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Statistical Study on the Effect of Yarn Fineness on Heat and Mass Transfer Properties of Single Jersey Knitted Fabrics

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Abstract
Heat and mass transfer properties of textile fabrics determine thermal comfort. This paper introduces a statistical study on the contribution of yarn fineness to the heat and mass transfer properties of single jersey cotton and polyester fabrics through relevant measurements. It is observed that yarn fineness affects those properties at different levels in differing fiber types.

Keywords
Single jersey, thermal conductivity, air permeability, water vapour permeability, wicking.

1. Introduction

There is no doubt that people tend to wear clothing which gives a comfort sensation. The comfort of clothing is described as the combined effect of mechanical and thermal properties of fabrics; thus, determined by thermal and non-thermal components [1,2], thermal comfort has been accepted as the main function determining over-all clothing comfort [3].

As the fabric contacts with the skin, the heat and moisture produced by the metabolism is transferred by several mechanisms that simply determine heat and mass transition from the body to the environment to obtain thermal equilibrium. This mechanism characterizes thermal comfort, which is certain result of thermal equilibrium. Thus, there are various papers concerning heat and mass transfer properties of fabrics that have a comparative approach to their thermal comfort level so as to improve clothing design [4-9]. Heat transfer through fabric depends mainly on thermal conductivity, while mass transport is determined by air transfer and water transition in both a vapour and liquid state. Mass transfer through fabric can be evaluated by measuring water vapour permeability, air permeability and wicking performance, respectively [7].

The thermal conductivity of fibrous materials made of solid fibers and air, such as a fabric, is defined as the combination of the thermal conductivity of those two components. Ukponmwan stated that fabric density and specific heat, as a description of the fiber type, should determine the rate of heat transfer [10]. To maintain thermal balance with the body and the environment, the amount of heat produced by the metabolism should be transferred through the clothing system; hence, a fabric should have a certain level of thermal conductivity.

Considering the thermal balance between the body and the environment, the water vapour permeability of the fabric is another important property. Previous research showed that for the same water vapour concentration and temperature gradient around the fabric, the transition rate of water vapour is strongly affected by the hygroscopicity of fiber. Water vapour transmission is higher when hydrophilic fibers are included in the fabric since they retain water molecules more. Also, since liquid vapour can pass through, the fabric openings affect the water vapour permeability [11-13].

The air permeability of a fabric is strongly related to thermal comfort in several ways. It facilitates heat transfer and moisture transition in both the liquid and vapour phase. Also, the air transfer though fabric can only be managed though the openings, and still air around those openings influence thermal resistance [14,15].

Meanwhile, the interactions of fibrous surfaces with the liquid water depend on the fibre and liquid properties which determine the characteristics of liquid flow [16]. Liquid is transported in textiles through a capillary action called wicking. It was described before that wicking is a result of fibre-liquid attraction at the fibre surfaces and is determined by surface tension between liquid and fibre and effective capillary pore distribution [15,17]. Wicking within a fabric occurs through the thickness (perpendicular) and along (parallel) the fabric plane, happening simultaneously with perspiration.

Generally speaking, a fabric with a high permeability to air is also highly permeable to water vapour, and a fabric with a high wicking capability will be more comfortable to wear for sports and leisure clothing.

This paper investigates the effect of yarn fineness on heat and mass transfer properties of 100 % cotton (CO) and polyester (PET) single jersey knitted fabrics. Yarn fineness has been accepted as an important fabric parameter affecting thermal comfort properties through manipulating fabric density, the contact area between the fabric and skin, surface roughness, masking the inverse

Sample Code	Fiber Content	Yarn Count	Fabric weight (g/m^2)	Fabric thickness (mm)	Fabric density [a] (g/m^3)
PET1	100 % PET	Ne 20/1	186,00	0,54	0,34
CO1	100 % cotton	Ne 20/1	181,80	0,65	0,28
PET2	100 % PET	Ne 30/1	146,80	0,47	0,31
CO2	100 % cotton	Ne 30/1	141,00	0,51	0,28
PET3	100 % PET	Ne 40/1	102,00	0,39	0,26
CO3	100 % cotton	Ne 40/1	113,60	0,48	0,24

[a] Fabric density is calculated by dividing fabric weight by thickness

Table 1. Sample plan

relation between thermal conductivity and resistance, thickness and porosity by several researchers [18-20]; but there is lack of a study introducing a systematic research of yarn fineness in relation to the heat and mass properties of knitted fabrics. Single jersey is among the knit structures widely used in the sports and leisure clothing industry, where cotton and polyester are also largely consumed fiber types in the market. The findings allow us to assess the contribution of the yarn count on the heat and mass transfer of fabrics and evaluate which properties are significantly affected by the yarn count in different fiber types. The measurement results were also statistically analysed, and they were concluded to give valuable insight for the sports and leisure clothing industry.

2. Materials and Method

Fabrics were knitted using commercially available ring spun Ne 20/1, Ne 30/1 and Ne 40/1 100 % cotton (29.12 mm average fiber length, a_m: 112.7) and 100 % staple polyester yarns (38 mm fiber length, am: 110.5). The constructional parameters are given in Table 1. All samples were produced on the same circular knitting machine with a 22 gauge and 32″ diameter to have the same course and wale densities. (13×14 course × wales) The samples were subjected to pre-treatment including scouring and rinsing in an uncontrolled industry environment. Any other pre-treatment like mercerizing or finishing like softening was not applied so as not to hinder the sole effect of the fiber type.

The thermal conductivity of the samples, representing the heat transfer property, was measured by an Alambeta device, which satisfies ISO 8301, and water vapour permeability measurements were made by Permetest, which follows the identical procedure as required in ISO 11092. The working principle of these instruments is given in detail in [4,15]. The air permeability of the samples was measured in accordance with ASTM D 737 by SDL Atlas Air Permeability Tester. A wicking measurement of the capability of the sample to manage the transport of liquid moisture was made by means of an SDL Atlas Moisture Management Tester in accordance with AATCC 195. Overall moisture management capacity (OMMC) values were taken as the indication of wicking performance. A larger OMMC indicates a better overall moisture management capability of the fabric [21]. All the measurements were completed in standard and controlled laboratory environment conditions and repeated six times. The mean values of six measurements were used in assessments for each parameter.

For the statistical analysis of the results, the contribution of yarn count on each property was evaluated by completely randomized one-way analysis of variance (ANOVA) for different fiber types. The results were evaluated at a 5 % significance level based on the F-ratio and the probability of the F-ratio. The contribution of yarn count was stronger and more significant when the F-ratio was higher, and the probability of the F-ratio was lower.

To define the exact classification, we also used the t-test to determine which sample is significantly different. The treatment levels were marked by letters according to their mean values, and any levels which do not have significant difference were marked with the same letter.

3. Results and Discussions

As the yarns get finer, the knitted fabrics gave a lower weight, thickness and, consequently, fabric density as expected. Since fabric density indicates the amount of the entrapped air layer; a lower fabric density represents a higher amount of the air layer in the fabric, which strongly affects the heat and mass transfer properties.

3.1. Water vapour permeability

As given in Figure 1, single jersey samples gave lower water vapour permeability at higher weight and thickness values (when coarser yarns were used). This tendency is also observed in Figure 2, where each sample is labelled with its average result of the measurement. On the other hand, when the samples are statistically analysed separately according to fiber type (Figure 3), PET samples had a narrower distribution in terms of water vapour permeability, as seen in the *All Pairs* section, and there was a slight intersection between samples with Ne 20/1 and Ne 30/1. The cotton samples gave a broader distribution of values, which indicated the variation of the results and larger error as a variation source that hinders the strength of the assessment. But in any case, the ANOVA given in Table 2 confirms the stronger contribution of yarn count on water vapour permeability in polyester samples than that of cotton due to the higher F-ratio. Ne 40/1 yarns produced single jersey

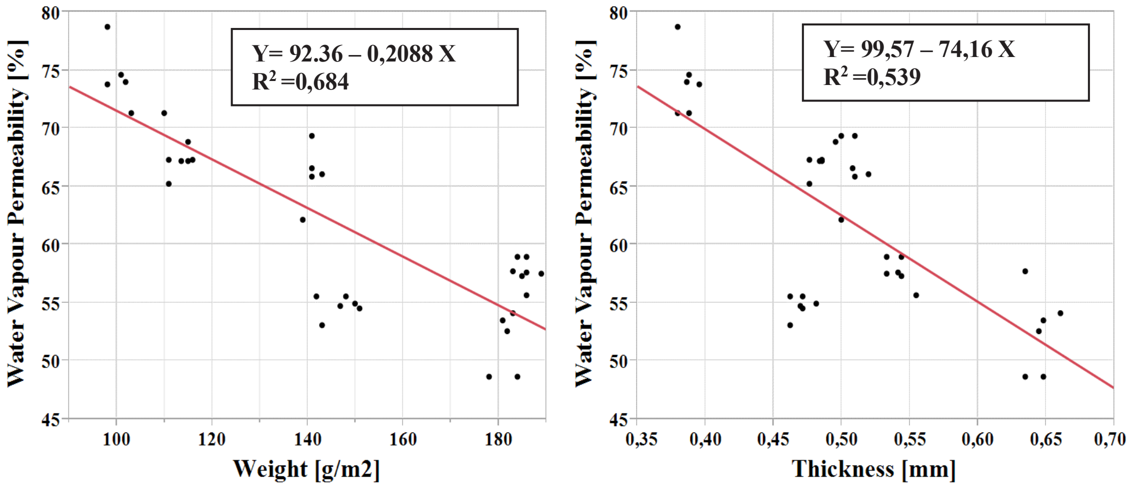

Fig. 1. Interaction between water vapour permeability, fabric weight and thickness of samples

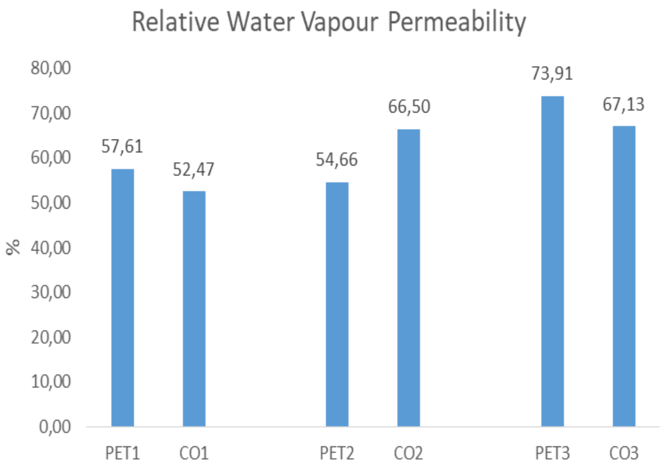

Fig. 2. Water vapour permeability measurement results of the samples

(a)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	644.878	198.340	< 0.001
Error	3.251		

(b)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	412.260	59.050	< 0,001
Error	6.982		

Table 2. ANOVA table for a) polyester and b) cotton samples for water vapour permeability

(a)		(b)	
Yarn Count	**Mean value**	**Yarn Count**	**Mean value**
Ne 40/1	73,91 a	Ne 40/1	67,13 a
Ne 20/1	57,61 b	Ne 30/1	66,49 a
Ne 30/1	54,66 c	Ne 20/1	52,47 b

Table 3. Range test for a) polyester and b) cotton fabrics for water vapour permeability

fabric which had significantly higher water vapour permeability, as given in the range test (Table 3), from which it is also possible to say that polyester single jersey fabrics had higher average values of water vapour permeability, especially when the finest yarns were used.

3.2. Thermal conductivity

Figure 4 and 5 show that samples with higher weight and thickness (when coarser yarns were used) gave higher thermal conductivity. This result is related with lower fabric density as yarn fineness increases with an increased amount of the air layer, which has very low thermal conductivity when compared with textile fibers. On the other hand the statistical analysis showed that yarn count had a stronger contribution to the thermal conductivity of single jersey polyester fabrics (Table 4) than that of cotton. Cotton samples tend to have higher thermal conductivity, as seen in Figure 6 and Table 5, as a result of having higher thickness, and Ne 20/1 yarn produced fabrics have significantly higher thermal conductivity for both fiber types.

3.3. Air permeability

Figures 7 and 8 clearly show the effect of yarn fineness on the air permeability of single jersey fabrics, where, as the yarns became finer, the samples had higher air

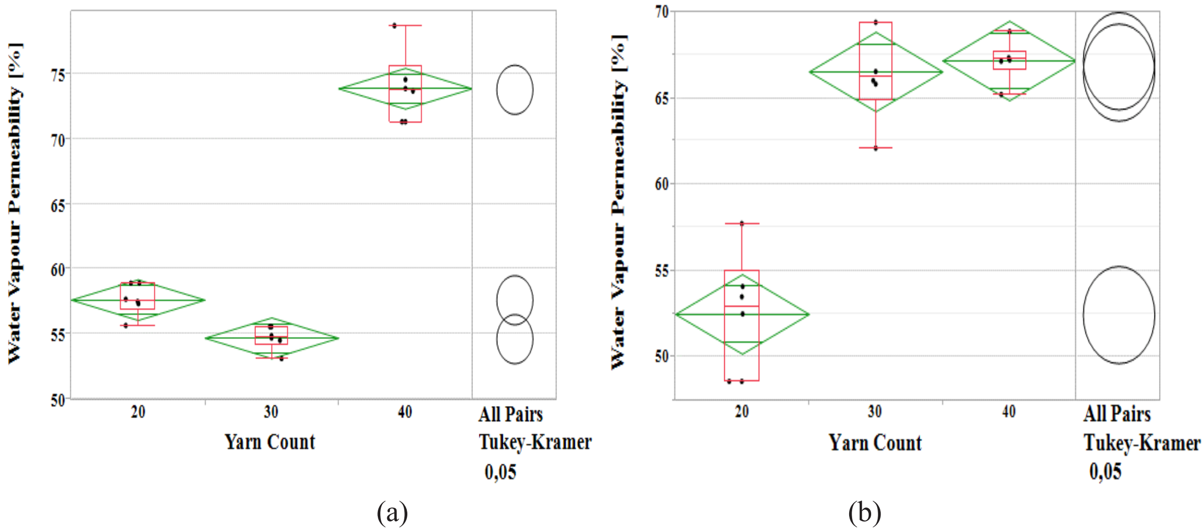

Fig. 3. Distribution of water vapour permeability values of a) polyester and b) cotton samples

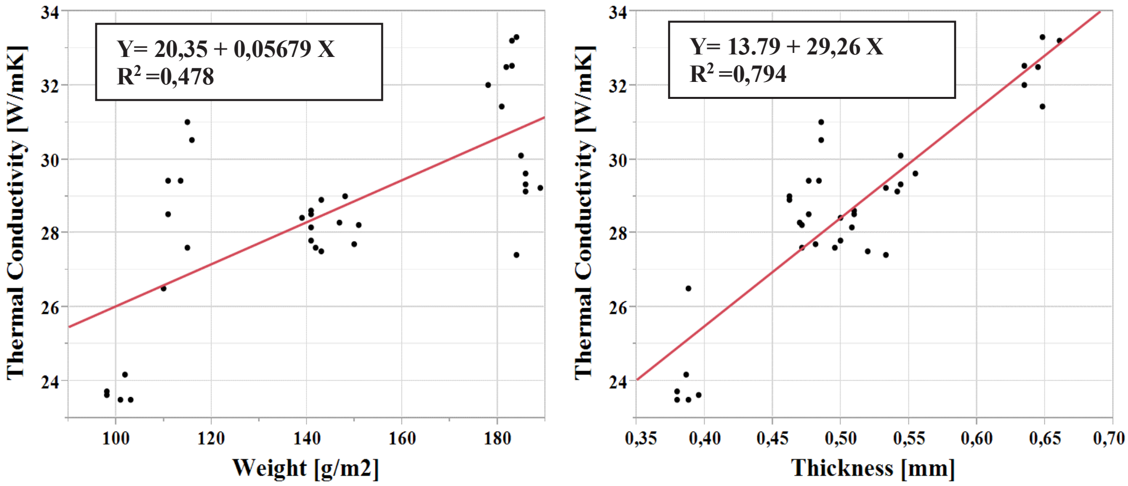

Fig. 4. Interaction between thermal conductivity, fabric weight and thickness of samples

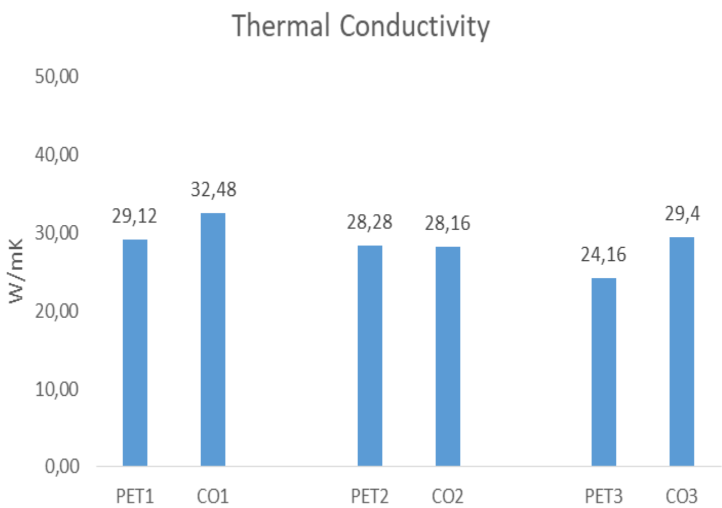

Fig. 5. Thermal conductivity measurement results of the samples

permeability. Similarly, air permeability values dropped as the samples' weight and thickness increased. This situation can be explained due to the reduced tightness factor of knitted fabric, which is a function of yarn linear density (yarn count); as the yarn got finer, the knitted fabric had a lower tightness, which resulted in a lower cover factor and enlarged porosity [22]. This effect of yarn fineness on fabric porosity is also observed in the reduced density (increased amount of the air layer). The statistical analyses given in Figure 9 and Table 6 showed that test results had a narrower distribution and a lower contribution of any error in the analyses, and that yarn fineness had a stronger contribution in cotton samples.

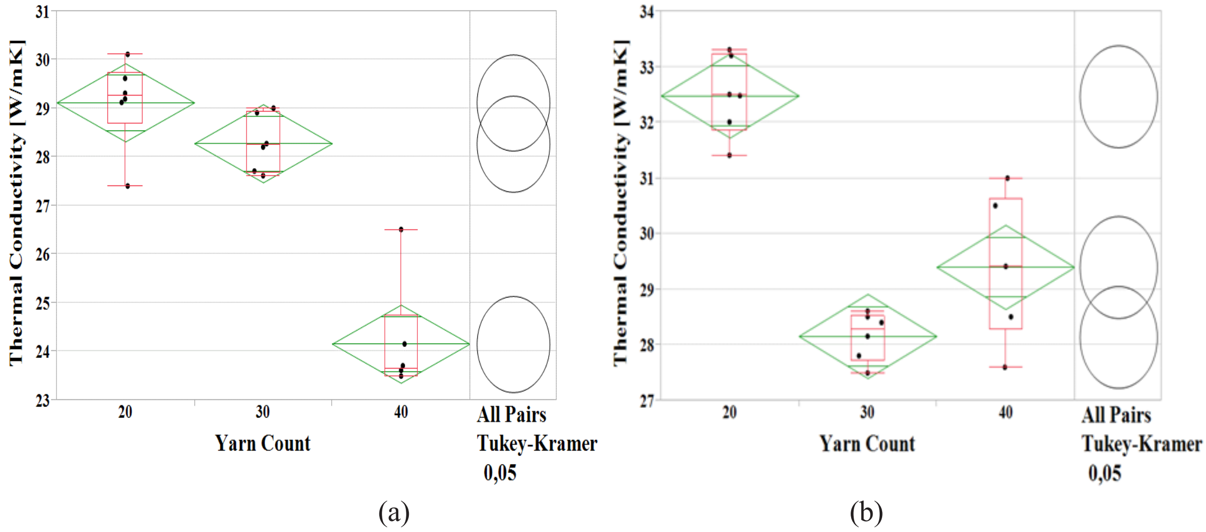

Fig. 6. Distribution of thermal conductivity values of a) polyester and b) cotton samples

(a)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	42.28	49.67	< 0.001
Error	0.85		

(b)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	29.69	39.27	< 0,001
Error	0.76		

Table 4. ANOVA table for a) polyester and b) cotton samples for thermal conductivity

(a)		(b)	
Yarn Count	Mean value	Yarn Count	Mean value
Ne 20/1	29.12 a	Ne 20/1	32.48 a
Ne 30/1	28.28 a	Ne 40/1	29.40 b
Ne 40/1	24.16 c	Ne 30/1	28.16 b

Table 5. Range test for a) polyester and b) cotton fabrics for thermal conductivity

The range test (Table 7) indicated that Ne 40/1 yarn usage gave significantly higher air permeability results.

3.4. Wicking

Although a relatively weak correlation was found between the fabric constructional parameters and wicking performance of samples, it could still be said that finer yarns gave better moisture management property, as seen in Figure 10 and 11. On the other hand, yarn fineness was found to have an insignificant effect on the wicking performance of polyester samples and for cotton, The F-ratio was the lowest among all properties assessed (Table 8 and 9). The resulting distribution

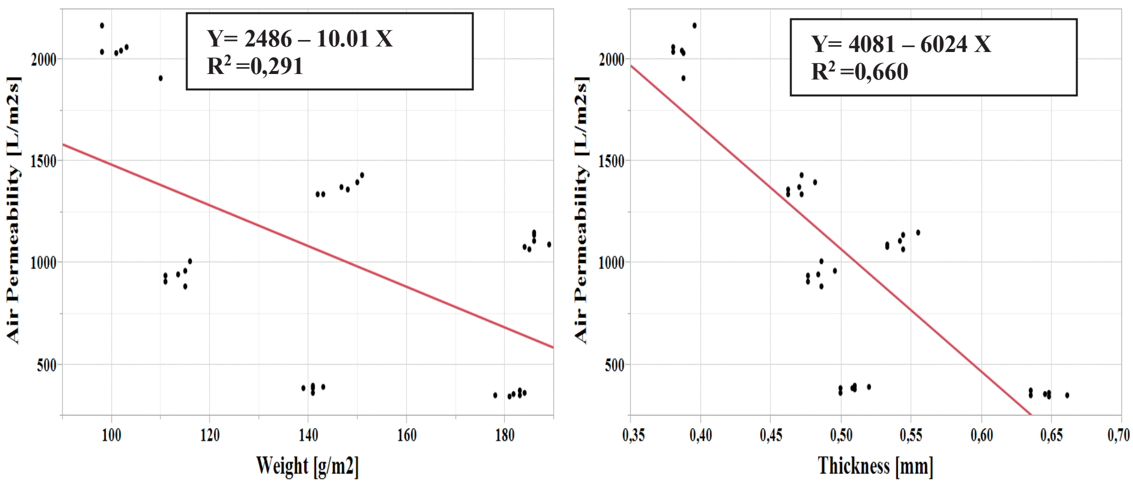

Fig. 7. Interaction between air permeability, fabric weight and thickness of samples

(a)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	1394144	455.40	< 0.001
Error	3061		

(b)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	654530	959.01	< 0,001
Error	683		

Table 6. ANOVA table for a) polyester and b) cotton samples for air permeability

(a)		(b)	
Yarn Count	Mean value	Yarn Count	Mean value
Ne 40/1	2042 a	Ne 40/1	941.2 a
Ne 30/1	1374 b	Ne 30/1	383.0 b
Ne 20/1	1106 c	Ne 20/1	356.2 b

Table 7. Range test for a) polyester and b) cotton fabrics for air permeability

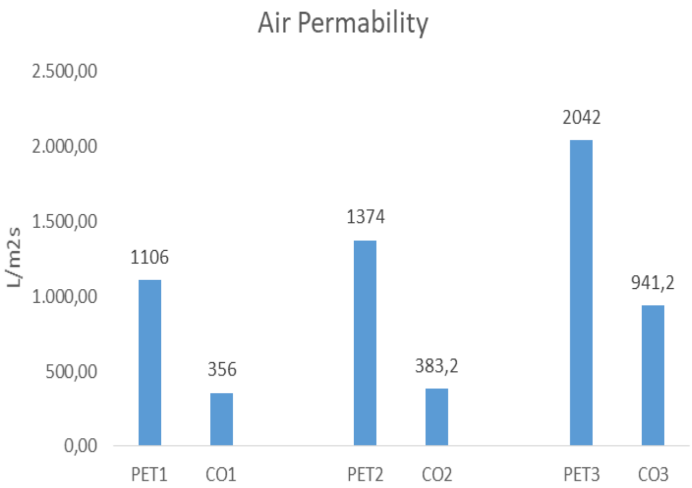

Fig. 8. Air permeability measurement results of the samples

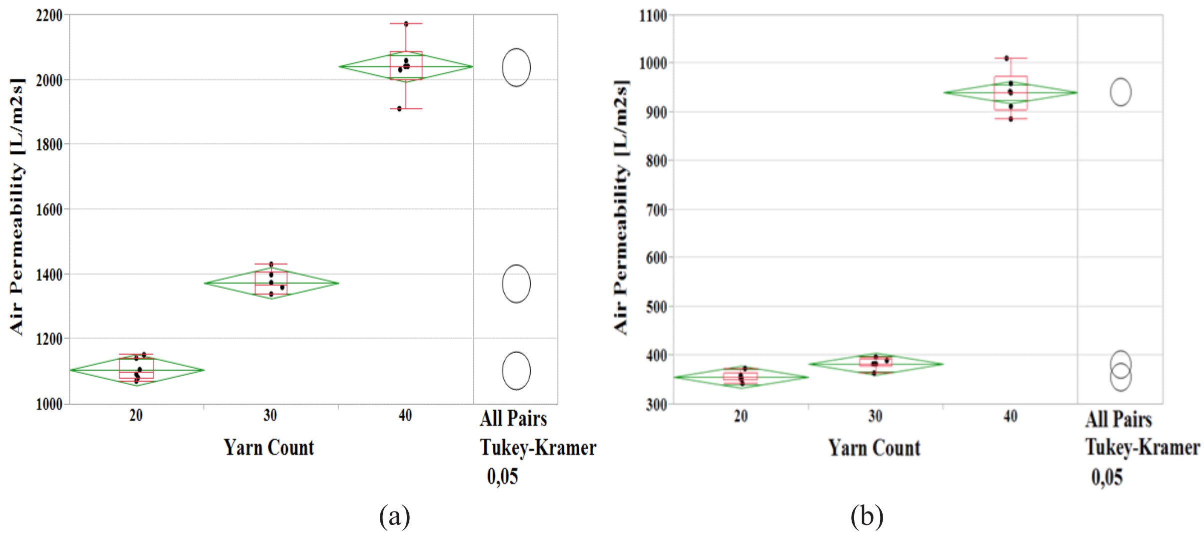

Fig. 9. Distribution of air permeability values of a) polyester and b) cotton samples

was wide for each fiber type, and a large intersection was observed in polyester samples, which also confirmed the insignificant effect (Figure 12). It could be said that yarn fineness had the weakest effect on the liquid transfer performance of single jersey knitted fabrics.

4. Conclusion

This paper investigates the effect of yarn fineness on the heat and mass transfer properties of 100 % polyester and cotton single jersey knitted fabrics by examining thermal conductivity (heat transfer), air permeability, water vapour permeability and wicking performance (mass transfer). Three different sample types differing in fiber type were produced by the same knitting machine with the same machine settings. It is found that heat and mass transfer properties were generally affected by yarn fineness; the finer yarns gave higher water vapour permeability, air permeability and somehow better wicking but reduced thermal conductivity. This is an explanation for fine yarns giving better thermal comfort in single jersey knitted fabrics which are recommended for summer garments. Similarly knitted fabrics with finer yarns are stated to be cooler, more open and show a more permeable structure, as stated before in [8,20]. Also, yarn fineness had a stronger contribution to water vapour permeability and thermal conductivity in polyester samples but an insignificant

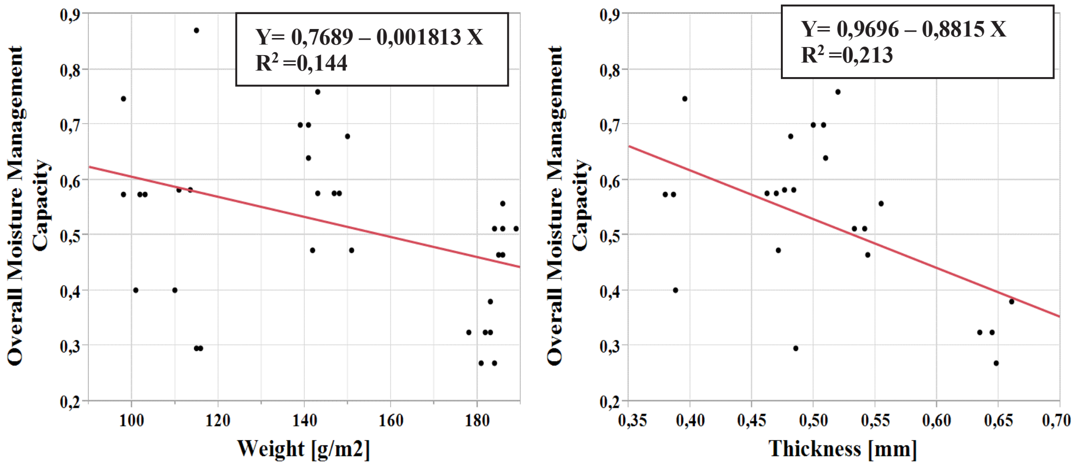

Fig. 10. Interaction between OMMC, fabric weight and thickness of samples

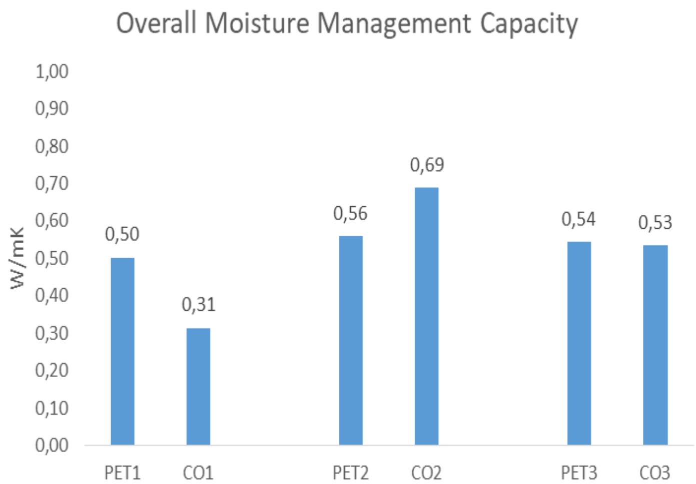

Fig. 11. OMMC measurement results of the samples

one to wicking ability. On the other hand, although cotton samples had lower air permeability than polyester samples, yarn fineness had a stronger effect on the air permeability of cotton samples. The same conclusion was also applicable for wicking performance. Also, it should be noted that yarn fineness had the strongest contribution to air permeability, followed by water vapour permeability, thermal conductivity and wicking. Thus, it is possible to manipulate the thermal comfort of single jersey fabrics by changing the yarn count: while for cotton single jersey fabrics, the air permeability could be manipulated, and for polyester single jersey fabrics - the water vapour permeability could be changed in larger amounts by means of the yarn count.

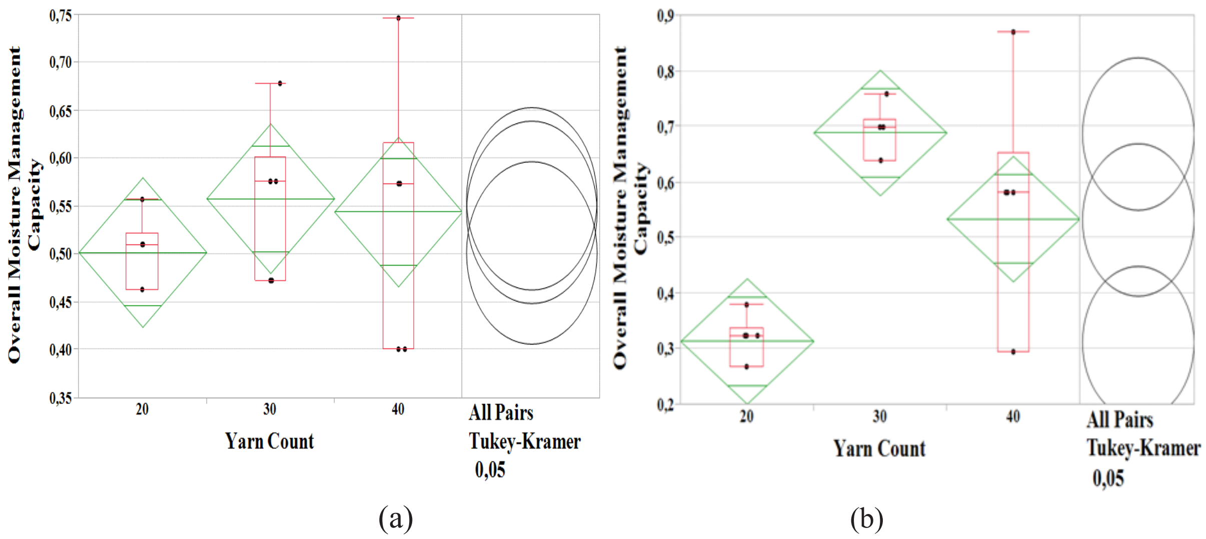

Fig. 12. Distribution of OMMC values of a) polyester and b) cotton samples

(a)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	0.005	0.6382	0.5420
Error	0.008		

(b)

Source	Mean Square	F-ratio	Probability (F-ratio)
Yarn Fineness	0.212	12.670	0.0006
Error	0.017		

Table 8. ANOVA table for a) polyester b) cotton samples for OMMC

(a)		(b)	
Yarn Count	**Mean value**	**Yarn Count**	**Mean value**
Ne 30/1	0.56 a	Ne 30/1	0.69 a
Ne 40/1	0.54 a	Ne 40/1	0.53 a
Ne 20/1	0.50 a	Ne 20/1	0.31 b

Table 9. Range test for a) polyester and b) cotton fabrics for OMMC

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References

1. Hollies N R & Fourt L. *Clothing Comfort and Function*. Marcel Dekker Inc. New York, USA, 1970, 254.
2. Li Y, *The Science of Clothing Comfort.* The Textile Institute International, Manchester, 2001, 138.
3. Geraldes M J, De Araujo M D & Hes L. High Performance Functional Knit Structures. *TECNITEX 2001 Autex Conference*, The University of Minho, Portugal, 26 – 29 June 2001.
4. Lubos, H. Non-Destructive Determination of Comfort Parameters during Marketing of Functional Garments and Clothing. *Indian Journal of Fibre & Textile Research*, 1996; 33: 239 – 245.
5. Hatch K, Woo S, Barker R L, Radhakrishnaiah P, Markee N L & Maibach H I. In Vivo Cutaneous and Perceived Comfort Response to Fabric Part .1: Thermophysiological Comfort Determinations for Three Experimental Knit Fabrics, *Text Res J,* 1990; 60, 7, 405 – 412.
6. Kothari V K,. Thermo-Physiological Comfort Characteristics and Blended Yarn Woven Fabrics. *Indian Journal of Fibre & Textile Research*, 2006; 31: 177 – 186.
7. Babalık E, Gunesoglu S, Utebay B, Bakadur A & Gunesoglu C. A New Objective Method for Comfort Assessment of Sportswear Knitted Fabrics. *Tekst Konf*, 2021; 31,4 : 318 – 328.
8. Jhanji Y, Gupta D & Kothari V K. Comfort Properties of Plated Knitted Fabrics With Varying Fibre Type. *Indian J Fibre Text Res Journal*, 2015; 40 : 11 – 18.
9. Ghaddar N & Ghali, K. *Handbook of Thermal Science and Engineering*. Springer Cham, Edinburgh, UK, 2018, 885.
10. Ukponmwan J O, *The Thermal Insulation Properties of Fabrics.* The Textile Institute International, Manchester, 1993, 25.
11. Fukazawa T, Kawamura H, Tochihara Y & Tamura T. Experiment and Analysis of Combined Heat and Water Vapor Transfer Through Clothes With Condensation. *Text Res J,* 2003; 73: 774 – 780.
12. Cui Y, Gao S, Zhang R, Cheng L & Jianyong Y. Study on the Moisture Absorption and Thermal Properties of Hygroscopic Exothermic Fibers and Related Interactions with Water Molecules. *Polymers*, 2020; 12, 1: 98 – 115.
13. Jahid M A & Hu J. Water Vapor Transmission and Water Resistant: Opposite but May Coexist. *Materials Today*, 2019; 16, 1485 – 1490.
14. Zang P, Gong R H, Yanai Y & Tokura H. Clothing Air Permeabiliy and Moisture

Regain on Human Thermal Regukaiton during Exercise, *TECNITEX 2001 Autex Conference*, The University of Minho, Portugal, 26 – 29 June 2001.
15. Gunesoglu S, Meric B. Heat and Mass transfer Properties of 2-Yarn Fleece Kniited Fabrics. *Indian J Fibre Text Res Journal*, 2006; 3; 415 – 421.
16. Wong K K,Tao X M, Yuen C W M & Yeung K W. Wicking Properties of Linen Treated with Low Temperature Plasma. *Text Res J,* 2001; 71: 49-56.
17. Namligöz E S, Coban S & Bahtiyari I. Comparison of Moisture Transport Properties of the Various Woven Fabrics. *Tekst Konf,* 2010; 2 :93 – 100.
18. Ozdil N, Marmarali A & Kretzschmar S D. Effect of Yarn Properties on Thermal Comfort of Knitted Fabrics. *Int J of Thermal Sci*, 2007; 46, 12: 1318 – 1322.
19. Prakash C & Ramakrishnan G. Effect of Blend Ratio, Loop Length, and Yarn Linear Density on Thermal Comfort Properties of Single Jersey Knitted Fabrics. *Int J of Thermophysics*, 2013; 34: 113 – 121.
20. Meena H C, Shakyawar D B, Varshney R K & Kadam V. Thermo-physiological Clothing Comfort of Wool-Cotton Khadi Union Fabrics. *Journal of Natural Fibers*, 2022; 19, 14: 7728 – 7737.
21. Ozkan E T & Meric B, Thermophysiological Comfort Properties of Different Knitted Fabrics Used in Cycling Clothes. *Text Res J*, 2015; 85, 1: 62 – 70.
22. Eltahan E A, Sultan M & Mito A B. Determination of Loop Length, Tightness Factor and Porosity of Single Jersey Knitted Fabric. *Alexandria Eng Journal*, 2016: 55, 2 : 851 – 856.