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Influence of the Knitting Structure of Double-Layered Fabrics on the Heat Transfer Process

Abstract

Most of the studies carried out in this area have been devoted to measuring static thermal properties. Nevertheless, not only the amount of heat released to the environment is important but also the process of heat transmission over time. However, investigations in the field of the heat transfer process through knitted fabrics are very few, especially through double-layered weft knitted fabrics from a combination of natural or man-made yarns in one layer with synthetic thread. The main goal of this work was to investigate which structural parameter – the knitting pattern structure or raw composition of the knit – influences the heat transfer process through double-layered fabrics at a higher level. It was found that the structure of the knit highly influences the heat transfer process as distinct from the raw composition of knit.

Key words: heating dynamic, double-layered fabric, weft knitted fabric.

Introduction

Clothing designed for leisure sports is worn not only for aesthetical reasons but also for special control functions of the human body [1]. Clothing must assist the body's thermal control function under changing physical loads in such a way that the body's thermal and moisture management is balanced and a microclimate is created next to the skin [2].

During the investigation, double-layered weft knitted fabrics for leisure sports were designed in order to make physiological and thermal comfort. A typical double-layered construction of knitted fabrics includes the following elements [3 - 5]:

- One layer of knitted fabric made of conductive and diffusive yarns, which directly adjoins the body. Its role is to remove and transport sweat from the body in liquid and vapour forms.
- Another layer of knitted fabric made of absorptive yarn, which is not in direct contact with the skin. The role of this layer is to keep humidity far from the body and vaporise it to the environment.

Consumers of textile and clothing products are becoming increasingly aware of the importance of comfort. In addition to aesthetic appearance, comfort is one of the main properties of clothing which affect the choice of a product. Thermal comfort is a subjective concept recognised by the person experiencing it. A state of comfort can only be achieved when clothing comfort includes three main considerations: thermo-physiological, and sensorial and psychological comfort [1, 4]. Clothing

must assist the body's thermal control function under changing physical loads in such a way that the body's thermal and moisture management is balanced and a microclimate is created next to the skin [6 - 8].

Human thermal comfort depends on a combination of clothing, climate, and physical activity. The human organism is homoeothermic, which means that it has to maintain its core temperature within close limits around 37 °C. During all kinds of activity, the human body produces a certain amount of heat, for example, in the range of 80 W while sleeping, to over 1000 W during intensive effort [6, 7]. The basic heat transfer mechanisms (conduction, convection and radiation) are well known to anyone in engineering. All following heat transfer mechanisms coexist in the heat transfer process from a heated surface through a porous fabric attached onto it. In general, heat transfer from the heated body to the fabric takes place by convection, conduction and radiation concurrently [8 - 11]. This process through textiles is very sophisticated and not easily described theoretically or predicted [9, 10].

The thermal property of knitted fabric is very important not only for its thermal comfort but also for protection against cross weather conditions [12]. The thermal resistance of clothing as a set of textile materials depends on the thickness and porosity of the particular layer. The warmth of a fabric is due to insulation provided by air trapped between fibres and yarns. Fabrics from strain filament yarns remove heat rapidly by conduction when placed next to the skin. Fabrics

from hairy yarns feel warm on contact with the skin due to the insulating air held between the fabric fibres and the skin [8, 11].

Hitherto most of the studies carried out have been devoted to measuring static thermal properties. Nevertheless, not only the amount of heat released to the environment is important but also the process of heat transmission over time. However, there are few investigations in the field of the heat transfer process through knitted fabrics, especially double-layered weft knitted fabrics made from a combination of natural or man-

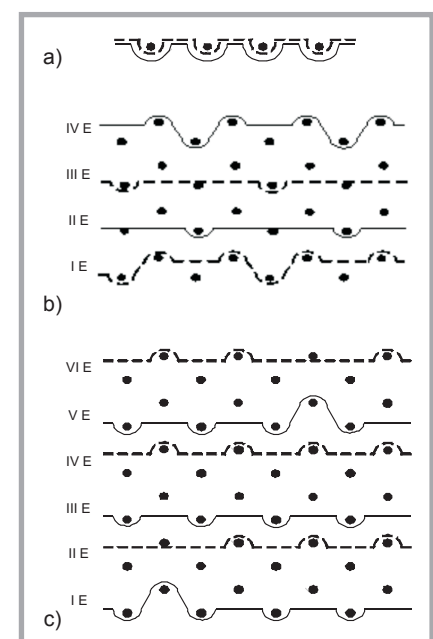


Figure 1. Pattern of knitted fabrics investigated: a) plain plated single jersey, b) combined I (piqué), c) combined II; ——— cotton C or bamboo B yarn, - - - - - PP, PA, PES, or Coolmax yarn.

made yarns in one layer with the synthetic threads.

The main goal of this work was to investigate which structural parameter – the knitting pattern structure or the raw composition of the knit – influences at a higher level the heat transfer process through double-layered fabrics.

Object and methods of investigation

Investigations were carried out on double-layered fabrics knitted on a circular knitting machine at a gauge of 22E in a plain plating pattern with two types of combined structure and made from cotton or man-made bamboo yarns in the outer (located outer from the skin) layer and PP, PA, PES & Coolmax® (tetra-channel fibres by DuPont) yarns in the inner (located next to the skin) layer. Characteristics of the knitted fabrics tested are presented in **Table 1**, and the knitting structure – in **Figure 1**.

All experiments were carried out in a standard atmosphere according to the standard ISO 139:2002. Structure parameters of the knitted samples were analysed according to British Standard BS 5441:1998.

Air permeability tests of the double-layered knitted fabrics investigated were conducted according to Standard EN ISO 9237:1997, using a head area of 10 cm² and pressure difference of 100 Pa [3].

The heat interchange dependence on the structure and raw material of the knitted fabrics was investigated using an IG/ISOC (Giuliani Technologies, Italy) device designed for the establishing of heat insulation. The measurement error of the digital thermometer with a platinum thermo sensor was equal to $\pm (0.071 \div 0.076)$ °C. The knitted fabric was laid down on a heated plate and a thermo sensor was superimposed on the outward side (knitted from cotton or man-made bamboo yarns) of the fabric. The plate was heated up to 40 °C, and the temperature was recorded every 10 seconds. Changes in temperature were observed for 14 minutes and recorded every 10 seconds until the results were within the margins of error. The results of changes in the temperature of the fabrics tested are presented in **Table 2**.

Results and discussion

What is very important for consumers of sports clothing is the ability of clothing

Table 1. Characteristics of knitted fabrics tested. **Note:** the relative error of all counts δ is less than 5%.

| Sample code | Pattern | Linear density of yarns and percentage composition | Course density A, cm ⁻¹ | Wale density B, cm ⁻¹ | Loop length, l, mm | Thickness, b, mm | Air permeability, dm ³ /(m ² ·s) |
|-------------|---------------------|--|------------------------------------|----------------------------------|--------------------|------------------|--|
| LSI-1 | Plain plated | Cotton, 20 tex, 71% | 24.5 | 12.5 | 2.84 | 0.617 | 860 |
| | | PA, 7.8; 29% | | | | | |
| LSI-2 | | Cotton, 20 tex, 71% | 24.5 | 12.5 | 2.79 | 0.692 | 852 |
| | | Coolmax, 7.8; 29% | | | | | |
| LSI-3 | | Cotton, 20 tex, 71% | 24.5 | 12.5 | 2.79 | 0.646 | 855 |
| | | PES, 8.3; 29% | | | | | |
| LSI-4 | | Cotton, 20 tex, 71% | 25 | 12 | 2.88 | 0.661 | 899 |
| | | PP, 8.4; 29% | | | | | |
| LSII-1 | | Bamboo, 20 tex, 71% | 24 | 12.5 | 2.85 | 0.524 | 896 |
| | | PA, 7.8; 29% | | | | | |
| LSII-2 | | Bamboo, 20 tex, 71% | 24 | 12.5 | 2.81 | 0.658 | 871 |
| | | Coolmax, 7.8; 29% | | | | | |
| LSII-3 | | Bamboo, 20 tex, 71% | 24 | 12.5 | 2.81 | 0.566 | 881 |
| | | PES, 8.3; 29% | | | | | |
| LSII-4 | Bamboo, 20 tex, 71% | 24.5 | 12 | 2.93 | 0.590 | 927 | |
| | PP, 8.4; 29% | | | | | | |
| KI-1 | Combined (pique) | Cotton, 20 tex, 71% | 16 | 12 | 3.11 | 0.908 | 863 |
| | | PA, 7.8; 29% | | | | | |
| KI-2 | | Cotton, 20 tex, 71% | 16 | 12 | 3.10 | 1.142 | 882 |
| | | Coolmax, 7.8; 29% | | | | | |
| KI-3 | | Cotton, 20 tex, 71% | 16 | 12 | 3.10 | 0.988 | 877 |
| | | PES, 8.3; 29% | | | | | |
| KI-4 | | Cotton, 20 tex, 71% | 16 | 11 | 3.21 | 1.028 | 920 |
| | | PP, 8.4; 29% | | | | | |
| KII-1 | Combined | Cotton, 20 tex, 76% | 15 | 11.5 | 3.24 | 1.243 | 788 |
| | | PA, 7.8; 24% | | | | | |
| KII-2 | | Cotton, 20 tex, 76% | 15 | 11.5 | 3.26 | 1.474 | 779 |
| | | Coolmax, 7.8; 24% | | | | | |
| KII-3 | | Cotton, 20 tex, 76% | 15 | 11.5 | 3.26 | 1.268 | 772 |
| | | PES, 8.3; 24% | | | | | |
| KII-4 | | Cotton, 20 tex, 76% | 15 | 11 | 3.35 | 1.392 | 876 |
| | | PP, 8.4; 24% | | | | | |

Table 2. Temperature in °C of knitted fabrics tested.

| Sample code | Time, s | | | | | | | | | | | | | |
|-------------|---------|------|------|------|------|------|------|------|------|------|------|------|------|------|
| | 0 | 10 | 20 | 40 | 60 | 80 | 100 | 120 | 240 | 360 | 480 | 600 | 720 | 840 |
| LSI-1 | 23.0 | 24.2 | 25.6 | 28.2 | 30.0 | 31.6 | 32.6 | 33.0 | 35.4 | 36.4 | 36.6 | 36.8 | 37.0 | 37.0 |
| LSI-2 | 23.0 | 24.0 | 25.4 | 27.8 | 29.6 | 31.0 | 32.0 | 32.8 | 35.0 | 35.6 | 36.4 | 36.8 | 36.8 | 36.8 |
| LSI-3 | 23.0 | 24.2 | 25.6 | 28.0 | 29.8 | 31.0 | 32.2 | 33.0 | 35.2 | 36.2 | 36.8 | 36.8 | 37.0 | 37.0 |
| LSI-4 | 23.0 | 24.2 | 25.4 | 28.0 | 29.4 | 31.2 | 32.0 | 32.6 | 35.0 | 36.0 | 36.4 | 36.6 | 36.6 | 36.6 |
| LSII-1 | 23.0 | 24.4 | 25.2 | 28.0 | 29.8 | 31.0 | 31.8 | 32.6 | 34.4 | 35.4 | 36.2 | 36.8 | 36.8 | 37.0 |
| LSII-2 | 23.0 | 24.2 | 25.6 | 27.6 | 29.6 | 30.6 | 31.8 | 32.0 | 34.6 | 35.6 | 35.8 | 36.0 | 36.4 | 36.6 |
| LSII-3 | 23.0 | 24.4 | 26.2 | 28.6 | 30.0 | 31.0 | 32.0 | 32.6 | 35.2 | 36.0 | 36.2 | 36.4 | 36.6 | 36.8 |
| LSII-4 | 23.0 | 24.4 | 25.4 | 28.0 | 29.6 | 30.6 | 31.8 | 32.4 | 34.6 | 35.8 | 36.4 | 36.4 | 36.4 | 36.6 |
| KI-1 | 23.0 | 24.0 | 25.0 | 27.0 | 28.2 | 29.2 | 30.2 | 31.0 | 33.4 | 34.8 | 35.6 | 35.8 | 35.8 | 35.8 |
| KI-2 | 23.0 | 23.8 | 24.8 | 26.8 | 28.4 | 29.4 | 30.2 | 31.2 | 33.4 | 34.6 | 35.2 | 35.8 | 35.8 | 35.8 |
| KI-3 | 23.0 | 24.0 | 25.0 | 27.0 | 28.6 | 29.6 | 30.6 | 31.4 | 33.8 | 34.6 | 35.4 | 35.8 | 36.2 | 36.4 |
| KI-4 | 23.0 | 24.0 | 25.0 | 26.8 | 28.6 | 29.4 | 30.4 | 31.2 | 33.6 | 35.0 | 35.6 | 35.8 | 35.8 | 35.8 |
| KII-1 | 23.0 | 24.0 | 25.0 | 26.6 | 27.8 | 29.2 | 30.0 | 30.8 | 33.4 | 34.6 | 35.4 | 35.6 | 36.0 | 36.0 |
| KII-2 | 23.0 | 23.8 | 24.8 | 26.8 | 28.0 | 29.2 | 30.2 | 30.8 | 33.6 | 34.8 | 35.6 | 35.8 | 35.8 | 36.0 |
| KII-3 | 23.0 | 24.0 | 25.0 | 26.8 | 28.2 | 29.2 | 30.2 | 30.8 | 33.6 | 34.6 | 35.2 | 35.4 | 35.8 | 36.0 |
| KII-4 | 23.0 | 23.8 | 24.8 | 26.6 | 28.2 | 29.2 | 30.0 | 30.8 | 33.4 | 34.6 | 35.4 | 35.6 | 35.8 | 35.8 |

to release heat from the body to the environment. The quick exchange of heat allows the well-being of the athlete. Even a few tithes of temperature degree can

influence the health and well-being of a human [6, 7].

The measurements of heat exchange for all knits investigated are presented in

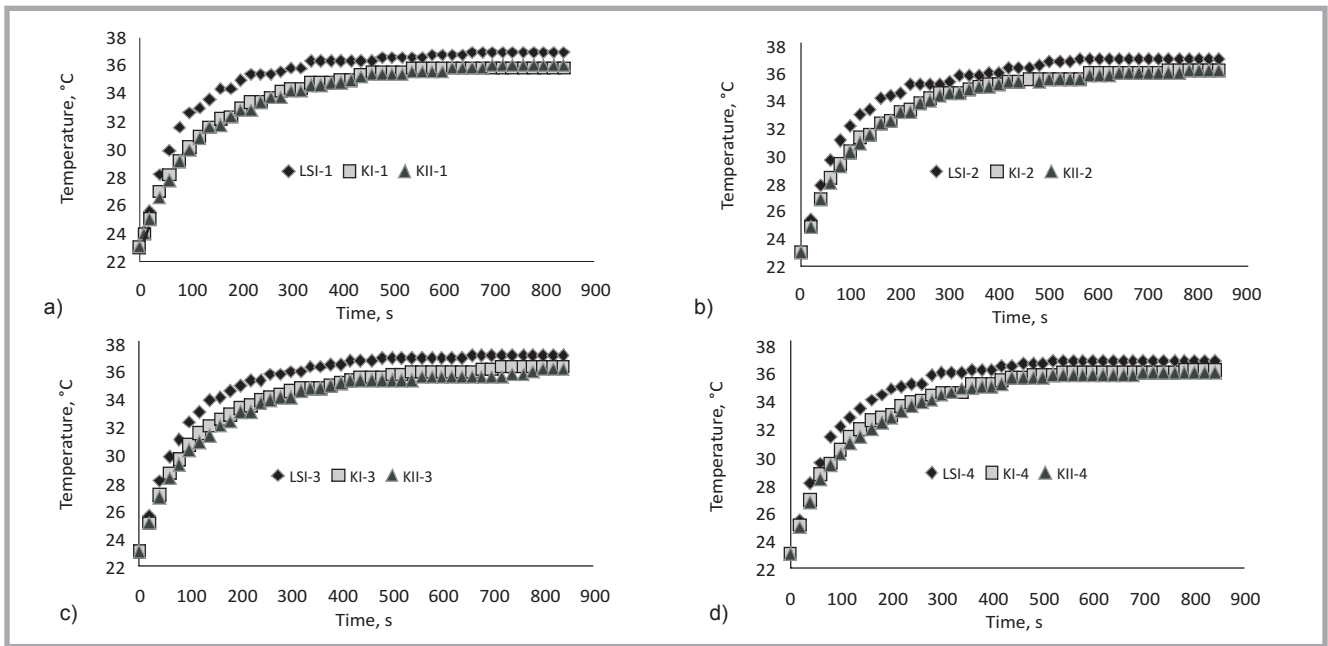


Figure 2. Influence of the knitting structure (LSI, KI, KII) of fabrics knitted from cotton yarns and PA (a), Coolmax (b), PES (c), and PP (d) threads on the heat transfer process.

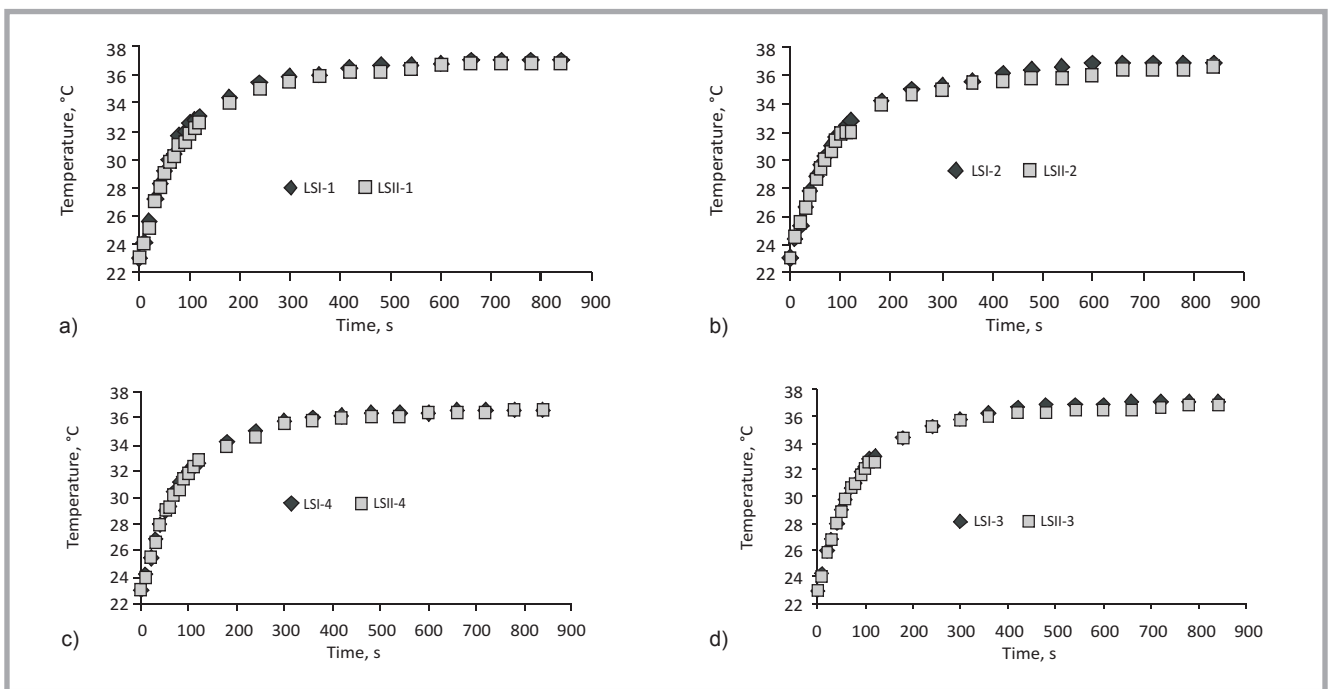


Figure 3. Influence of the raw composition of fabrics knitted from cotton or man-made bamboo yarns with PA (a), Coolmax (b), PES (c), and PP (d) threads in a plain plated pattern on the heat transfer process.

Table 2 and **Figures 2 & 3.** The curves present average values calculated from five tests for each knit at each time point (the coefficient of variation of the measurements ranges from 0.84% to 2.51%).

As shown in **Figures 2** and **3**, the knitting structure has the main influence on the heat exchange process, whereas the impact of raw material composition on the process of heating through the knits investigated is very low. The results of

temperature measurements between knits LSI and LSII and between other knits in the same knitting pattern group are very close. Hence, it may be concluded that the raw material commonly used for this type of clothing has no significant effect on the heat transfer process, while there is a clear influence of the knitting structure (**Figure 2**). Heat transfer through the plain plated knitted fabric is faster than through the fabrics of combined structure. In the plain plated structure

the loops are ranged in one layer, only the threads are spread over two layers, whereas in a combined structure knitted on a double-bed knitting machine, the loops are ranged in two layers, connected only in certain places. Therefore the amount of air in the knit of the combined structure is greater than in the plain plated structure. On the other hand, air is the best thermal insulator. Consequently, because the heat transfer process through plain plated knitted fabric is faster, this

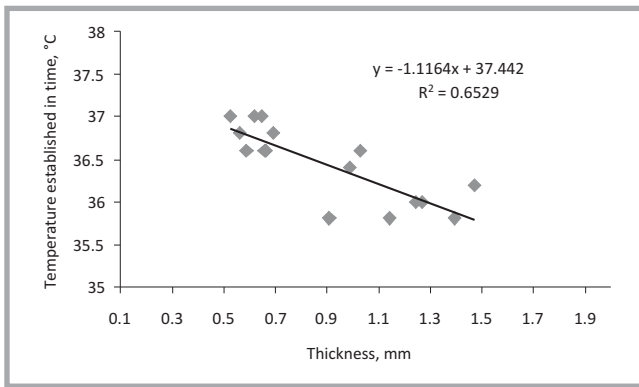


Figure 4. Dependence of temperature established in time on the thickness of knitted fabric.

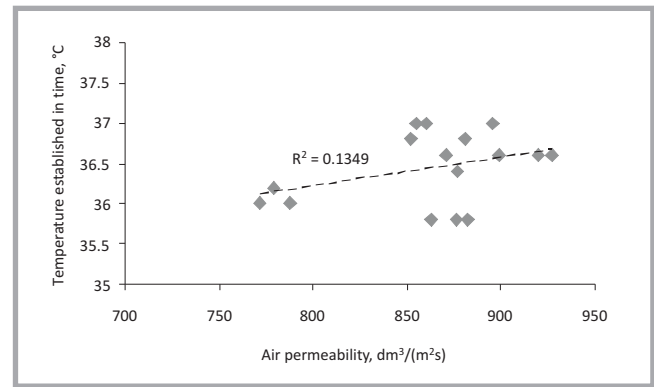


Figure 5. Dependence of temperature established in time on air permeability.

structure may be recommended for warmer seasons (in order to reduce body temperature), whereas the fabrics knitted with a combined structure are more suitable for a cold season.

The results of both of the combined structures investigated (KI and KII) are close, but there is a tendency that the heat transfer process through knit KI is faster (for all variants of raw composition) than through knit KII. In the combined structure KI separate layers are connected through the loops in each course and every second wale, while in the combined structure KII separate layers are connected through twice as many loops – in every second course and every fourth wale. Therefore, as a result of the looser structure, the heat transfer process through fabric KII proceeds more slowly and can be regarded as insignificant.

Many researchers state that heat transfer immediately depends on fabric thickness. The results obtained, presented in **Figure 4**, show that such a dependence is not strong (the coefficient of determination is low $R^2 = 0.6529$), proving that the heat transfer process depends not only on the thickness of the fabric but also on the knitting structure, because the amount of air in the knitted fabric also depends on the order of loops ranged in the fabric. Consequently, to maintain that thickness is the main factor determining the heat transfer process through knitted fabric is not right. Talking about the relevant dependence of heat interchange on thickness is possible only for fabrics knitted in the same knitting pattern.

It was also found that the heat transfer rate through the fabric is not related to its air permeability. The results presented in **Figure 5** illustrate this phenomenon,

which could be explained as follows: The air permeability strongly depends on the porosity of the fabric through which air is permitted, whereas fabric porosity has an influence only to a certain level of the thermal resistance of the fabric. This proves once again that the heat transfer process strongly depends on the structure of the knit.

Conclusions

- The heat transfer process depends on the knitting pattern because the structure of the knit determines the amount of air therein, which depends on the order of loops ranged in the fabric
- The raw material commonly used for active leisure clothing has no significant effect on the heat transfer process.
- The use of air permeability or thickness for the prediction of the thermal properties of knits is an insufficient method because the thermal properties also depend on the structure of the knit.

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