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Comparative Studies on Thermal Comfort Properties of Eri Silk, Wool/Eri Silk, Cotton, and Micro-denier Acrylic Double-layered Knitted Fabrics

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ABSTRACT

In this study, 100% Eri Silk, 85:15% Wool/Eri silk, Cotton, and Micro-denier Acrylic yarns have been used to develop double-layered knitted fabrics. The thermal comfort properties such as air permeability, thermal resistance, thermal conductivity, and water vapor transmission have been evaluated. In this study, it is found that 100% eri silk double-layered knitted fabrics have better air permeability properties when compared with the other fabrics (85:15% Wool/Eri silk and 100% micro-denier acrylic fabrics) due to their thin and porous structure. As far as thermal conductivity is concerned, 100% Eri silk double-layered knitted fabrics have better thermal conductivity, whereas 85:15% wool/Eri silk double-layered knitted fabrics show poor thermal conductivity. In the case of thermal resistance, 85:15% wool/Eri silk double-layered knitted fabrics have maximum thermal resistance and 100% Eri silk shows poor thermal resistance when compared to other samples. A total of 100% Eri silk double-layered knitted fabrics have better water vapor transmission and 85:15% wool/Eri silk double-layered knitted fabrics have poor water vapor transmission when compared to other samples.

摘要

本研究以100%Eri丝、85:15%羊毛/Eri丝、棉和细旦腈纶纱线为原料, 开发了双层针织物. 对其透气性、热阻、导热性和水蒸气透过性等热舒适性进行了评价. 本研究发现, 100%eri真丝双层针织物由于其薄而多孔的结构, 与其他织物 (85:15%羊毛/eri真丝和100%细旦腈纶织物) 相比, 具有更好的透气性能. 就热导率而言, 100%的Eri丝绸双层针织物具有更好的热导率, 而85:15%的羊毛/Eri丝绸双层针织物具有较差的热导率. 在耐热性方面, 与其他样品相比, 85:15%羊毛/Eri丝绸双层针织物的耐热性最高, 100%Eri丝绸的耐热性较差. 与其他样品相比, 100%Eri真丝双层针织物具有更好的透湿性, 85:15%羊毛/Eri真丝双层针织物具有较差的透湿性.

KEYWORDS

Cotton; double-layered knitted fabrics; eri-silk; micro-denier acrylic; thermal comfort; wool

关键词

棉; 双层针织物; 埃里丝; 细旦丙烯酸; 热舒适性; 羊毛

Introduction

Demands of fashion and usage of fabrics changing rapidly, accordingly developments of technology also growing equally faster to meet the demands. Knitted fabrics meet the rapidly changing demands due to their clothing comfort. Several research works have been carried out on the thermal comfort properties of knitted structures of single-layered and multi-layered fabrics. Bivainyte and

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Mikucioniene (2011a) stated that the main influence of water vapor permeability of double-layered knitted fabrics is the kind of raw material. On the other hand, for raw materials wetting and wicking properties, there is no correlation between water vapor permeability and air permeability of double knitted fabrics. It is also reported that the heat transfer process depends on the double-layered knitting pattern because the structure of the knit determines the amount of air therein; on the other hand, raw material used for active leisure clothing has no significant effect on the heat transfer process (Bivainyte, Mikucioniene, and Milasiene 2012). In the other research work, it is proved that the fabrics knitted in combined plated patterns of different raw materials have higher thermal conductivity values than the fabrics knitted in plain plated patterns. If the fabric thickness is increased, thermal resistance also increases, which means thicker knitted fabric gives a warmer sense (Bivainyte, Mikucioniene, and Kerpauskas 2012). He also investigated that the fabrics knitted from a PP thread and cotton yarn combination showed a poor ability to absorb water. On the other hand, the sensation of dryness is better when wearing a product made of a weft-knitted fabric of plain plated pattern (Bivainyte and Mikucioniene, 2011b).

Oglakcioglu and Marmarali (2011) reported that different knitting structures have different comfort properties. Double jersey structures have high thermal insulation which may be preferred for winter garments. Single jersey structures are preferred for sports or summer garments due to their better moisture management properties. Islam et al. (2014) noted that single jersey knitted fabrics are having better moisture management and thermal properties which is most suitable for sports and summer garments. Double jersey knitted fabrics are having higher thermal conductivity and less water vapor permeability which is suitable for winter wear. Organic cotton knitted fabric provides better thermal comfort properties over conventional cotton knitted fabrics. Majumdar, Mukhopadhyay, and Yadav (2010) mentioned that bamboo blended yarn knitted fabrics have lower thickness and lower mass per square meter than conventional cotton yarn fabrics. As the proportion of the bamboo fibers increases, the water vapor permeability and air permeability also increased. Plain knitted fabrics show the minimum thermal conductivity and thermal resistance values and maximum water vapor permeability when compared to rib and interlock structures.

Ucar and Yılmaz (2004) stated that the heat loss through the fabric will decrease as the fabric becomes tighter, due to less air permeability. On the other hand, if fabric tightness is considered for each fabric design, convective heat loss becomes more important than conductive heat loss due to the fibers and air gaps. Prakash, Ramakrishnan, and Koushik (2012) investigated that air permeability, thermal resistance, water vapor permeability, and thermal conductivity are significantly affected by the fiber blend ratio of cotton/regenerated bamboo knitted fabrics. They also investigated that water vapor permeability and air permeability shows proportionally increased as the proportion of bamboo fiber increases.

Prakash et al. (2015) studied the geometrical and air permeability properties of single-jersey-knitted fabric structures made from cotton, bamboo, and cotton–bamboo-blended yarns. The study determined the influence of blend ratio, yarn linear density, and stitch length on geometrical and air permeability properties of bamboo cotton-knitted fabrics. The air permeability of the fabrics was observed to increase with an increase in bamboo content.

Vigneswaran, Chandrasekaran, and Senthilkumar (2009) stated that the thermal conductivity value depends on the proportion of jute component in the yarn blend. The lower thermal conductivity was observed at a higher jute blend proportion in the jute/cotton blended knitted fabrics. They also investigated that higher fabric tightness factor and fabric thickness result in decreasing trend of thermal conductivity. Czaplicki, Mikołajczyk, and Prążyńska (2018) indicated that the functional properties of knitted fabrics depend on the type and composition of the yarn and the type (variant) of the stitch. Kadapalayam Chinnasamy and Chidambaram (2017) studied the influence of the blend ratio and linear density on the thermal comfort properties of regenerated bamboo cotton blended single jersey knitted fabrics. An increase in the regenerated bamboo fiber ratio in the fabric influences the thermal comfort properties. In this study, 100% Eri silk, 85:15 Wool/Eri silk, Cotton, and Micro-denier Acrylic yarns have been used to develop double-layered knitted fabrics and study the thermal comfort properties of knitted fabrics.

Das et al. (2021) proved that eri silk woven fabric can be used as summer wear due to its good thermal comfort properties. Senthil Kumar, Senthil Kumar Boominathan and Vijay Kirubhakar Raj (2021) investigated the thermal comfort properties of eri silk, wool, and bamboo knitted fabrics by both subjective and objective assessments and found that eri silk based knitted fabric performed better than other fabrics. The novelty of this study, eri silk was used to develop double layer knitted fabrics (100% and 85:15 Wool/Eri silk). Similarly, eri silk knitted fabrics are getting popular in recent years and it is necessary to study the comfort properties of these fabrics and hence to address the gap, this study has been takenup.

In this study, the thermal comfort properties of different materials of double-layered fabrics have been investigated. Engineering the garments for different seasons such as winter and summer are based on the thermal comfort properties of the fabrics. The thermal comfort properties differ from material to material and in this study, four different materials such as 100% Eri silk, 85:15% wool/Eri silk, cotton, and micro-denier acrylic have been used to develop double-layered knitted fabrics. The thermal comfort properties such as air permeability, thermal resistance, thermal conductivity, and water vapor transmission of all four materials have been evaluated. The results have been critically analyzed which will be helpful while engineering the garments for getting suitable wearer comfort in different climatic conditions.

Materials and methods

Materials

The fibers used in the production of the yarn and fabric samples were obtained from a spinning mill; Cotton: fiber length 25.78 mm, fiber length uniformity ratio 85.1%, fiber fineness 4.26 mic, moisture regain 7.5% and trash content 0.19%, Eri silk: fiber length 38.1 mm, fiber fineness 0.97 dtex and fiber tenacity 47.1 cN/tex, Wool: Staple length −45 mm, fineness- 2.17 tex and strength 1.5 g/d, Acrylic: staple length – 38 mm, linear density – 1.66 dtex and tenacity – 23.18 g/tex. Four different yarns of 100% Eri silk, 85:15 wool/Eri silk, Cotton and micro-denier acrylic have been used for this study. Table 1 shows the physical properties of the above yarns. In this study,16 tex yarns have been used in the case of 100% Eri silk and 85:15 wool/Eri silk. Cotton and micro-denier acrylic yarns of the same tex count have also been used for this study. Yarn tests were carried out using standard textile testing equipment. For the calculations of CV % and yarn imperfections, unevenness of textile strands using capacitance testing equipment ISO 16549 was used. For the measurements of yarn strength and % elongation at break, the standard method of IS 1670:1991 (RA 2007) instrument was used.

In this study, 2 track rib knitting machine of Pailung make 18 gauge with 30” diameter and 60 feeders of 3 mm constant loop length have been used to develop the double-layered knitted structures using the above-mentioned yarns.

Methods

The thermal comfort properties of double-layered knitted structures have been evaluated using standard testing equipment and methods. For the air permeability testing, KES FB-8, Kato Tech Co., Ltd. instruments have been used with the BS-3424-16-1995 standard testing method. Water Vapor Transmission ASTM E96, Intertek standard cup method has been used to assess the water vapor transmission of double-layered knitted structures. A SDL-ATLAS- M259B sweating guarded hot plate tester with ISO 11092 has been used to assess the thermal resistance values of the knitted structures. The quantitative data of objective measurements were analyzed by SAS System (version 8 for Windows). Two-way ANOVA was used to identify the significance of differences between thickness and knitted fabrics thermal comfort properties. Any differences were considered to be significant if P value was equal to or less than 0.05.

Table 1. Physical properties of yarns.

Materials	Count (Tex)	CV %	Imperfections/1000 m Thin -50%	CV %	Thick +50%	CV %	Neps +200%	CV %	Total imperfections	CV %	Average Hairiness Index	CV %	TPM	CV %	Average Single Thread breaking cN force	CV %	Elongation at break %	CV %	Tenacity cN/tex	CV %
100% Eri-Silk Yarn	16	0.5	16	5.2	18	5.6	24	5.5	58	5.1	8.19	5.3	876	5.1	305	4.3	11.9	3.6	19.1	3.8
Micro-Denier Acrylic	16	0.9	18	6.4	20	6.9	45	6.3	83	6.1	5.9	5.4	864	5.6	237	3.6	12.5	4.1	14.8	3.9
Cotton	16	1.2	32	7.45	30	8.2	46	6.1	108	6.5	5.5	5.8	820	5.9	238	4.5	8.31	4.3	14.9	4.2
85:15 Wool/Eri Yarn silk	16	0.8	38	5.4	50	6.1	64	7.1	152	6.8	6.8	5.1	760	5.2	218	3.9	5.47	3.9	13.6	3.4

Table 2. Thermal comfort properties of double layered knitted structures.

Fabric Structure	Material	Thickness mm	Weight per unit area g/m^2	Air permeability dm^3/dm^2sec	Thermal resistance m^2K/W	Thermal Conductivity W/mK	Water vapor transmission $gm/m^2/day$
Double layered knitted fabrics	100% Eri silk	0.83	204	0.67	0.0307	0.0270	2303
	85:15 Wool/Eri silk blend	0.90	198	0.154	0.0426	0.0160	1786
	100% Cotton	0.84	192	0.81	0.0370	0.0211	1824
	100% Micro denier Acrylic	0.80	190	0.146	0.0368	0.0227	1943

Results and discussion

The thermal comfort properties of the double-layered knitted structures are given in Table 2.

Air permeability

Air permeability is one of the important comfort properties which influence the flow of vapor from the fresh atmospheric air to the body and from the human body to the environment. Figure 1 shows the air permeability values of all four fabrics. The test result indicated that 100% eri silk has the highest air permeability values. Micro-denier acrylic has 6% lower air permeability than 100% eri silk. Whereas cotton has 47% and 85:15 wool/eri silk has 57% lesser air permeability than 100% eri silk. Kumar, Kumar Boominathan, and Vijay Kirubakar Raj (2021) proved that 100% eri silk has higher air permeability and better thermal comfort properties, due to the fine structure of the eri silk and air gap between the yarns of the knitted fabric allows more air in 100% eri silk, whereas the bulk nature of the wool with the compact structure of the knitted fabric restricts the flow of air when compared to 100% eri silk. Atalie and Rotich (2020) reported that, for better sensorial comfort especially for clothes worn next to the skin such as innerwear, cotton fibers can be considered when compared to 100% eri silk. In this study, from the results, it is noticed that 100% cotton also has the highest air permeability values and lesser thermal conductivity and water vapor transmission properties. Hence, when compared with the overall performance, 100% eri silk is having better thermal comfort properties when compared to 100% cotton and also other fabrics (85:15% wool/eri silk and 100% micro-denier acrylic).

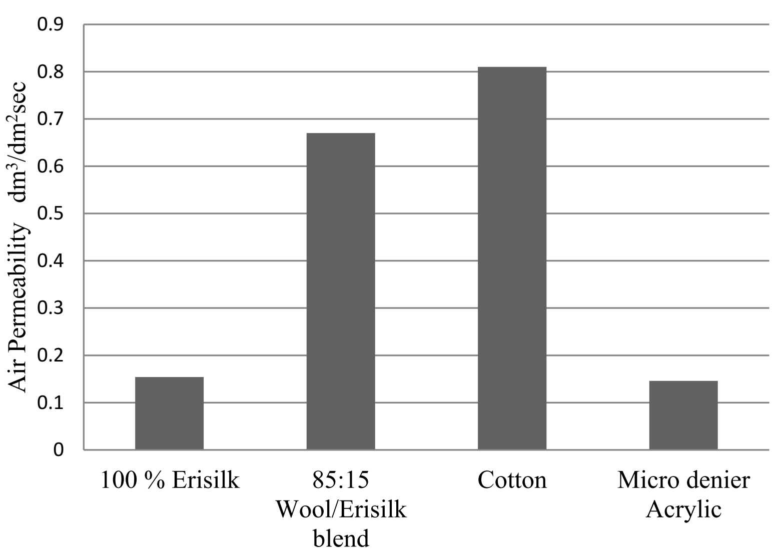

Figure 1. Air permeability values of double layer knitted fabrics.

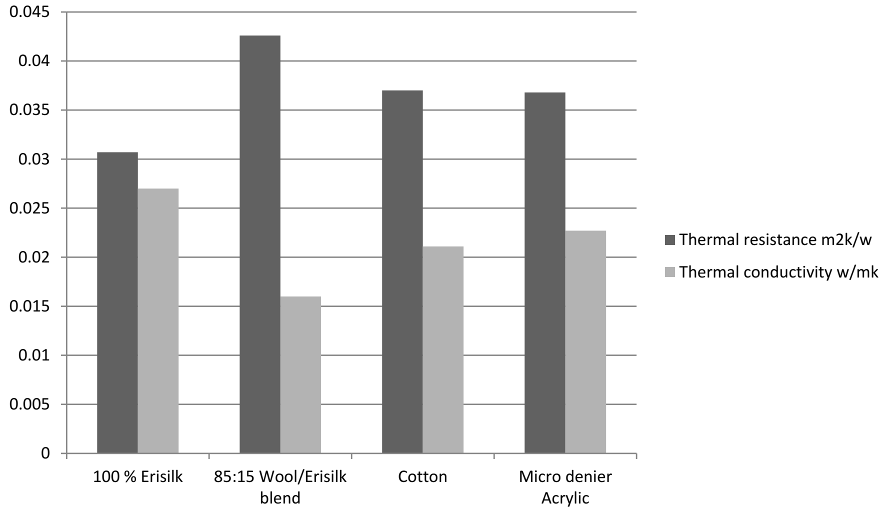

Figure 2. Thermal resistance and conductivity values of double layer knitted fabrics.

Thermal resistance and conductivity

Figure 2 shows the thermal resistance values of all the four double layer knitted structures. The thermal resistance of the material is the ability to prevent heat from flowing through it. If the thermal resistance of the material is lower, heat energy will tend to gradually decrease which gives a cool feeling to the wearer. Among all, 85:15 wool/eri silk shows a higher thermal resistance value. This is because wool has a good thermal resistant characteristic. The higher the specific heat capacity the better will be the thermal insulation and hence the 85:15 wool/eri silk fabric provides better thermal insulation when compared to other samples. Similarly, cotton has 13% lower values and micro-denier acrylic has 14% lesser values of thermal resistance than 85:15 wool/eri silk. In the case of 100% eri silk, it is 28% lower values of thermal resistance than 85:15 wool/eri silk, which keeps the body cool in summer and warm in winter and is considered as best suited garments for both seasons. Das et al. (2021) proved that eri silk woven fabric can be used as summer wear due to its good thermal comfort properties. Figure 2 shows the thermal conductivity values of all the four double layer knitted structures. The thermal conductivity of 100% eri silk shows the highest value and 85:15 wool/eri silk shows the lowest thermal conductivity characteristics, which is 41% lower than 100% eri silk. Similarly, micro-denier acrylic is 16% lower and cotton 25% lower thermal conductivity when compared to 100% eri silk.

Water vapor transmission

Figure 3 shows the water vapor transmission values of all four double-layered knitted structures. It is the ability to transmit vapor from the body to the atmosphere and vice versa. The higher the water vapor transmission facilitates the easy passage of water vapor through the fabrics. Atalie et al. (2021) also reported that the water vapor transmission was highly affected by hairiness on the yarn, fabric thickness and porosity. Among the four knitted fabrics, 100% eri silk shows a higher value of water vapor transmission than the other three samples due to its thin filament structure and no hairiness. It shows 100% eri silk double-layered knitted fabric allows the water vapor easily from the body to the atmosphere and vice versa. This gives maximum comfort when compared to other fabric samples. However, in the other fabric samples due to the fabric thickness and the hairiness present on the yarns results in less water vapor transmission properties. Overall when compared with 100% eri silk double-layered knitted fabrics, micro-denier acrylic fabric shows 16% lower, cotton double-layered knitted fabric shows 21% and 85:15% wool/eri silk shows 22% lower than 100% eri silk.

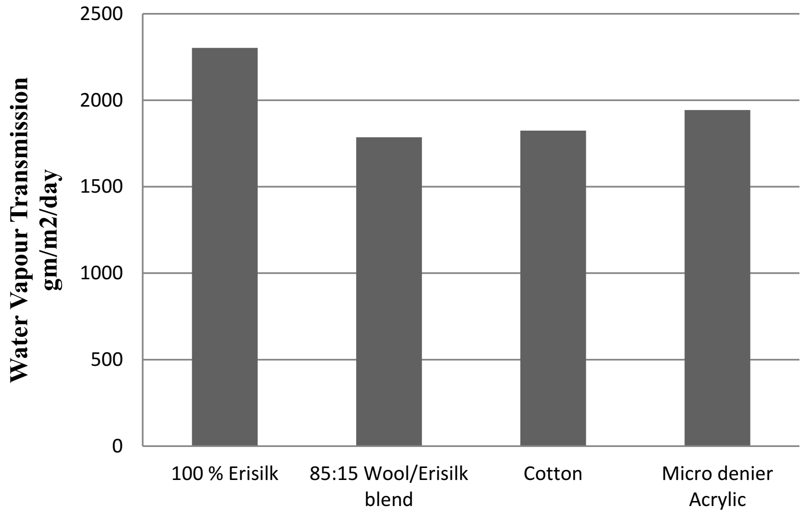

Figure 3. Water vapor transmission values of double layer knitted fabrics.

Statistical analysis

To conclude whether the parameters are significant or not, p values were examined. Ergun emphasized that parameter with $p < .05$ as insignificant and can be ignored. The results of Two-way ANOVA are given in Table 3. From the Table, p value for thermal comfort properties is $p < .05$. This shows that there is significant difference in the thickness and thermal comfort properties at 95% confidence level. Therefore it can be concluded that thickness deteriorate the thermal comfort properties of knitted fabrics.

Conclusion

In this paper, the thermal comfort properties of four different double-layered knitted fabrics have been evaluated. It is observed that 100% eri silk shows that higher air permeability, thermal conductivity, and water vapor transmission values when compared to the other three different materials of double-layered knitted fabrics, which is more suitable for both seasons summer and winter. It is also proved by earlier researchers that through the fabric engineering approach, eri silk fibers can be utilized for textile clothing for both summer and winter wear applications. Whereas 85:15 wool/eri silk double-

Table 3. Statistical analysis.

Source of Variation	SS	df	MS	F	*P*-value	F crit
Air permeability						
Thickness	41.33724	3	13.77908	1.046168	0.0437	4.7571
Air permeability	101771.2	2	50885.58	3863.457	4.67E-10	5.1433
Thermal resistance						
Thickness	0.003082	3	0.001027	1.361577	0.04029	9.2766
Thermal resistance	1.298386	1	1.298386	1720.708	3.08E-05	10.1279
Thermal Conductivity						
Thickness	0.002233	3	0.000744	0.719669	0.04603	9.2766
Thermal Conductivity	1.347425	1	1.347425	1302.502	4.68E-05	10.1279
Water vapor transmission						
Thickness	83309.77	3	27769.92	0.999682	0.5001	9.2766
Water vapor transmission	7707975	1	7707975	277.4774	0.0004	10.1279

layered knitted fabric shows the poor air permeability, thermal conductivity, and water vapor transmission, which is suitable for winter garments. Cotton double-layered knitted fabrics have 16% higher air permeability, 24% higher thermal conductivity, and almost equal water vapor transmission values when compared to 85:15 wool/eri silk. Hence, it is more suitable for summer garments than 85:15 wool/eri silk double-layered knitted fabrics. The micro-denier acrylic double-layered knitted fabric shows closer to 100% eri silk and better than cotton and 85:15 wool/eri silk double-layered knitted fabrics.

Disclosure statement

No potential conflict of interest was reported by the author(s).

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