties of stabilised fabrics is essential for designing reliable, high-performance materials.

The present study aims to investigate the effect of wet thermal stabilisation on the structural, comfort, and functional properties of three-dimensional weft-knitted fabrics designed for PPE applications. These materials are evaluated in accordance with the general framework established by Regulation (EU) 2016/425 [6] on PPE and the essential performance requirements specified in EN ISO 13688:2013+A1:2021 [7], which define criteria for ergonomics, comfort, innocuousness, and mechanical robustness of protective textiles. By analysing twelve variants differing in binding ratio and stitch cam depth setting, this work seeks to identify how these technological parameters influence the balance between mechanical resistance, permeability, and dimensional behaviour. The results provide a framework for selecting and engineering knitted fabrics suitable for inclusion as constituent layers in Category II PPE, such as gloves, workwear, jackets, and vests.

MATERIALS AND METHODS

Knitted fabrics

Twelve three-dimensional weft knitted fabrics were produced on a flat knitting machine, each consisting of two identical cotton outer layers (100% cotton, Nm 50/1×2) interconnected by an inner high-tenacity polyester monofilament binding yarn (5.5 cN/dtex) with a diameter of 0.10 mm.

The binding yarn (E-SPACE®) was especially developed by the Monosuisse company as an alternative to conventional polyurethane foam fillings in three-dimensional textile structures, providing high elastic recovery, reduced weight, enhanced breathability and effective structural reinforcement of the new architecture [8]. Two technological variables were controlled: (i) the monofilament binding ratio (four levels, coded A–D) and (ii) the stitch cam depth setting (three levels: 13, 12 and 11, corresponding to loose, medium and highly compact structures, coded 1–3). The binding yarn setting was kept constant across all variants (table 1). For clarity, codes A1-D3 refer to the unfinished fabrics, while the suffix (F) denotes the corresponding fabrics after wet thermal treatment (washing and steaming), applied as a structural stabilisation stage.

Table 1

KNITTED FABRICS CODING

Binding ratio	Stitch cam division (N.P.)	Knitted fabric code	
		Untreated fabric	Treated fabric
1:1	13	A1	A1 (F)
	12	A2	A2 (F)
	11	A3	A3 (F)
1:3	13	B1	B1 (F)
	12	B2	B2 (F)
	11	B3	B3 (F)
1:7	13	C1	C1 (F)
	12	C2	C2 (F)
	11	C3	C3 (F)
1:15	13	D1	D1 (F)
	12	D2	D2 (F)
	11	D3	D3 (F)

Wet thermal treatment

The wet thermal treatment was applied as a structural stabilisation stage after knitting, using a domestic-type manual procedure [9], in accordance with the general principles described in EN ISO 3759:2008 [10] and EN ISO 6330:2022 [11]. The washing sequence consisted of the following steps: ***soaking*** in a warm water bath at (30–40)°C for 60 min, with a liquor ratio of 1:30 and a detergent concentration of 3 g/L, followed by ***washing*** under gentle manual agitation, at 40±2°C for 15 min. A commercially available manual laundry detergent intended for delicate white and coloured textiles (Savex®) was used, selected for its mild formulation based on anionic surfactants and the absence of bleaching agents or aggressive finishing additives, to minimise any chemical influence on the structural behaviour of the knitted fabrics. After draining the washing bath, the specimens were subjected to five consecutive ***rinsing*** cycles in clean water, using a liquor ratio of 1:50. Rinsing was carried out at an initial water temperature of 40°C for 3 min per cycle, followed by repeated rinsing with gradual cooling of the water. Excess water was removed by gentle manual pressing without wringing. The samples were then ***dried*** flat on a horizontal surface until constant mass was achieved. After drying, the fabrics were first subjected to a steaming step to ensure controlled ***re-moistening*** of the structure, followed by ***ironing*** using a steam iron at approximately 200°C, corresponding to the recommended temperature for cotton fabrics. The treated panels were subsequently relaxed under standard atmospheric conditions for 24 hours before dimensional measurements. This treatment sequence ensured the effective release of residual stresses and the structural stabilisation of the knitted fabrics before further testing.

RESULTS AND DISCUSSIONS

The experimental design primarily focused on identifying the influence of the wet thermal treatment on the defining structural parameters of the three-dimensional weft knitted fabrics (i.e. fabric mass, fabric thickness and stitch density). Comfort and function-related properties (i.e. air permeability, dimensional behaviour, abrasion resistance, bursting strength and deformation) were subsequently assessed on the wet thermal-stabilised fabrics, as this condition represents the intended and relevant state for PPE-oriented performance assessment.

The influence of wet thermal treatment on structural parameters

Influence on fabric mass

The mass per unit area of the knitted fabrics [12] generally increased after wet thermal treatment, indicating a densification of the loop structure associated with the release of internal stresses generated during knitting. For the treated fabrics, mass values ranged from approximately 270 to 640 g/m^2, depending on the stitch cam division and the monofilament binding ratio. This increase followed a consistent trend across all fabric groups, with higher mass values recorded for lower stitch cam divisions (NP 11) and higher binding ratios (groups C and D). For instance, variants knitted at NP = 11 showed post-treatment masses above 440 g/m^2, reaching up to 642 g/m^2 for D3 (F), whereas looser structures (NP=13) generally remained below 430 g/m^2. The mass growth is mainly attributed to structural compaction occurring during the combined washing and steaming process, which resulted in shorter loop lengths and a more cohesive fabric surface. Only two exceptions were recorded, variants A1 and B1, where the mass decreased slightly after treatment (from 294 to 273 g/m^2 and from 278 to 268 g/m^2, respectively). These variants also exhibited among the highest extension values in the wale direction after stabilisation, leading to a looser configuration and consequently, to a reduction in surface mass (figure 1). From an application perspective, the resulting mass range remains compatible with flexible PPE components, where sufficient surface mass is required to ensure mechanical robustness, while maintaining conformability and ergonomic comfort.

Influence on fabric thickness

As shown in figure 2, the thickness response to wet thermal treatment [13] depended strongly on the structural parameters. Most fabric variants exhibited a moderate decrease in thickness, from initial values ranging between 2.75 and 5.67 mm for untreated fabrics to a narrower range of 2.04 to 4.00 mm after wet thermal treatment, indicating a consolidation of the sandwich architecture. This behaviour is attributed to a partial collapse of the sandwich structure, which promoted closer contact between the outer layers and the monofilament binding yarn, resulting in a reduction of the overall fabric height. For variants produced with a higher stitch cam division (NP 13), a pronounced thickness reduction was observed after treatment, reflecting the relaxation and rearrangement of initially looser loop structures. In contrast, fabrics with higher monofilament binding ratios (groups C and D) retained comparatively greater thickness due to stronger internal reinforcement, confirming the stabilising effect of an increased number of monofilament connections. From an application perspective, the resulting thickness interval of the stabilised fabrics remains suitable for flexible PPE components, where moderate thickness is required

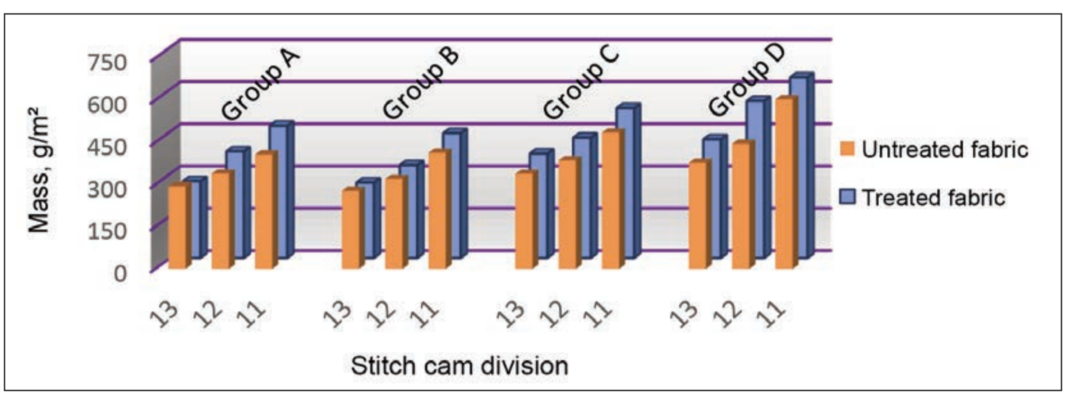

Fig. 1. Fabric mass per unit area (g/m^2) before and after wet thermal treatment

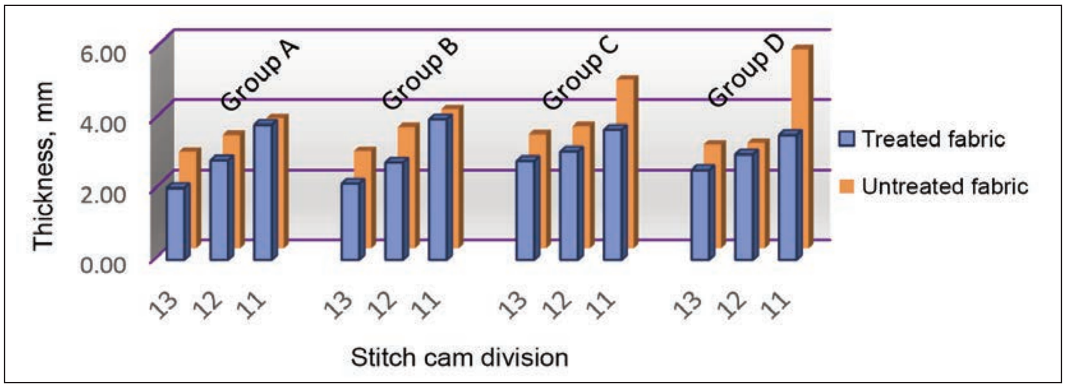

Fig. 2. Fabric thickness (mm) before and after wet thermal treatment

to provide mechanical support and durability while preserving conformability and ergonomic comfort.

Influence on fabric stitch density

Stitch density was determined according to EN 14971 [14], both before and after wet thermal treatment, in order to quantify the degree of structural compactness and the dimensional rearrangement of the knitted fabrics. After wet thermal treatment, stitch density increased in both wale and course directions, reflecting the contraction of the knitted structure during stabilisation. For the treated fabrics, stitch density values ranged approximately from 970 to over 2100 stitches/5 cm^2, depending on the stitch cam division and the monofilament binding ratio. This increase followed a consistent pattern and was more pronounced in fabrics knitted with the smallest stitch cam division (NP = 11), compared to those knitted at NP = 12 or NP = 13. The reduced cam depth results in shorter loop lengths and inherently higher compactness, which amplifies the dimensional contraction occurring during wet thermal stabilisation. The combined increase in mass per unit area and stitch density confirms the effective structural stabilisation of the knitted fabrics after wet thermal treatment, which is essential for ensuring uniformity and reproducibility in technical and protective textile applications, where dimensional stability and mechanical integrity are required without excessively compromising flexibility (figure 3).

Comfort properties of wet thermal-treated fabrics

Air permeability after wet thermal treatment

The air permeability of the wet thermal-treated fabrics exhibited a systematic decrease in air flow rate with increasing structural compactness, primarily governed by the stitch cam division and the monofilament binding ratio. Fabrics knitted at NP = 13 (loose setting) recorded the highest air flow rates, exceeding 2000 L/m^2/s, whereas those produced at NP = 11 (compact setting) showed values close to 1000 L/m^2/s. Within each stitch cam division, air permeability decreased progressively from group A (binding ratio 1:1) to group D (binding ratio 1:15), as higher binding ratios involve an increased number of monofilament connections and a denser inner layer (figure 4). The reduced permeability observed in the stabilised fabrics indicates that the increased number and length of monofilament connections between the outer layers lead to a reduction in effective pore size, thereby restricting air passage through the three-dimensional structure. This behaviour is consistent with previously reported trends in multilayer knitted structures, where increased loop compactness and reduced inter-yarn spacing result in lower air permeability [3, 15, 16]. Despite this reduction, the measured permeability values remain within ranges compatible with PPE applications requiring a balance between

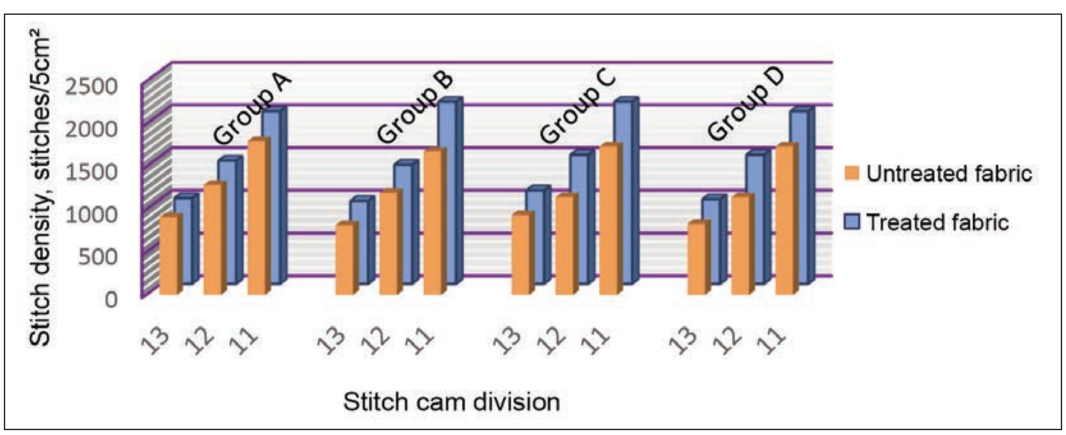

Fig. 3. Stitch density of the fabric (stitches/5 cm^2) before and after wet thermal treatment

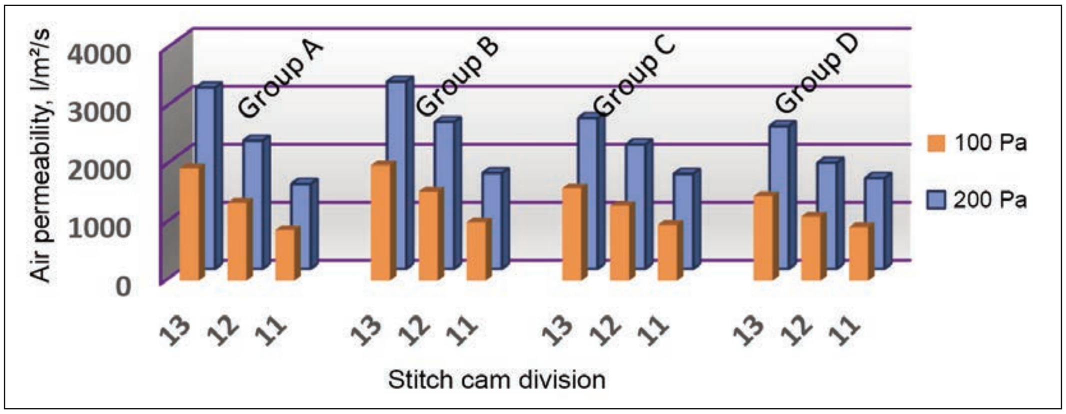

Fig. 4. Air permeability (L/m^2/s) of the wet thermal-treated fabrics

breathability and mechanical integrity, such as gloves and workwear components.

Dimensional behaviour after wet thermal treatment

The dimensional behaviour of the knitted fabrics was evaluated after the complete wet thermal treatment sequence- consisting of washing, drying, steaming and relaxation- according to EN ISO 5077:2008 [17]. Dimensional changes were expressed as a percentage, in both the course and wale directions, using the following relation:

$$\lambda = \frac{l_1 - l_0}{l_0} \cdot 100,\ \% \qquad (1)$$

where l_0 is the distance between reference marks, before the treatment (mm), and l_1 – the corresponding distance, after the treatment (mm).

A positive value of λ indicates elongation, while a negative value denotes shrinkage [18].

As illustrated in figure 5, the dimensional changes were more pronounced in the wale direction, reaching a contraction of up to –27%, whereas the course direction exhibited moderate extension values, up to +28%. This anisotropic behaviour reflects the structural rearrangement of the knitted loops during the wet thermal stabilisation process. Fabrics with looser structures (NP 13, binding ratio 1:1) showed higher dimensional deformation, while more compact variants (NP 11, binding ratio 1:15) exhibited superior dimensional stability. These results confirm that the applied wet thermal treatment effectively released the internal stresses accumulated during knitting, leading to a stable structural configuration suitable for subsequent functional testing.

Functional properties of wet thermal-treated fabrics

Bursting strength and deformation of wet thermal-treated fabrics

The bursting strength [19] of the stabilised knitted fabrics increased markedly with both structural compactness and the monofilament binding ratio. Values ranged from approximately 227 kPa for the A1 (F) variant to about 590 kPa for D3 (F), indicating that tighter interconnections between the outer layers

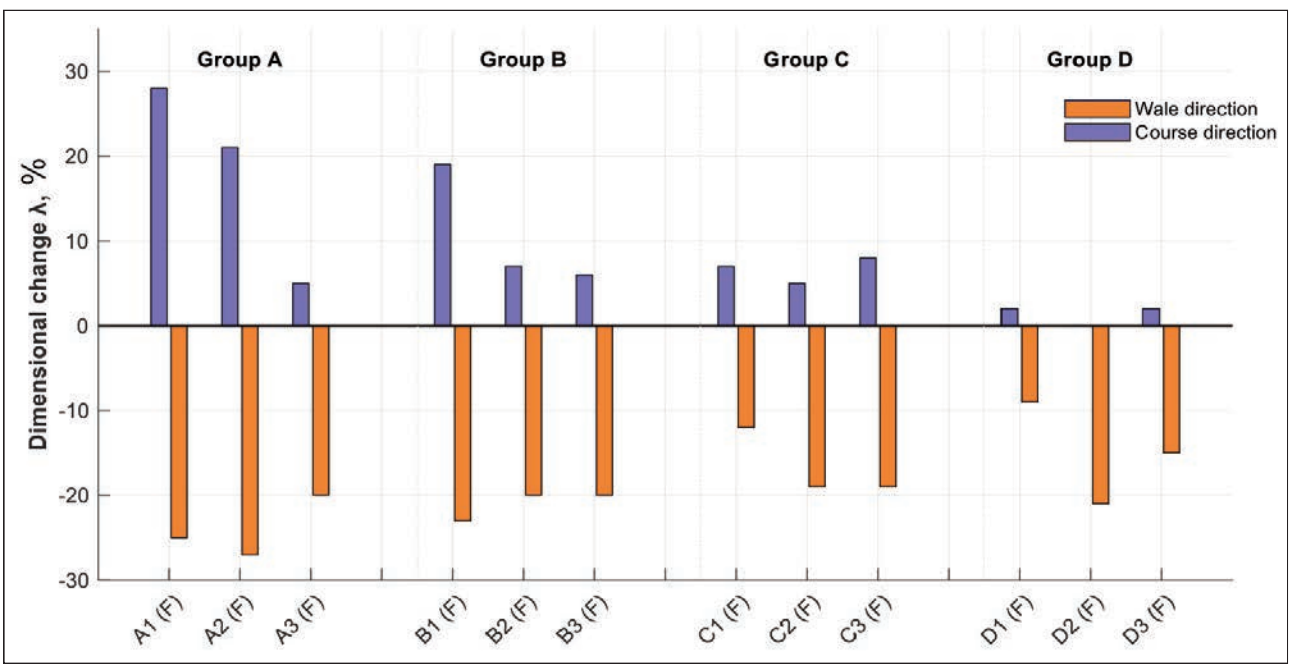

Fig. 5. Dimensional changes (%) in wale and course directions after wet thermal treatment

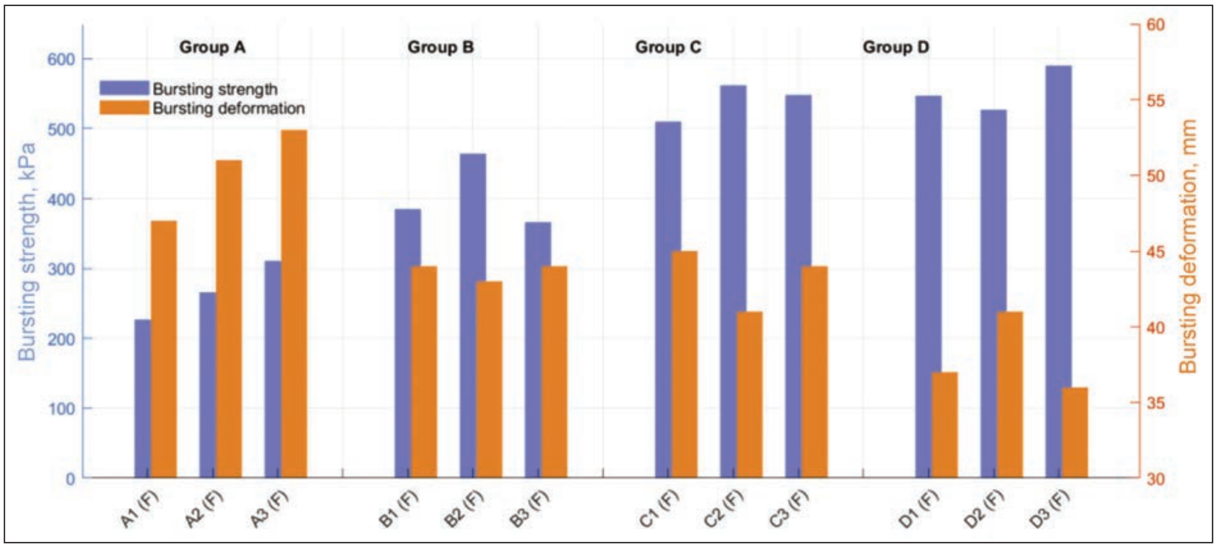

Fig. 6. Bursting strength (kPa) and deformation (mm) of the wet thermal-treated fabrics

significantly enhance resistance to multidirectional stress. This improvement can be attributed to the increased number of binding points, which promote a more uniform distribution of the applied load across the three-dimensional network, thereby reducing localised strain concentration. Conversely, bursting deformation (expressed in mm) exhibited an inverse trend, slightly decreasing with increasing fabric density. This behaviour suggests that looser fabrics (groups A and B) were more extensible and capable of sustaining greater elastic deformation before rupture, whereas more compact fabrics (groups C and D) provided superior strength at the expense of reduced deformability (figure 6). The observed balance between strength and deformation confirms that the monofilament binding ratio is a key parameter governing the mechanical response of spacer knitted fabrics, in agreement with previous studies on knitted structures for protective and technical applications [12, 20].

Abrasion resistance of wet thermal-treated fabrics

The abrasion resistance [21] results showed a pronounced dependence on the internal architecture of the knitted sandwich structure, particularly on the monofilament binding ratio and stitch cam division. Fabrics from groups A and B, characterised by a lower binding ratio (1:1 and 1:3), exhibited moderate abrasion resistance, with failure occurring between 3300 and 10,000 abrasion cycles. In contrast, samples from groups C and D (binding ratios 1:7 and 1:15) withstood up to 15,000 abrasion cycles without significant surface damage, highlighting the mechanical reinforcement provided by the increased number of monofilament connections. This reinforcement effectively restricted yarn mobility and reduced frictional wear, thereby enhancing endurance under repeated contact. However, the increased internal reinforcement was also associated with reduced elasticity and breathability, consistent with the trade-off previously observed between abrasion resistance, bursting strength and air permeability (figure 7).

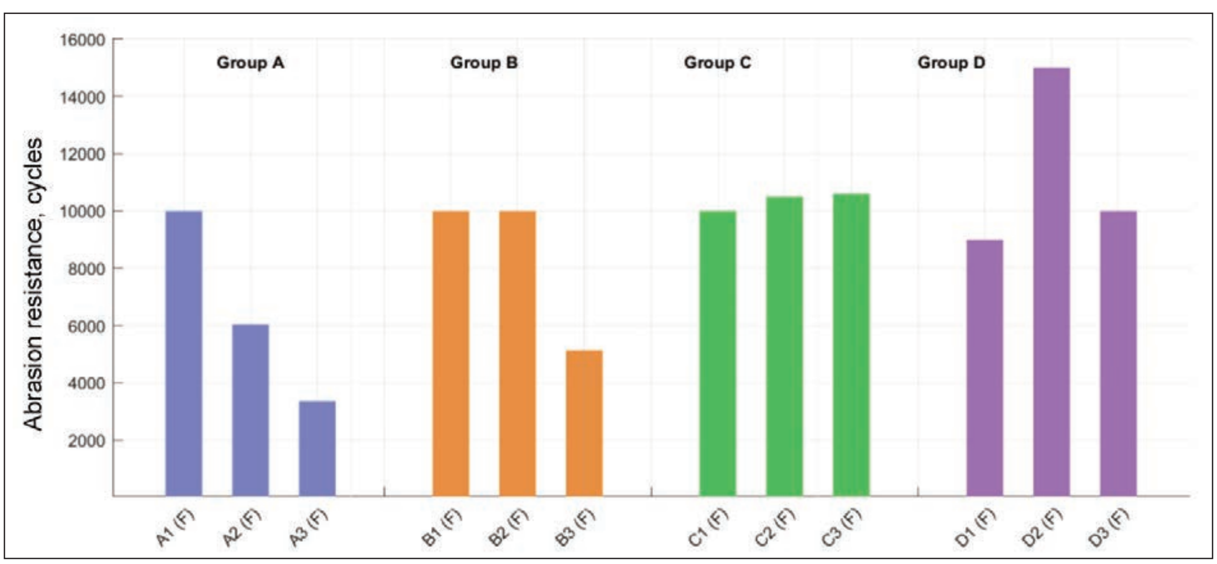

Fig. 7. Abrasion resistance (cycles) of the wet thermal-treated fabrics

These findings confirm that an optimal balance between flexibility and abrasion durability can be achieved by tailoring the monofilament binding ratio, in agreement with prior studies on technical and protective knitted fabrics [22, 23].

The mechanical performance results demonstrate that the three-dimensional weft-knitted fabrics stabilised through the wet thermal treatment process exhibit property levels corresponding to Category II personal protective equipment, as defined by Regulation (EU) 2016/425. According to this regulation, Category II PPE covers protective equipment intended for intermediate risks, which are neither classified as minimal risks under Category I nor as risks that may cause very serious consequences or irreversible harm under Category III. In accordance with the general framework of EN ISO 13688, which establishes requirements related to material robustness, dimensional stability and ergonomic comfort, the investigated fabrics exhibited a balanced combination of mechanical resistance and comfort-related properties. In particular, the experimentally determined abrasion resistance values of up to 15,000 cycles correspond to performance level 4, while the bursting strength values ranging between 227 and 590 kPa correspond to levels 1–3, according to the classification system defined in EN 388:2016+A1: 2018 [24] for protection against mechanical risks. These performance levels are representative of PPE intended for intermediate mechanical and physical risks, confirming that the stabilised knitted fabrics are suitable as constituent layers for Category II PPE applications, such as gloves, workwear, jackets and vests, where mechanical robustness must be ensured without compromising comfort and conformability [25–27].

CONCLUSIONS

The present study investigated the influence of wet thermal treatment, applied as a structural stabilisation stage immediately after knitting, on the structural, comfort-related and functional properties of weft-knitted sandwich fabrics intended for personal protective equipment applications. By systematically varying the monofilament binding ratio and the stitch cam division, clear relationships were identified between manufacturing parameters and the resulting fabric performance.

The results showed that the wet thermal treatment induced a structural rearrangement of the knitted architecture, reflected by changes in mass, thickness and stitch density, confirming the effective release of residual stresses generated during the knitting process. An increase in structural compactness was generally observed after stabilisation, with its magnitude strongly dependent on both the stitch cam division and the monofilament binding ratio.

From a structural perspective, mass per unit area and stitch density generally increased, whereas thickness slightly decreased due to the closer contact between the outer layers and the monofilament binding yarn. Dimensional analysis revealed anisotropic behaviour, characterised by contraction in the wale direction and moderate extension in the course direction, depending on fabric looseness and binding configuration.

In terms of comfort-related properties, air permeability decreased systematically with increasing structural compactness and binding ratio, indicating that reduced inter-yarn spacing and tighter loop configurations limited airflow through the fabric structure.

With respect to functional properties, both bursting strength and abrasion resistance improved substantially with higher binding ratios and tighter stitch cam settings, reaching maximum values of 590 kPa and 15,000 abrasion cycles, respectively. This mechanical reinforcement was associated with a reduced deformation capacity at rupture and lower air permeability, highlighting the inherent trade-off between mechanical protection and comfort-related performance.

Overall, the findings demonstrate that the structural parameters, namely the monofilament binding ratio and stitch cam division, are key factors governing the balance between structural stability, mechanical resistance and comfort-related properties. Within the scope of the investigated characteristics, the stabilised knitted fabrics exhibit a balanced structural and functional behaviour, supporting their suitability as constituent layers for Category II personal protective equipment, such as gloves and workwear garments, jackets, and vests.

ACKNOWLEDGEMENT

This paper is published within the framework of the project Centre for Research and Innovation in Textiles and Fashion Industry – SMART-Tex-IS, MySmis code 334492.

REFERENCES

[1] Grosu, C., Scarlat, V.R., Stefan, E.I., Blaga, M., *Interactive Guide for Study the Vibrations Protection Textile Materials*, The 17th International Scientific Conference eLearning and Software for Education, 2021

[2] Blaga, M., Seghedin, N.E., Horodinca, M., Grosu, C, Gaaloul, H., Babay, A., Dhouib, S., Azouz, B., *Behaviour of Knitted Materials in a Vibrating Environment*, In: Materials, 2025, 18, 3, 1–22

[3] Asayesh, A., Shahangian, Z.S., *The influence of stress relaxation on the compressional properties of weft-knitted spacer fabrics compared to PU foam*, In: Rapid Prototyping Journal, 2025, 31, 9, 1977–1989

[4] Dejene, B.K., Gudayu, A.D., *Exploring the potential of 3D woven and knitted spacer fabrics in technical textiles: A critical review*, In: Journal of Industrial Textiles, 2024, 54

[5] Bukhonka, N.P., *Experimental study of structural characteristics, dimensional change in washing, non-creasing properties and air permeability of Swiss double piqué flax knit fabrics*, In: Journal of Engineered Fibers and Fabrics, 2023, 18, 1–20
[6] European Parliament and of the Council, *Regulation (EU) 2016/425 on personal protective equipment*, 2016
[7] EN ISO 13688:2013+A1:2021. Protective clothing – General requirements, 2013
[8] Monosuisse, *Spacer Fabrics*, Available at: https://monosuisse.com/ [Accessed on August 2025]
[9] Harpa, R., *Metrologie in Textile – Pielarie. Aplicatii ale proceselor de măsurare*, Performantica, 2008
[10] EN ISO 3759. Textiles – Preparation, marking and measuring of fabric specimens and garments in tests for determination of dimensional change, 2008
[11] EN ISO 6330. Textiles – Domestic washing and drying procedures for textile testing, 2022
[12] EN 12127. Textiles – Fabrics – Determination of mass per unit area using small samples, 2003
[13] EN ISO 5084. Textiles – Determination of thickness of textiles and textile products, 2001
[14] EN 14971. Textiles – Knitted fabrics – Determination of number of stitches per unit length and per unit area, 2006
[15] Akkas, M., Erdumlu, N., Candan, C., *Effects of structural parameters on the bursting strength and air permeability of knitted fabrics*, In: Fibres & Textiles in Eastern Europe, 2017, 25, 1, 59–64
[16] EN ISO 9237. Textiles – Determination of permeability of fabrics to air, 1995
[17] ISO 5077. Textiles – Determination of dimensional change in washing and drying, 2007
[18] Acar, E., Tama D. B., Özdemir, G., *Impact of repetitive washing on recycled cotton knitted fabrics: a comprehensive physical property analysis*, In: Industria Textila, 2025, 76, 1, 98–106
[19] EN ISO 13938-2. Textiles – Bursting properties of fabrics. Part 2: Pneumatic method, 2019
[20] Zhang Y., Hu, H., *Compression and mechanical performance of warp-knitted spacer fabrics for protective application*s, In: Textile Research Journal, 2014, 84, 6, 659–670
[21] EN ISO 12947-2. Textiles – Determination of abrasion resistance of fabrics by the Martindale method. Part 2: Determination of specimen breakdown, 2016
[22] Matusiak M., Skowrońska, A., *Influence of structural parameters of knitted fabrics on abrasion resistance and pilling tendency*, In: Textile Research Journal, 2019, 89, 3, 467–478
[23] Özdil, N., Kanat, Z.E., Topuz, B.E., Özçelik, G., Mengüç, G.S., *Properties of the fabrics knitted from yarns with different slub parameters*, In: Industria Textila, 2025, 76, 1, 89–97
[24] EN 388:2016 + A1:2018. Protective gloves against mechanical risks, 2018
[25] Grosu, C., Blaga, M., Seghedin, N.-E., Avădanei, M.-L., Perdevară, M., Marmarali, A., *Knitted linings for protective equipment against vibrations*, In: Industria Textila, 2025, 76, 1, 44–51, https://doi.org/10.35530/IT.076.01.2023142
[26] Loghin, E.C., Dulgheriu, I., Hristian, L., Buhu, L., Avădanei, M., Ionesi, S.D., *Assessing the quality level of the technical fabrics intended for protective equipment for firefighters by determining synthetic indicators*, In: Industria Textila, 2024, 75, 6, 710–721, http://doi.org/10.35530/IT.075.06.202465
[27] Lexi, T., Fumei, W., Tong, P., Yi, S., Zimin, J., Xinghua, H., Hua, S., *Investigation of thermal insulation of cold protective clothing under different underwear and ambient conditions*, In: Industria Textila, 2025, 76, 1, 31–37, https://doi.org/10.35530/IT.076.01.2023131

Authors:

CRISTINA GROSU[1,2], MIRELA BLAGA[2,3], RODICA HARPA[2], DANIELA FĂRÎMĂ[2], MIHAI PENCIUC[2], ANA RAMONA CIOBANU[2], MIHAELA PERDEVARĂ[2]

[1]National Research and Development Institute for Textiles and Leather,
16 Lucretiu Patrascanu Street, 030508, Sector 3, Bucharest, Romania
e-mail: cristina.grosu@incdtp.ro

[2]"Gheorghe Asachi" Technical University of Iasi, Romania, Faculty of Industrial Design and Business Management,
Blvd. Mangeron, No. 29, 700050, Iasi, Romania
e-mail: rodica.harpa@academic.tuiasi.ro; daniela.farima@academic.tuiasi.ro; mihai.penciuc@academic.tuiasi.ro; ana-ramona.ciobanu@academic.tuiasi.ro; mihaela.perdevara@student.tuiasi.ro

[3]Centre for Research and Innovation in Textiles and Fashion Industry – SMART-Tex-IS,
Prof. Dr. Doc. Dimitrie Mangeron, 29, 700050, corp TEX 4, Iasi, Romania

Corresponding author:

MIRELA BLAGA
e-mail: mirela.blaga@academic.tuiasi.ro