Study on thermal comfort behaviour of seams made of micro-denier polyester sewing thread for high active sportswear

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Abstract

This work aims to investigate the thermal comfort behaviour of polyester seamed fabric regarding the change in sewing thread filaments fineness for two different seam classes: seam 514 and seam 607. Five seamed fabric samples were constructed with using micro-denier polyester filament of 16.66 tex made of five different filament numbers (38, 48, 108, 144 and 288). It was noticed that the seam thermal properties, air and water vapour permeability, and wicking can be improved if the seam is constructed with using the micro-denier polyester sewing thread. It was also found that the investigated properties increase with the increase in the sewing thread filament fineness on the seam line. The statistical results have also shown that the sewing thread filament fineness is significantly affecting thermal behaviour of the seamed fabric.

Keywords: clothing comfort; seams and stitches; thermal behaviour of seams; sewing thread; micro-denier filaments.

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1. INTRODUCTION

Clothing comfort is an essential garment requirement, especially for garments like sportswear. There are two components of clothing comfort, one is thermo-physiological and the other one is sensorial comfort. Heat and moisture transfer of clothing and the manner of maintaining the heat balance of the human body during activities is termed as thermo physiological wear comfort, while mechanical interaction of the fabric with the skin is termed skin sensorial comfort. The latter indicates possible prickle, irritation, bending, and softness and adherence of the wet fabric [1]. In case that clothing is not transmitting sweat and heat effectively to the surrounding this leads to accumulation of excess heat and could even cause death [2]. Active sportswear design should address both aesthetic requirements and thermal comfort optimization [3]. To attain the comfortable state, the cloth should be able to transmit the body heat and both sensible and insensible perspiration to the surrounding environment quickly.

The moisture management properties are also influencing thermo-physiological properties of cloth [4]. Many studies focus on improving the ability for quick-absorbing and transferring the moisture to the surrounding. In addition to that, seam comfort should be also studied to avoid the body sweat stored on the seam line which can lead to skin rashes due to continuous rubbing of damp seamed fabric during various levels of activities. As mentioned by many researchers, fabric comfort is always different from the seam comfort [4]. Improving the seam comfort will contribute to the overall garment comfort. The seam has a minimum of two layers of fabrics that are joined by the sewing thread. It is proved that the flat lock seam has higher thermal insulation than the overlock and adhesive seams.

Seam's thickness, bulkiness and tightness affect garment thermal comfort properties [5]. Seam consists of multi-layers, which limit the heat and moisture transfer in and around the seams and thereby affect thermal properties of clothing [6]. It was reported in literature that the fabric made of micro-denier polyester shows better comfort properties

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than the fabric made of staple polyester fibre. In the former case, heat enters more quickly because of the smaller diameter of the micro-denier fibres providing also softer feel to the skin [7]. Increase in the fibre liner density leads to increased thermal resistance and lower thermal conductivity and absorptivity, giving a warm feel to the wearer [8].

One approach to improving the seam comfort is by modifying the sewing thread characteristics by which the overall garment comfort can be improved especially for garments like high active sportswear. Traditionally, sportswear seam is constructed by using the sewing thread, which is made of spun polyester yarns. This study is mainly focused on the influence of micro-denier polyester sewing thread on the thermal comfort properties of the flatlock seam. Subjectively, it was observed that the seam made of such a thread provides a softer texture than the seam made of the standard sewing thread. Twist in the yarn is one the factors influencing the wicking of yarn [9]. In this research, a modified sewing thread is made of textured micro-denier polyester yarns with different fineness: from medium fine to micro fibres. A staple micro fibre or filament has the linear density of approximately 1 denier or less [5].

2. MATERIALS AND METHODS

2. 1. Sewing thread preparation

In order to study the impact of micro-denier filaments on the seam comfort properties, five sewing threads with different fibre fineness (from medium fine to micro fibres) are taken. The fabric used for constructing seams was 100 % polyester which is manufactured in Tirupur, India. Sewing threads of 16.6 tex are made of textured micro-denier polyester filaments with five different filament numbers 38, 48, 108, 144, and 288 with the low twist per metre 157, represented as 3.94, 3.1, 1.38, 1.04, and 0.52 dpf (denier per filament), respectively. These polyester filaments are manufactured by Reliance Industries limited, India.

2. 2. Seam preparation

As per the ASTM D6193-11 standard practice for stitches and seams, the most common ones that are used for the construction of sportswear are the Class 500 overlock or overedge and the Class 600 covering stitch or flatlock [4].

2. 3. Flatlock and overlock stitch seam

For the most commonly used Stitch class 607, five thread flatlock stitched seams were constructed using the Class 2: lapped seams are prepared using five different sewing threads (*i.e.* 3.94, 3.1, 1.38, 1.04, and 0.52 dpf) and are represented as FLseam1 to FLseam5, respectively. Similarly, for the second important stitch class 514, four thread overlock stitched seams are constructed using the Class 5: superimposed seams are prepared using the same five different sewing threads (with the same different finenesses) represented as OLseam1 to OLseam5, respectively.

Increasing the number of seams within the sample increases the impact of seams on the overall thermal comfort components of the tested sample. The flatlock seams are prepared by overlapping the fabric raw edges for a small magnitude of seam allowances. This flatlock seam employs 3 needle threads, 1 looper thread and 1 spreader. The overlock seams are prepared by overlapping the two fabric raw edges and sewing together and it is pressed to one side when it is opened. It employs 2 needle threads and 2 looper threads. The gap between seams was maintained as 2.54 cm in both flatlock and overlock seamed fabric (Table 1). 10 samples in total were constructed, with five overlock seams of various finenesses and five flatlock seams of various finenesses.

2. 4. Air permeability

Textest FX 3300 air permeability tester (TEXTEST made in Switzerland) was used to evaluate the air permeability of all samples at a pressure of 100 Pa (according to the standard ASTM D737-18). Average of ten readings was noted for each sample. All the test samples are tested at standard atmospheric conditions (22°C and 65% RH).

2. 5. Moisture vapour transmission rate

Moisture vapour transmission rate was evaluated by Permetest instrument (Labthink Instruments Co.Ltd, China) based on the ISO 11092 standard.

2. 6. Thermal conductivity and resistivity

Thermal comfort properties of seamed fabrics are measured by using an Alambeta instrument (Sensora, Liberec, Czech Republic). The seamed fabric with a series of stitches is tested as per the test procedure of the standard ISO 11092. Thermal resistivity is calculated by the equation:

$$R = h / \lambda \tag{1}$$

where R is the thermal resistance, h is the fabric thickness and λ is the thermal conductivity.

2. 7. Vertical wicking

The fabric samples were cut into 25.4×2.54 cm strips; seam lines were introduced along the lengthwise centreline of the strip and immersed vertically in a distilled water container up to 2 cm of the fabric sample for determining the vertical wicking behaviour of seamed and unseamed fabric. Every 5 min, the water travelled upward on the strip was measured as the height of wicking of water by the sample and each sample was inspected. This test was carried out as per the BS 3424 standard.

2. 8. Statistical analysis

The One-way ANOVA test results prove that there are significant differences in thermal characteristics when the sewing thread filament fineness varies on the seam line and there are significant differences in thermal characteristics among the various seam and stitch classes. The results of the ANOVA analysis are tabulated in Table 2. In order to confirm the reliability of the results, Tukey HSD method is also done using SPSS software and the results are shown in the Table 3.

Table 1: Technical parameters of seams constructed with single jersey 100% polyester fabric (175 g m^{-2} weight); stitch density in all cases was 4 stitches per cm

Sample	Seam class and stitch class	Seam thickness, mm	Sewing thread filament fineness, dpf
Seam 1	Class1: Superimposed seam; Stitch class: 514 (Overlock stitch)	1.90	3.94
	Class2: Lapped seam; Stitch class: 607 (Flatlock stitch)	1.80	3.94
Seam 2	Class1: Superimposed seam; Stitch class: 514 (Overlock stitch)	1.81	3.10
	Class2: Lapped seam; Stitch class: 607 (Flatlock stitch)	1.79	3.10
Seam 3	Class1: Superimposed seam; Stitch class: 514 (Overlock stitch)	1.75	1.38
	Class2: Lapped seam; Stitch class: 607 (Flatlock stitch)	1.66	1.38
Seam 4	Class1: Superimposed seam; Stitch class: 514 (Overlock stitch)	1.63	1.04
	Class2: Lapped seam; Stitch class: 607 (Flatlock stitch)	1.62	1.04
Seam 5	Class1: Superimposed seam; Stitch class: 514 (Overlock stitch)	1.58	0.52
	Class2: Lapped seam; Stitch class: 607 (Flatlock stitch)	1.50	0.52

3. RESULT AND DISCUSSION

3. 1. Thermal conductivity

Thermal conductivity values of seams made of sewing threads with different filament fineness are shown in Figure 1. The results show that the thermal conductivity of the seamed fabric is increased when using finer sewing thread filaments. Finer fibre allows heat enters the fibre quickly helping the garment to maintain the heat balance [10]. The seams made of threads with fine filaments have thus better heat conductivity when compared to those made of threads with coarser filaments so that the overall increase in thermal conductivity from seem 1 to 5 is significant (Fig. 1). However, the differences between the values determined for seams 1 and 2 as well as for 3 and 4 are not as pronounced as differences in values determined for seams 2 and 3 and seams 3 and 5. These results correspond to differences in filament finenesses (*e.g.* the fineness difference for the seams 1 and 2 is 0.86 dpf, while for seams 2 and 3 it is 1.7 dpf). When comparing the overlock and flatlock seams, the latter shows higher thermal conductivity for all filament finenesses. This may be due to the slight differences in the seam thickness as well as in the stitch patterns.

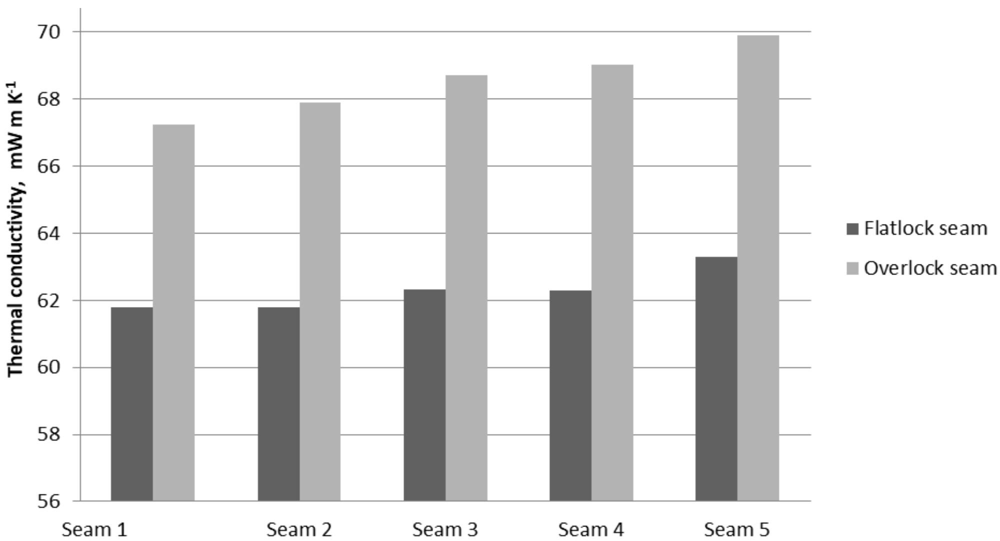

Figure 1. Thermal conductivity of seams made of sewing threads with different filament finenesses

3. 2. Thermal resistance

Thermal resistances of seamed fabric made with sewing threads with different filament finenesses are shown in Figure 2. Seam thermal resistance is determined by the seam thickness and the seam thermal conductivity. The amount of heat-insulated by the seam is decreased with the increase in the sewing thread filament fineness. Finer fibres conduct heat easily and quickly [10]. Thus, the heat transfer is faster in seams made of finer filaments. A decrease in the thermal resistance is seen from the seam 2 to 3 possibly due the decrease in the seam thickness (Table 1) and the increase in the thermal conductivity (Fig. 1). Though there are significant changes in thermal conductivity from the seam 1 to 5 (Fig. 1), there is an only slight change in the seam thickness (Table 1). This is the reason why there is a lower impact on the thermal resistivity for the seam range 3 to 5 (Fig. 2).

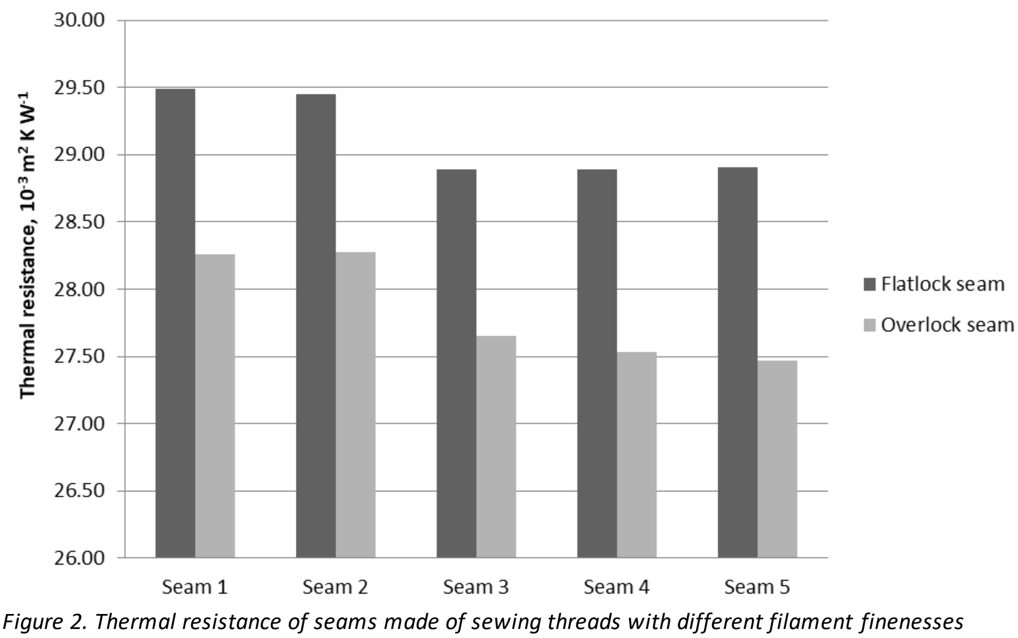

Figure 2. Thermal resistance of seams made of sewing threads with different filament finenesses

3. 3. Moisture vapour transmission rate

Figure 3 presents the water vapour permeability of seams made of micro-denier polyester sewing threads with different filament finenesses showing that the sewing thread fineness plays a vital role in moisture vapour transmission on the seam line. The seam 1 made of coarser filament sewing threads was characterized by the lowest moisture vapour transmission rate, whereas the seam 5 had the highest moisture vapour transmission rate. When the sewing thread becomes finer and the number of filaments is increased, gaps are establishes through which moisture vapour passes from one to the other side of the seam line. The sewing thread is not tightly packed since it has lower number of twists per length (TPI 3 to 4) than the standard sewing thread (TPI 24 to 26) which is also a major factor for creating the gaps among filaments. There are more gaps between finer filaments through which the moisture escapes easier when compared to the coarser filaments.

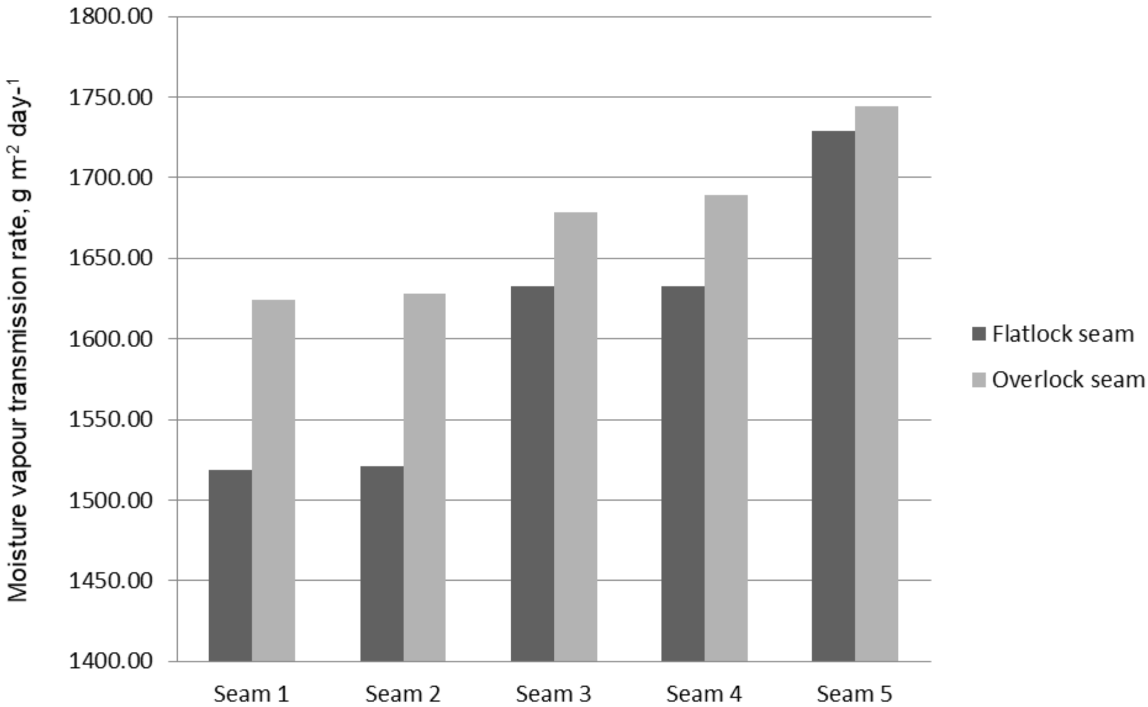

Figure 3. Moisture vapour transmission rate of seams made of sewing threads with different filament finenesses

3. 4. Air permeability

Air permeability of the seamed fabric was determined by measuring the airflow rate passing through the series of seams of a specified area under the standard air pressure. Figure 4 clearly shows that the airflow through the seamed fabric is significantly influenced by the sewing thread characteristics. Airflow increases with an increase in the sewing thread fibre fineness from the seam 1 to 5. A fabric which is allowing moisture transport will usually allow the air transport, too, since air and water vapour permeabilities are closely connected. Air permeability as well as the water vapour permeability of the fabric were improved by the increase in the yarn fineness (Figs. 3 and 4), which provides a less dense structure [11]. This increased airflow may be due to the gaps between the increased number of polyester filaments in the sewing thread for the same sewing thread size. There is no significant change between the seams 1 to 2 due to only slight changes in the sewing thread filament fineness.

3. 5. Wicking

Figure 5 shows wicking properties of the investigated seams. It is evident that the wicking height is increased with the increase in the sewing thread filament fineness on the seam line. Micro-fibres are absorbing water amounting to more than seven times the fibre weight and dry in one-third of the time required for drying of ordinary fibres. Capillary action in the micro-filament sewing thread is better than in a normal denier fibre [10]. This action can be apparently improved by increasing the sewing thread fineness.

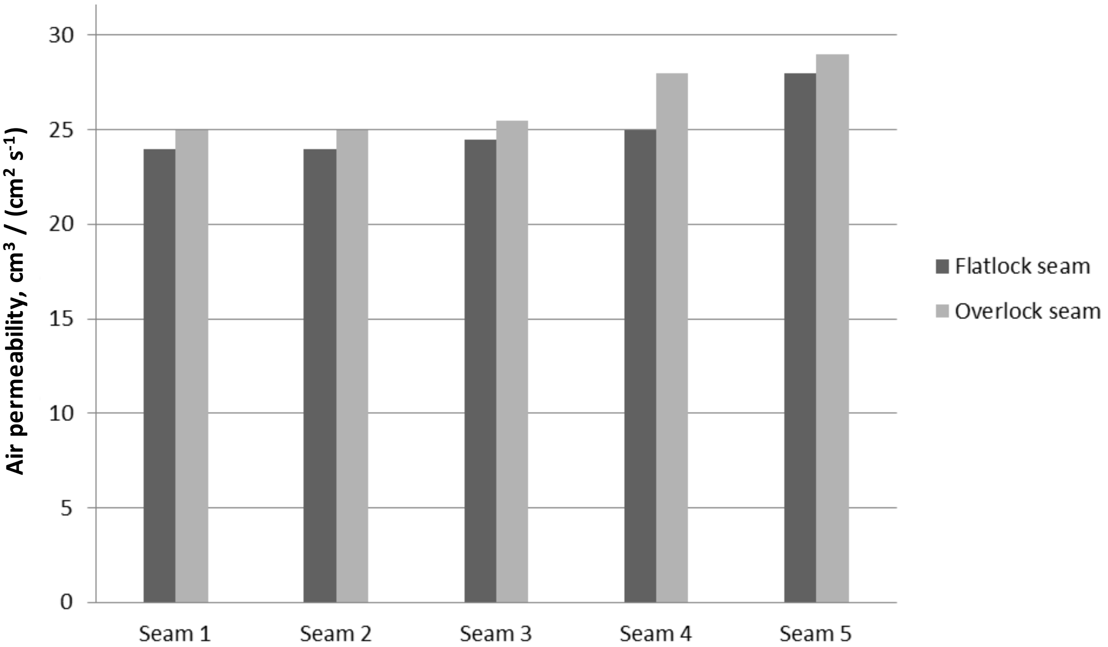

Figure 4. Air permeability of seams made of sewing threads with different filament finenesses

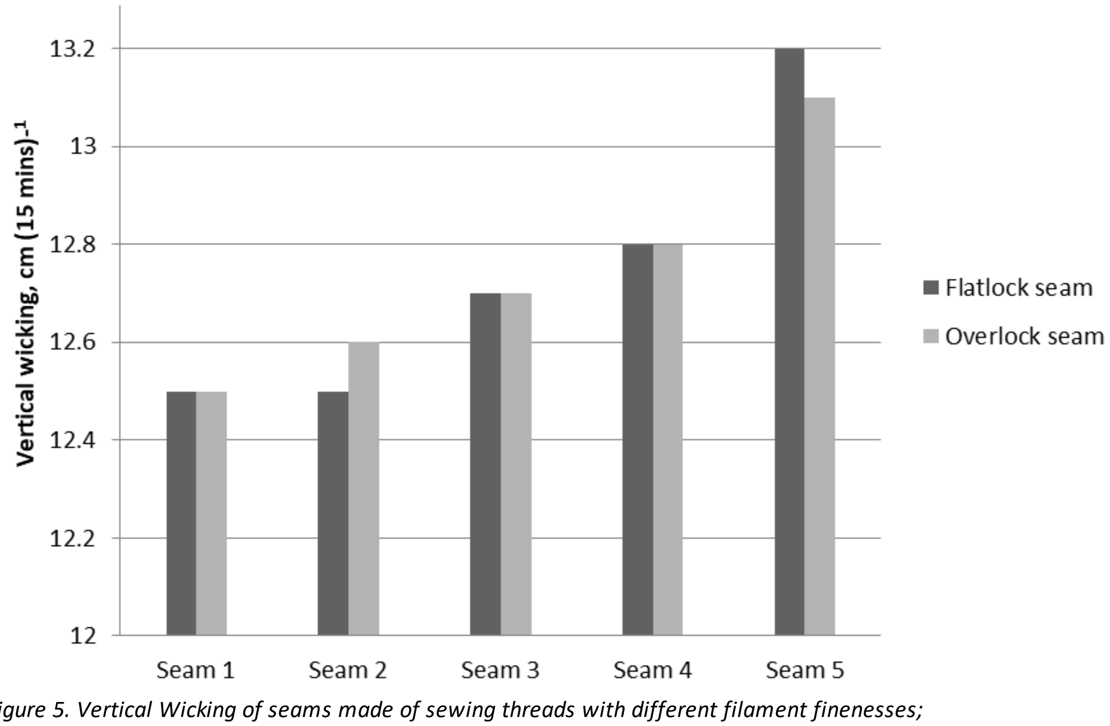

Figure 5. Vertical Wicking of seams made of sewing threads with different filament finenesses;

3. 6. Statistical analysis

One-way analysis of variance (ANOVA) has been performed at 0.05 significant level and the results are shown in Table 2. For all the responses it was obtained that $F_{critical} < F_{actual}$, which means that the sewing thread fineness significantly affects the investigated thermal comfort properties of the seam. Even a slight change in the sewing thread filament fineness is significantly affecting the thermal comfort properties of seams and obviously it will affect the garment's overall comfort. The results of thermal conductivity and thermal resistance are tested by using the Tukey's

HSD (Honestly significant difference) test, too (Table 3). It is evaluated which pairs of the results among all the results are significantly different with respect to each other. The p-value of the given result corresponding to the *F*-statistic of one-way ANOVA, lower than 0.01 strongly indicates that one or more pairs of samples are significantly different. The *Q* critical value ($Q_{(5,40)}$= 4.93) is lower than the *Q* actual value for all the pair comparisons. This analysis strongly confirmed that the sewing thread filament fineness greatly influences the thermal comfort properties of seams.

Table 2: Statistical analysis using one-way ANOVA

Seam type	Thermal conductivity, mW m K^{-1}		Thermal resistance, 10^{-3} m^2 K W^{-1}		Moisture vapour trans-mission rate, g m^{-2} day^{-1}		Air permeability, cm^3 / (cm^2 s^{-1})		Vertical wicking, cm (15 min)$^{-1}$	
	F value	*P* value*	*F* value	*P* value*	*F* value	*P* value*	*F* value	*P* value*	*F* value	*P* value*
Flatlock seam	1954.42	1.1102	381769.21	1.1102	2273.21	1.1102	4267.66	1.1102	1162.70	1.1102
Overlock seam	9720.68	1.1102	1,740.11	1.1102	1339.79	1.1102	4541.91	1.1102	129.71	1.1102

*All *P* values should be multiplied by 10^{-16}

Table 3: Post hoc Tukey HSD multiple comparisons

Dependent variable	Comparisons between samples	Standard error	Significant difference	95 % confidence interval	
				Lower bound	Upper bund
Thermal conductivity	SEAM4 *vs.* SEAM5	0.798758	0.000	-8.82174	-4.37926
	SEAM3 *vs.* SEAM5	0.798758	0.000	-11.06474	-6.62226
	SEAM3 *vs.* SEAM4	0.798758	0.000	-4.46424	-0.02176
	SEAM2 *vs.* SEAM5	0.798758	0.000	-11.82524	-7.38276
	SEAM2 *vs.* SEAM4	0.798758	0.003	-5.22474	-0.78226
	SEAM2 *vs.* SEAM3	0.798758	0.000	-2.98174	1.46074
	SEAM1*vs.* SEAM5	0.798758	0.000	-15.82724	-11.38476
	SEAM1 *vs.* SEAM4	0.798758	0.000	-9.22674	-4.78426
	SEAM1 *vs.* SEAM3	0.798758	0.000	-6.98374	-2.54126
	SEAM1 *vs.* SEAM2	0.798758	0.000	-6.22324	-1.78076
Thermal r esistance	SEAM4 *vs.* SEAM5	0.722149	0.000	068330	3.33309
	SEAM3 *vs.* SEAM5	0.722149	0.000	-0.01646	3.99994
	SEAM3 *vs.* SEAM4	0.722149	0.000	-1.34135	2.67504
	SEAM2 *vs.* SEAM5	0.722149	0.000	1.74120	5.75760
	SEAM2 *vs.* SEAM4	0.722149	0.001	0.41631	4.43270
	SEAM2 *vs.* SEAM3	0.722149	0.000	-0.25054	3.76586
	SEAM1 *vs.* SEAM5	0.722149	0.000	2.91111	6.92751
	SEAM1 *vs.* SEAM4	0.722149	0.000	1.58622	5.60262
	SEAM1 *vs.* SEAM3	0.722149	0.001	0.91937	4.93577
	SEAM1 *vs.* SEAM2	0.722149	0.001	-0.83829	3.17811

*The mean difference is significant at the 0.01 level

5. CONCLUSIONS

Increase in the sewing thread filament fineness leads to the higher thermal conductivity and lower thermal resistance in seams. Increase in the filament fineness induces also the increase in air and moisture vapour permeabilities attributable to the enhanced availability of free voids in the seam structure. Vertical wicking of the seams made of different fibre finenesses are slightly influenced by the fibre fineness in both overlock and flatlock seams. Overall thermal comfort properties of overlock seams were better when compared to the flatlock seam due to the larger seam thickness and bulkiness in the latter case. The conclusion is that the seams made of micro-denier polyester sewing thread provide better thermal comfort than overclock seam. The study concludes that the thermal comfort properties of seams can be improved by reducing sewing thread filament fineness.

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Toplotni komfor šavova formiranih upotrebom šivaćeg konca od poliestarskih mikrofilamenata namenjenih za profesionalnu sportsku odeću

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(Naučni rad)

Izvod

Cilj ovog rada je ispitivanje svojstava toplotnog komfora poliestarske pletenine sa šavovima izrađenim od poliestarskih šivaćih konaca različite finoće filamenata. Primenjene su dve vrste iz dve različite klase šavova – 514 i 607. Konci za šivenje iste finoće 16,66 tex izrađeni su od različitog broja teksturiranih poliestarskih filamenata (38, 48, 108, 144 and 288). Na taj način, eksperimentalni materijal je obuhvatio ukupno 10 različitih uzoraka sa šavovima svrstanim u pet grupa (različita finoća filamenata) sa po dve vrste šava. Uočeno je da se termička svojstva, propustljivost vazduha i vodene pare, i kapilarno kvašenje šava mogu poboljšati upotrebom poliestarskog šivaćeg konca izrađenog od finijih (mikro) filamenata. Takođe, utvrđeno je da se sa povećanjem finoće filamenata šivaćeg konca povećava propustljivost vazduha i vodene pare, kapilarno kvašenje i sposobnost prenosa toplote na liniji šava. Uticaj finoće filamenata šivaćeg konca na toplotni komfor šavova potvrđen je statističkom analizom.

Ključne reči: udobnost odeće; šavovi i ubodi; termičko ponašanje šavova; konac za šivenje; mikro-dener filamenti