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NOVEL ELASTIC WARP KNITTED FABRIC WITH PERFORATION

MELNYK LIUDMYLA* AND KYZYMCHUK OLENA

Kyiv National University of Technologies and Design, Ukraine, Nemyrovycha-Danchenko str. 2, Kyiv, 01011, Ukraine

ABSTRACT

The aim of this project is to create novel elastic knitted materials with improved comfort for medical products. In this context, warp knitted structures were produced using different weft threads laying in. The elastic warp knitted fabric produced with transverse weft threads for the whole width was used as a reference sample. It is widely used in medical products. Laying in weft threads with a partial set according to a certain repeat allows us to get structures in which there is no connection in adjacent wales in certain places. This leads to the formation of through holes in the structure. As a result of increased permeability, comfort properties are improving. The structure, functional and comfort properties of developed and reference elastic warp knitted fabrics were investigated. It was found that novel elastic fabrics have higher values of comfort indicators and provide the necessary functional properties.

KEYWORDS

Elastic fabric; Warp knitting; Permeability; Perforation.

* **Corresponding author:** Melnyk L., e-mail: *melnik.lm@knutd.edu.ua*

INTRODUCTION

The demand for such medical products as bandages and corsets is growing every year [0]. For the treatment of diseases of the thoracic, lumbar and sacral regions, simple medicines are not enough, but also supportive devices are needed. The manufacturing of textile products for preventive and rehabilitation purposes is relevant in the socio-economic aspect as well. They allow you to normalize body motion and human well-being; to ensure the limits of a normal state in the life cycle, to preserve health, and to prevent future disease development. The history of the creation and development of medical and preventive products goes back decades, during which the product designs have undergone significant changes. They gained the greatest development with the appearance of elastic textile bands and fabrics [0].

Different textile technology (braiding, weaving, knitting, and non-weaving) are used for the manufacture of medical products. Knitting is the most promising method because of favorable technical and economic indicators as well as product quality [0]. Knitted fabrics with their huge variety of interlooping, differences in the raw material composition, stitch density, thickness, and so on have got a wide range of physical-mechanical and comfort properties. In addition, they also ensure a good fit for the different shapes of the body surface.

High stretchability and elasticity are the main functional properties of knitted fabric for rehabilitation products. It is provided by the use of elastomers such as polyurethane or latex threads and is determined by their location. In weft knitting, elastomeric threads are used as a transverse weft (coursewise stretching fabric) [0] or for loops formation (bi-stretching fabric) [0], while in warp knitting, elastomeric threads are usually vertically laid (walewise stretching fabric) [0]. It should be noted that the warp-knitted band manufactured on the Crochet knitting machine is the preferred material for corsets and bandages [0]. The pillar stitch with the closed loop is ground interlooping. The elastomer threads are laid longitudinally in every wale and positioned between the loop`s overlap and underlap. They are fed into knitting zone with up to 270% pre-elongation. The weft filling yarns are used for connecting the separate chains into the fabric and are laid for the whole width on both sides of elastomeric threads to cover them better. Such fabric has very compact structure (Figure 1) with high stitch density vertically as a result of elastomer relaxation after knitting.

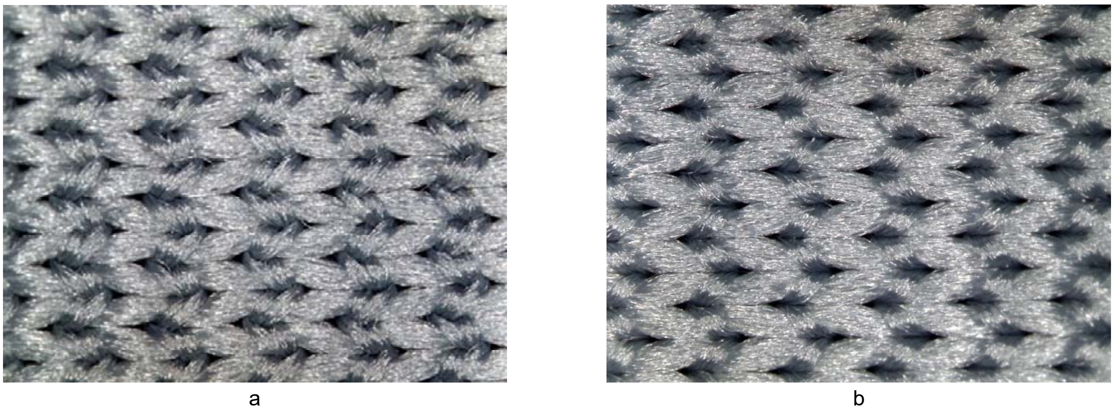


Figure 1. Photos of elastic warp knitted fabric: (a) – face side; (b) – back side.

The comfort is the second important aspect of developing elastic materials for medical and preventive products [0]. is a complex parameter because it involves both objective (permeability, hygroscopicity, thermal conductivity) and subjective (individual human approach) scores [0]. It is paid considerable attention now. These requirements are usually provided by the raw material composition [0].

The goal of this research is to develop novel elastic warp knitted material with through holes in terms of improving the permeability and future providing a higher comfort level of medical products.

EXPERIMENTAL PART

Materials

Four fabric variants differ by transvers weft (Table 1) were produced on 15-gauge T.C.H crochet knitting machine. Technological parameters as yarn feeding tension, fabric takedown load, and the number of used needles were kept constant for all samples.

The 16.7 tex polyester threads are used as ground (1st guide bar) for pillar stitches (Fig. 2.a) and 0.8 mm diameter polyurethan threads (3rd guide bar) are used as longitudinal elastomer component (Fig. 2.b). Both guide bars are fully threaded.

The 33.4 tex (96 filaments) polyester threads of 2-ply (A variant) and 4-ply (B variant) were used as weft in transverse direction. In order to create novel structure and to study the effect of interlooping on fabric properties two variants of weft yarn laying-in repeat were used:

- the whole width weft (W variant) introduced by special feeders on both sides of elastomer threads in opposite directions (reference samples);
- the patterned weft (P variant) introduced by incomplete (1 in, 5 out) guide bars (Figure 3) on both sides of elastomer threads in same directions (novel structure).

The lapping diagrams on figures 2 and 3 were created by using Warp Knitting Pattern Editor of TexMind [0].

Table 1. Elastic warp knitted fabric.

Cod	Linear density of weft thread	Variant of weft
AW	33.4 tex * 2	whole width
AP	33.4 tex * 2	patterned
BW	33.4 tex * 4	whole width
BP	33.4 tex * 4	patterned

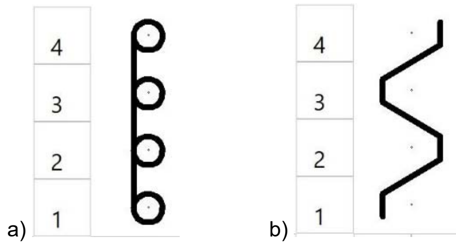


Figure 2. Lapping diagram: a – 1st guide bar (pillar stitch); b – 3rd guide bar (elastomer thread).

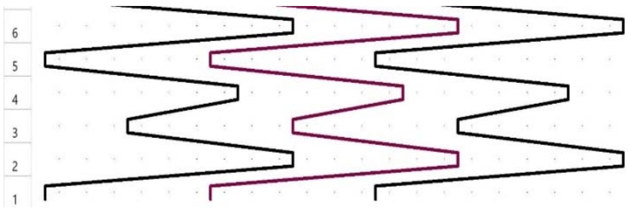


Figure 3. Lapping diagram for: 2nd and 4th guide bars (patterned weft).

Methods

The structural properties of the fabrics were tested using the following standards: BS EN 14971:2006 [0] for stitch density, ISO 5084: 1996 [0] for thickness, and ASTM D3776 [0] for mass per unit area. The mean value for 10 parallel measurements were used for result analyses.

Photos of fabrics were taken on a digital microscope Microsafe ShinyVision MM-2288-5X-BN. Loop size and hole areas were measured by ImageJ software (Figure 4). The mean value for 10 parallel measurements were used for result analyses.

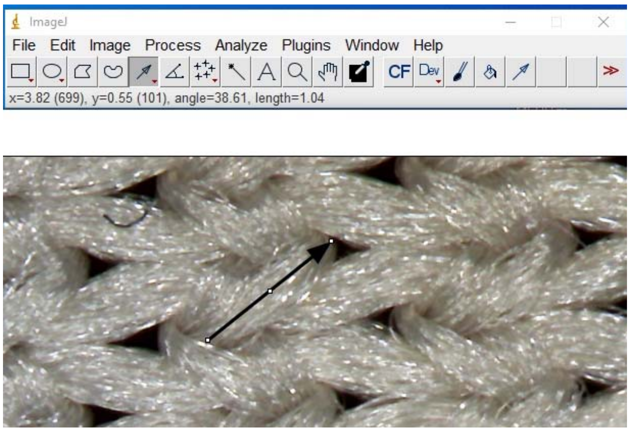


Figure 4. Measurement with ImageJ software.

The study of stretchability and elasticity of elastic warp-knitted fabric was performed according to BS EN ISO 20932-1:2020 [0] on Zwick Roell Z010. Required cycling limits are the following: gauge length settings 100 mm; the number of cycles 5; cycling load 35 N, recovery period 30 min. 3 specimens (300 mm x 50 mm) were tested for each fabric's variant. The following indicators are calculated from obtained data: elongation, permanent deformation, recovered elongation and elastic recovery.

Comfort properties of the fabrics were tested using the following standard methods:

- Air permeability is according ISO 9237:1995 [0] on Textest FX 3300 (pressure of 100 Pa and sample area of 20 cm2). Each fabric sample was tested 10 times.
- Thermal conductivity is according ISO 8301:1991 [0] on Alambeta (Sensora instruments). Each fabric sample was tested 3 times.
- Water vapour resistance is according TS EN ISO 11092:2014 [0] on Permetest. Each fabric sample was tested 5 times.

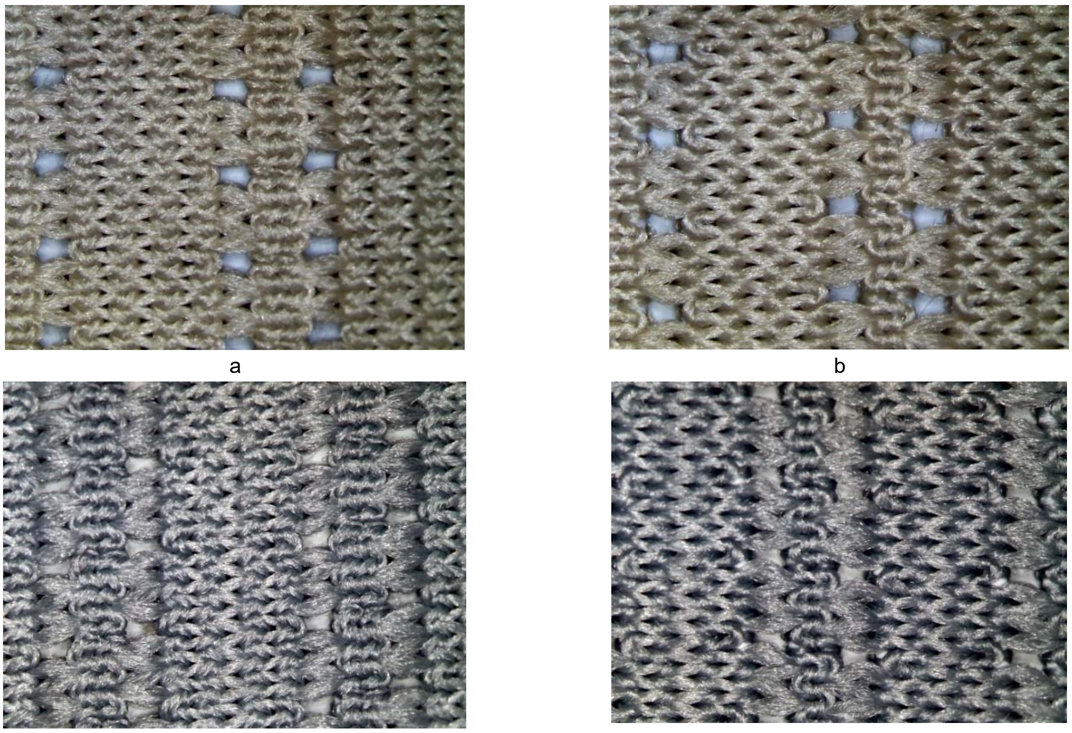
RESULTS AND DISCUSSION

Fabric structure

The fabrics with the patterned weft yarns (variants AP and BP) have got through holes in 3rd and 4th courses of repeat at places where no connection between the two adjacent weft yarns (Figure 3). The photos of fabric after knitting and relaxation during 48 hours in standard environmental conditions (20 °C and 101 kPa) are presented in Figure 5. The measurement results of stitch size and hole areas are presented in Table 2.

As a result of the analysis of the stitch size (loop`s width and height), it was established that the novel fabrics with perforation correspond to the reference elastic warp-knitted fabrics. There is a difference in loop positioning only. For fabric with a 2-ply weft yarn, the loop skeleton is more inclined to the horizontal line. It is the result of both the total linear density of weft yarn and better conditions for elastomer relaxation.

It should be noted that the size of the through holes is larger for AP fabric despite the smaller loop`s height. It is because the ticker weft yarn in BP fabric fills the part of a hole.



a b c d

Figure 5. Photos of novel elastic warp knitted fabric: (a) – AP face side; (b) – AP back side; (c) – BP face side; (d) – BP back side.

Table 2. Stitch size and hole area of elastic warp knitted fabric.

Cod	Loop`s width, W [mm]	Loop`s height, W [mm]	Angle to horizontal [°]	Hole`s area, S [mm^2]
Reference samples				
AW	1.05	0.76	38.8	-
BW	0.96	0.76	42.9	-
Developed structure				
AP	1.04	0.73	38.7	0.74 ± 0.01
BP	1.01	0.79	40.3	0.45 ± 0.01

Table 3. Parameters of elastic warp knitted fabric.

Cod	Stitch length [mm]			Stitch density per 100 mm		Thickness [mm]	Mass per unit area [g/sq.m]
	loop	elastomer	weft	wales	courses		
Reference samples							
AW	5,50 ± 0,01	0.50	1.67 ± 0.01	62	204 ± 3	1.48 ± 0.01	809.4 ± 4.2
BW	5,82 ± 0,01	0.53	1.70 ± 0.01	62	168 ± 2	1.68 ± 0.02	947.7 ± 4.6
Developed structure							
AP	5,56 ± 0,02	0.51	1.50 ± 0.02	62	193 ± 3	1.69 ± 0.02	794.2 ± 4.0
BP	5,79 ± 0,02	0.51	1.51 ± 0.02	62	186 ± 3	1.78 ± 0.02	886.0 ± 4.6

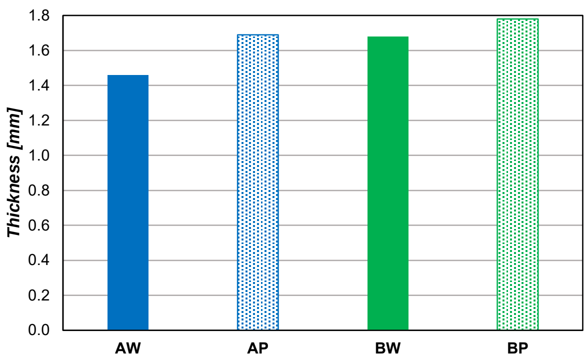


Figure 6. The thickness of elastic warp knitted fabric.

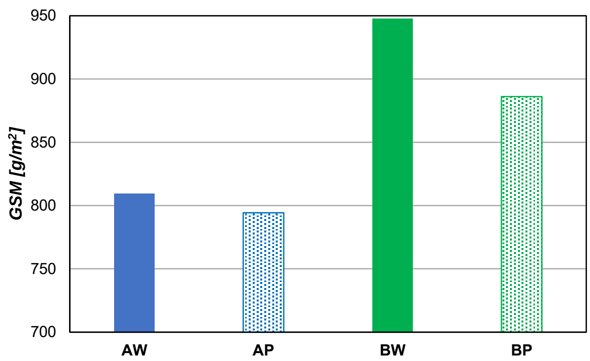


Figure 7. The mass of elastic warp knitted fabric.

Structural parameters

The structural parameters of elastic warp knitted fabrics are presented in Table 3.

The total linear density of weft threads affects the stitch length. The loop`s length for fabrics with 4-ply weft yarn is 5.5 % longer than for fabrics with 2-ply weft yarn. The length of elastomer per stitch for BP fabric is longer than for AP fabric as well. Research results show that weft yarn repeat affects its length only. The weft length per stitch for developed fabrics is 10% less than that for reference ones.

It is obvious that all knitted fabrics have the same stitch density horizontally (62 wales per 100 mm) because the distance between the wales is determined by the needle pitch. There is difference in stitch density vertically. For the reference samples the density of BW fabric is 35 stitches (17 %) less than AW fabric. The difference for developed structure is not so big. It is only 7 stitches (4 %).

As for thickness, the fabrics with 4-ply weft yarn are thicker than the corresponding fabrics with 2-ply weft yarn (Figure 6). It was found that developed fabrics are thicker than reference ones. It is the result of the overlapping of two weft threads in the contact areas. Developed elastic warp-knitted fabrics have reduced mass (Figure 7) that leads to a decrease in materials consumption and weight of the final product.

Elasticity

The research results for elasticity of elastic warp knitted fabric are presented in Table 4. They show that both reference and novel elastic warp knitted fabric with perforation provides a high level of stretchability and elasticity. The fabrics` elongation is more than 140 [%] and only for the AP variant is 127 [%] but it is quite high. A permanent deformation does not exceed 3 [%]. All studied elastic warp knitted fabrics provide high level of elasticity: elastic recovery is more than 98%.

Table 4. Elasticity of elastic warp knitted fabrics.

Cod	Elongation, S [%]	Permanent deformation, C [%]	Recovered elongation, D [%]	Elastic recovery, R [%]
Reference samples				
AW	147 ± 2	2.3 ± 0.3	144	98.4
BW	142 ± 3	0.3 ± 0.0	142	99.8
Developed structure				
AP	127 ± 1	1.7 ± 0.3	125	98.7
BP	142 ± 3	3.0 ± 0.5	139	97.9

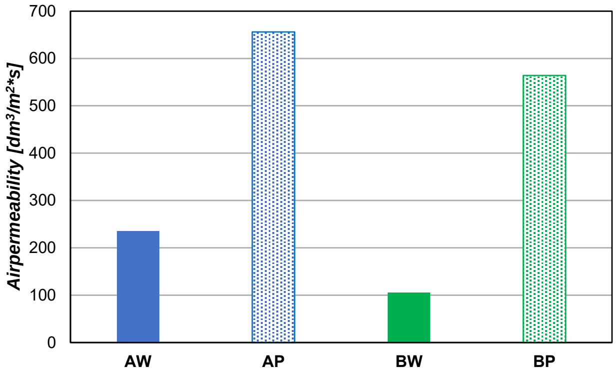


Figure 8. The air permeability of elastic warp knitted fabric.

Table 5. Water vapor properties of elastic warp knitted fabrics.

Cod	Relative Water Vapour Permeability, RWVP [%]	Water Vapour Resistance, Ret [Pa·m^2·W^{-1}]
Reference samples		
AW	30 ± 1.1	10.7 ± 0.43
BW	31 ± 1.1	12.9 ± 0.54
Developed structure		
AP	41 ± 1.2	8.1 ± 0.25
BP	33 ± 0.8	9.6 ± 0.48

Table 6. Thermal properties of elastic warp knitted fabrics.

Cod	Thermal conductivity coefficient λ 10^3 [W·m^{-1}·K^{-1}]	Thermal diffusivity coefficient, a 10^{-6} [m^2·c^{-1}]	Thermal absorptivity coefficient, b [W·s$^{1/2}$·m^{-2}·K^{-1}]	Thermal resistivity coefficient, R 10^{-3} [K·m^2·W^{-1}]
Reference samples				
AW	76.3 ± 0.9	0.105 ± 0.009	236 ± 7	19.2 ± 0.3
BW	78.7 ± 0.6	0.056 ± 0.003	333 ± 7	20.6 ± 0.2
Developed structure				
AP	66.1 ± 0.7	0.071 ± 0.003	248 ± 3	25.6 ± 0.2
BP	63.7 ± 0.6	0.095 ± 0.001	206 ± 2	28.0 ± 0.3

Air permeability

The results of the fabrics` air permeability testing are presented in Figure 8. Predictably, novel fabrics have much greater value because of through holes. The value is greater for fabrics with 2-ply weft yarn both reference and developed structures.

Water vapor permeability

Research results obtained at the Permetest instrument are presented in Table 5.

The reference elastic warp knitted fabrics AW and BW have 30-31% relative water vapour permeability (RWVP) that is not affected by the total linear density of transverse weft threads. The novel elastic warp knitted fabrics has improved water vapour permeability that depends on the total linear density of transverse weft threads. AW sample has 8% higher RWVP compared to BP sample.

The Water Vapour Resistance coefficient (Ret) of novel elastic warp knitted fabrics is lover compared to reference samples. It allows developed fabric to be used in medical products for moderate efforts. They are more pleasant to wear during physical activity.

Thermal properties

Research results obtained at the Alambeta instrument are presented in Table 6.

The decrease in the thermal conductivity coefficient and the increase in the thermal resistance coefficient indicate the lower thermal insulation properties for novel elastic warp-knitted fabrics (AP and BP). As described before, the novel fabric is developed for medical products used daily and worn on underwear or even on the body directly. In this case, the lower thermal insulation properties lead to improving the comfort of products.

CONCLUSIONS

Taking into account the fact that elastic warp-knitted fabrics are widely used for the production of medical support products, new structures with perforations were developed. In contrast to the widespread fabrics with the whole-width weft, weft threads are laid according to a certain repeat and used incomplete threading of the guide bar. Through holes are formed in courses where there are no contacts between two adjacent weft threads. The conducted research showed that the main functional properties of the novel fabrics (stretchability and elasticity) correspond to the properties of the reference fabrics. Due to the presence of perforations, the comfort of the products is improved: air and water vapour permeability indicators have significantly increased and thermal protection indicators have decreased.

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REFERENCES

1. IMARC Group, Medical Textiles Market: Global Industry Trends, Share, Size, Growth, Opportunity and Forecast 2022-2027 (https://www.imarcgroup.com/medical-textiles-market)
2. Melnyk L.M., Kyzymchuk O.P. (2012) The utilization of elastic knitted materials in the medical-preventive goods. Bulletin of Kyiv National University of Technologies and Design, 4, 139-145. – in Ukranian
3. Sadhan Chandra R. (2012). 27 - Scope of knitting in the manufacture of medical textiles. In: Sadhan Chandra R, editor. Fundamentals and Advances in Knitting Technology: Woodhead Publishing India, 326-9. https://doi.org/10.1533/9780857095558.326
4. Kyzymchuk, O. & Melnyk, L. (2016). Influence of miss knit repeat on parameters and properties of elasticized knitted fabric, IOP Conf. Series: Materials Science and Engineering, 141, 012006. http://dx.doi.org/10.1088/1757-899X/141/1/012006
5. Pavko-Cuden A. (2010) Parameters of Compact Single Weft Knitted Structure (Part 2): Loop Modules and Munden Constants – Compact and Supercompact Structure. Tekstilec, 53 (10–12), 259–272
6. Kyzymchuk, O., Melnyk, L., Arabuli, S. (2020). Study of Elastic Warp Knitted Bands: Production and Properties. Tekstilec, 63(2), 113-23. DOI: 10.14502/Tekstilec2020.63.113-123
7. Kyzymchuk, O., Melnyk, L. (2018) Stretch properties of elastic knitted fabric with pillar stitch. Journal of Engineered Fibers and Fabrics, 13 (4): 1-10. https://doi.org/10.1177/1558925018820722
8. Ng Sau-Fun, Hui Chi-Leung & Wong Lai-Fan (2011) Development of medical garments and apparel for the elderly and the disabled, Textile Progress, 43:4, 235-285, https://doi.org/10.1080/00405167.2011.573240
9. Mallikarjunan K., Senior L. (2011) Comfort and Thermo Physiological Characteristics of Multilayered Fabrics for Medical Textiles, Journal of Textile and Apparel, Technology and Management, 7 (1), 1–15.
10. Oglakcioglu N. (2016) Design of functional knitted fabrics for medical corsets with high clothing comfort characteristics. Journal of Industrial Textiles. 45(5), 1009-1025. https://doi.org/10.1177/1528083714551438
11. Warp Knitting Pattern Editor. TexMind. Web site: http://texmind.com/wp/products/warp-knitting-software/
12. BS EN 14971:2006 Textiles. Knitted fabrics. Determination of number of stitches per unit of length and unit area
13. ISO 5084: 1996 Textiles - Determination of thickness of textiles and textile products
14. ASTM D3776. Standard Test Methods for Mass Per Unit Area (Weight) of Fabric.
15. BS EN ISO 20932-1:2020+A1:2021 Textiles. Determination of the elasticity of fabrics. Strip tests.
16. ISO 9237:1995, Textiles -- Determination of the permeability of fabrics to air
17. ISO 8301:1991 Thermal insulation; determination of steady-state thermal resistance and related properties; heat flow meter apparatus.
18. TS EN ISO 11092:2014 Textiles. Physiological effects. Measurement of thermal and water-vapour resistance under steady-state conditions