Research on thermal comfort and moisture management properties of drapery fabrics produced with polyester yarns having different fibre cross-sectional shapes and TiO_2 amount

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ABSTRACT – REZUMAT

Research on thermal comfort and moisture management properties of drapery fabrics produced with polyester yarns having different fibre cross-sectional shapes and TiO_2 amount

This study aims to provide an investigation regarding the effect of fibre cross-sectional shape, incorporated TiO_2 amount (%) during polyester yarn production, and the weft density parameters respectively, on thermal comfort, moisture management, water vapour permeability, and air permeability properties of polyester drapery fabrics. Completely randomized three-factor analysis of variance (ANOVA) was conducted at the significance level of 0.05. SNK tests were also performed to observe the means of each parameter. Some of the weft yarn production parameters and the weft density (picks/cm) factors were found as significant factors in some thermal comfort and moisture management, water vapour, and air permeability properties of drapery samples.

Keywords: *fibre cross-sectional shape, drapery fabrics, thermal comfort properties, MMT, water vapour permeability, air permeability*

Studiu privind confortul termic și proprietățile de gestionare a umidității țesăturilor pentru draperii produse cu fire din poliester având diferite forme de secțiune transversală a fibrelor și cantități de TiO_2

Acest studiu își propune să ofere o analiză privind influența formei secțiunii transversale a fibrei, a cantității de TiO_2 încorporate (%) în timpul obținerii firelor din poliester și a desimii firelor de bătătură asupra confortului termic, proprietăţilor de gestionare a umidității, permeabilității la vapori de apă și permeabilităţii la aer ale ţesăturilor din poliester pentru draperii. Analiza de varianță cu trei factori complet randomizată (ANOVA) a fost efectuată la un nivel de semnificație de 0,05. Au fost efectuate și teste SNK pentru observarea mediilor fiecărui parametru. Unii dintre parametrii de producție a firului de bătătură și factorii de desime a bătăturii (fire de bătătură/cm) au fost identificaţi ca factori semnificativi pentru unele proprietăți de confort termic și de gestionare a umidităţii, permeabilitate la vapori de apă și permeabilitatea la aer ale mostrelor de draperii.

***Cuvinte-cheie**: forma secțiunii transversale a fibrelor, țesături pentru draperii, proprietăți de confort termic, MMT, permeabilitate la vapori de apă, permeabilitate la aer*

INTRODUCTION

Drapery fabrics are the main furnishing textile groups which can be produced with different weave patterns by using different natural and man-made fibres like cotton, linen, rayon, polyester, or blends of those fibres. Although drapery fabrics are generally used to provide a decorative aspect, some additional properties have also been considered as the required features in recent years besides the aesthetic properties. Innovations related to drapery fabrics, light and UV resistant (black-out), thermal insulation and energy saving, protective effect against electromagnetic waves (EMI), and noise (sound) insulation are still progressing. For example, black-out curtains generally block the light, and these products are used in various fields to protect from light and UV radiation and personal privacy. Some antibacterial curtains are utilized in common public areas such as hotels, restaurants, or trains where such types of fabrics are highly demanded [1, 2].

Polyester is the most common fibre utilized as the raw material for drapery fabrics owing to its high mechanical properties in wet and dry state. Other synthetic and regenerated cellulosic fibres may be also utilized as the raw materials for these products. When the energy-saving properties are considered for these products, thermal comfort properties should also be evaluated in addition to mechanical and dimensional properties. The thermal comfort of fabric may be described by the movement of heat, moisture, and air. Non-sensorial comfort can be obtained from test equipment such as Alambeta, sweating guard hot plate moisture management tester (MMT) etc. Static thermal properties may be characterised by thermal conductivity, thermal resistance, and thermal absorption. Moisture management has the function of weight control of cloth by preventing moisture increase on the fabric. Water vapour permeability and air permeability are the other parameters that influence fabric comfort. Water vapour permeability indicates the vapour transmitted from the body which may be influenced mainly by fibre content, thickness, and fabric geometry. etc. Water vapor resistance which mainly depends on the air permeability is mentioned as the most important parameter for determining thermal comfort in many studies [3–16]. There are numerous studies evaluating the effect of fibre, yarn, and fabric structural properties on the comfort properties of fabrics. With the manner of thermal properties, many researchers have emphasized that the porosity and thickness of fabrics influence the thermal resistance of fabrics [17–22]. Matusiak and Sikorski [23] investigated the influence of the structure of woven fabrics on their thermal insulation properties. It was concluded in the study that weave and linear density of weft yarn significantly influenced the thermal properties of woven fabrics. Synthetic fibres can be engineered to provide a high level of thermal insulation, not only by bulking or texturing the yarn but also by introducing a modified fibre cross-section. The thermal properties of textile fabrics are influenced by many factors at microscopic (chemical composition, morphological characteristics, fineness, cross-section, porosity and water content of fibre components), mesoscopic (yarn structure and properties) and macroscopic levels (fabric physical and structural properties and finishing treatments). The fibre's cross-sectional shape and its related results, affect the thermal properties of yarns and fabrics which are produced from them. Considering the cross-sectional shape of fibres, heat flow between or inside the fibres will vary regarding the contact surface areas of fibres and the current porosity. Until recent years, the fibres were mostly produced as round cross-sections. But nowadays, instead of the round cross-section new versions of fibres are preferred to improve and develop fibre properties. As it is known in the melt spinning method, continuous filaments are obtained by passing the melt through the holes on the spinneret. The cross-section shapes of polyester fibres can be easily changed by the shape or size of the nozzle holes [24, 25].

Some synthetic fibres have been produced with a hollow core or channel. Hollow fibres have many unique properties and have found numerous applications as well. For example, hollow fibres can provide great bulkiness with less weight and are often used to make insulated clothing materials. Pac et al. [26] studied the effect of fibre morphology, yarn and fabric structure on the thermal comfort properties of the fabric. Ramakrishnan et al. [27] explained the effect of fibre fineness on the thermal resistance of fabrics. According to them, the microdenier fibre gives low thermal conductivity and higher thermal resistance. A total of eight woven fabrics were produced in two different weave patterns (plain and twill) from polyester yarns of four different fibre cross-sectional shapes (round, hollow round, trilobal and hollow trilobal) in Karaca et al.'s study [16]. Varshney et al. [28] investigated the effect of profiles of polyester fibres of four different cross-sectional shapes (circular, scalloped oval, tetrakelion and trilobal) on the physiological properties of their fabric. Tyagi et al. [29] studied the thermal comfort properties produced from polyester/viscose and polyester/cotton ring and air jet yarns where circular and trilobal cross-sectional polyester fibres were utilized. Manish et al. [30] determined the effect of using a tetra channel cross-section polyester fibre in place of cotton in a polyester/cotton blended yarn on various handle and thermal properties. Utilizing TiO_2 during the yarn extrusion of synthetic fabrics has also been one of the popular ways to apply some extra features to textile products. Titanium dioxide has high performance in many applications due to its many electrical, optical, and chemical properties. It is also used in the constituting yarns of drapery fabric owing to its high solar reflectivity [31, 32]. Apart from the investigation of fibre, yarn and fabric structure effect on comfort properties, some studies investigated the effect of utilising varying ratios of TiO_2 amount (% 0, 0.3, 0.6, 1, 1.4, 2.0, 2.4) during the melt spinning process of polyester yarn on thermal properties of fabric samples produced from those yarns [33]. Different ratios of TiO_2 during yarn extrusion were also utilized within our study to investigate the effect of this substance amount (%) on thermal comfort and moisture management properties of drapery fabrics which are estimated to have high solar absorbance at the same time.

From the literature investigated, it may be understood that thermal comfort and moisture management properties of polyester drapery fabrics have become a serious research area recently. It has also been discovered that there are not many studies related to the effect of fibre cross-sectional type, and the incorporated TiO_2 (%) amount during yarn spinning on drapery fabrics' some thermal comfort properties produced at different weft densities. The scope of this work is aimed to produce drapery fabrics with satisfying thermal comfort and moisture management properties. Hence woven fabrics of different structural parameters such as weft density, and weft yarn type where different polyester yarn production parameters were selected such as different fibre cross-sectional shapes, and the different incorporated amounts of TiO_2 (%) during extrusion were utilized to explore the effects of above-mentioned parameters on thermal comfort and moisture management properties of drapery fabrics.

EXPERIMENTAL

Materials and preparation

18 different drapery fabrics were produced by using 334/192 denier/fil draw textured polyester weft yarns produced with different fibre cross-sectional shapes (round, w, hollow) and different amounts of incorporated TiO_2 (0.3%, 1.2%, 1.8%) and with the same

50 denier polyester warp yarns at two different weft densities (24 and 28 threads/cm). The polyester multifilament weft yarns (334dtex/194 fil) utilized in this study were produced from semi dull polyester (PET) polymer via the melt spinning process. Only the spinneret cross-sectional shape and the incorporated TiO_2 amount (%) were altered. BARMAG FDY 21 Multifilament spinning machine was utilised for the process. 18 different polyester multifilament yarns of 334 dtex and 192 filaments with round, hollow round, trilobal sectional shapes were manufactured as the weft yarns. Details of the production parameters of carbon black - TiO_2 added pre-oriented polyester yarns were indicated in table 1. Carbon black and Titanium Oxide (TiO_2) added Pre (Partially) Oriented yarns were directed to a false twisting machine (Oerlikon Barmag). The drawn texturized (DTY) polyester yarn samples' images captured by OLYMPUS SC30 20X/0.40∞/0/FN22 microscope are revealed below in figure 1. The experimental design of 18 different drapery fabrics produced from these 334/192 denier/fil DTY polyester weft yarns is revealed in table 2.

Method

Before all tests, all fabrics were conditioned for 24 h in standard atmospheric conditions (at the temperature of 20±2°C and relative humidity of 65±2%). Drapery fabrics' thermal comfort performance and moisture management properties should also be evaluated considering that they may be utilized in hot and cold climates in front of the windows. Their windproof performance should also be considered

Table 1

POLYESTER WEFT YARN SPINNING CONDITIONS

Extruder temperature (°C)	1st region	2nd region	3rd region	4th region	difil
	286 (°C)	286 (°C)	286 (°C)	286 (°C)	286 (°C)
Winder speed (mpm)	3000				
1st Godet speed (m/min)	2800				
2nd Godet speed (m/min)	2970				
Melting pomp (rpm)	11.55				
Oil pomp (rpm/oil type)	40/mineral oil				
Nozzle pressure (bar)	135				

Table 2

EXPERIMENTAL DESIGN OF FABRICS PRODUCED FROM PARTIALLY ORIENTED YARNS WITH DIFFERENT PRODUCTION PARAMETERS

Fabric code	Fibre cross-sectional shape	Incorporated TiO_2 (%)	Incorporated carbon black (%)	Weft yarn type (denier/fil)	Texturing type	Weft density (picks/cm)	Warp yarn type (denier)	Warp density (picks/cm)
A1	round	0.3	1.05	334/192 PES DTY	Draw	24	50	112
A2	round	0.3				28		
A3	round	1.2				24		
A4	round	1.2				28		
A5	round	1.8				24		
A6	round	1.8				28		
A7	w	0.3				24		
A8	w	0.3				28		
A9	w	1.2				24		
A10	w	1.2				28		
A11	w	1.8				24		
A12	w	1.8				28		
A13	hollow	0.3				24		
A14	hollow	0.3				28		
A15	hollow	1.2				24		
A16	hollow	1.2				28		
A17	hollow	1.8				24		
A18	hollow	1.8				28		

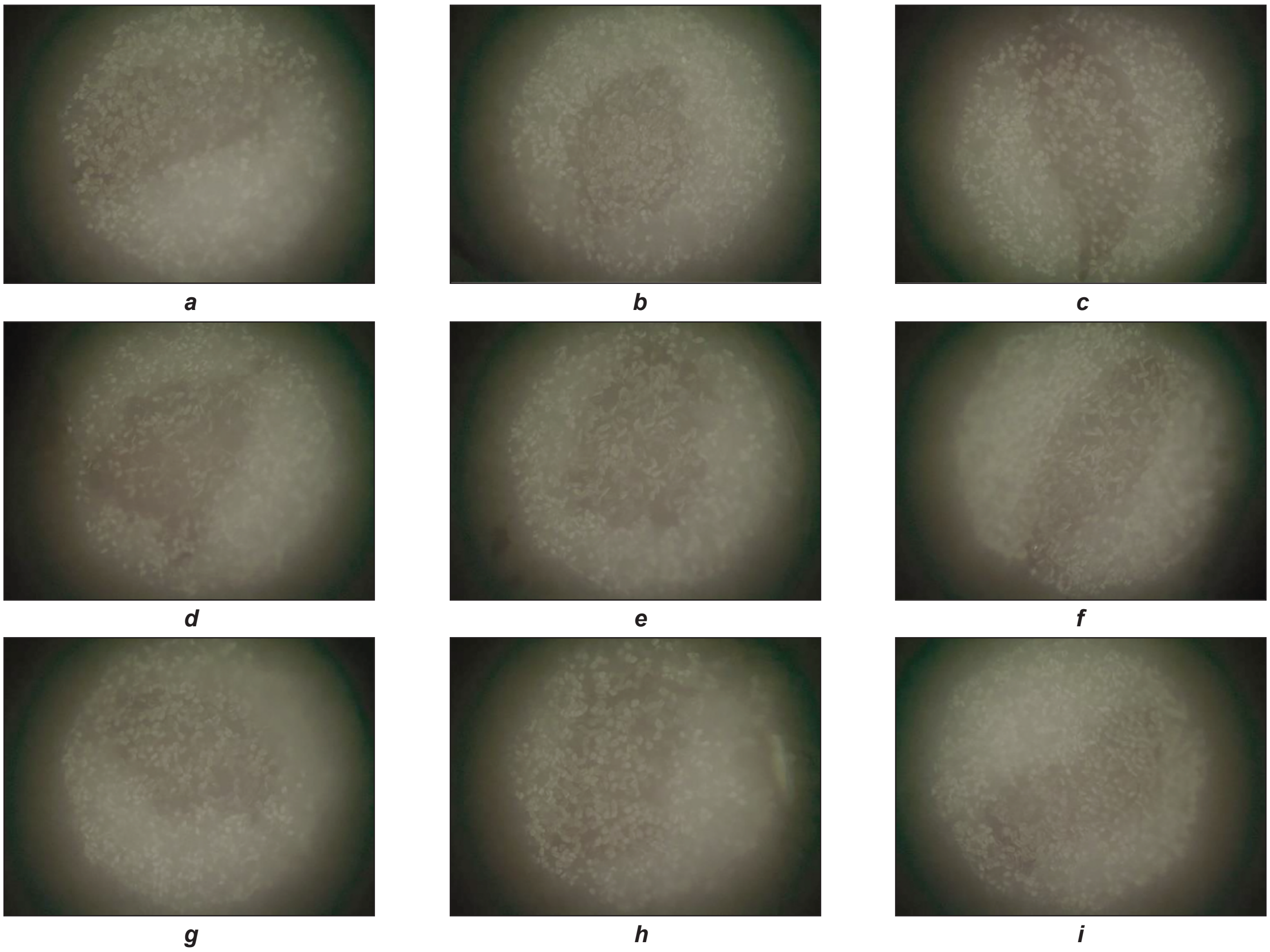

Fig. 1. Fibre cross-sectional shape of polyester yarns utilized for drapery fabrics: *a* – round cross-sectional fibres with 0.3 TiO_2 (%); *b* – round cross-sectional fibres with 1.2 TiO_2 (%); *c* – round cross-sectional fibres with 1.8 TiO_2 (%); *d* – “W” cross-sectional fibres with 0.3 TiO_2 (%); *e* – “W” cross-sectional fibres with 1.2 TiO_2 (%); *f* – “W” cross-sectional fibres with 1.8 TiO_2 (%); *g* – hollow cross-sectional fibres with 0.3 TiO_2 (%); *h* – hollow cross-sectional fibres with 1.2 TiO_2 (%); *i* – hollow cross-sectional fibres with 1.8 TiO_2 (%)

associated with the fabrics’ structural properties. Hence thermal comfort, moisture management, water vapour permeability and air permeability properties were evaluated by using the Alambeta device, Moisture management tester, Permetest device and SDL Atlas Digital Air Permeability Tester Model M021 A devices respectively which are placed in the laboratory of Textile Engineering Department, Bursa Uludağ University. Each measurement was performed according to the related standard indicated in table 3 below.

Table 3

TEST TYPE AND THE STANDARDS	
Measurement	**Device and standard**
Thermal comfort properties	Alambeta
Moisture management	SDL ATLAS, AATCC 195-2009
Water vapour permeability	Permetest, TS EN ISO 11092
Air permeability	SDL ATLAS, TS 391 EN ISO 9237

Thermal comfort properties were evaluated in terms of Thermal conductivity (λ), Thermal diffusivity (*a*), Thermal absorptivity (*b*), and Thermal resistance *(r)* results of samples. A moisture Management Tester (MMT, SDL Atlas) was utilized to measure the moisture management properties of fabrics based on the AATCC 195-2009 standard [34]. The results were expressed in terms of the wetting time for top and bottom surfaces (WTT, WTB), the absorption rate for top and bottom surfaces (ABST, ABSB), spreading speed (SST, SSB) and maximum wetted radius for top and bottom surfaces (MWRT, MWRB), accumulative one-way transport index (AOTI), and overall moisture management capability (OMMC). Additionally, table 4 reveals the grading of moisture management terms indices where the indices are graded and converted from value to grades of five levels: **1 – Poor, 2 – Fair, 3 – Good, 4 – Very good, and 5 – Excellent.** Relative water vapour permeability (RWP %) and absolute water vapour permeability (AWP) of drapery samples were measured via the PERMETEST device in the unit of m^2Pa/W. This instrument can determine non-destructive measurement of the samples according to ISO 11092 standard and it works on

Table 4

GRADING OF MMT INDICES [34]						
Index	**Grade**					
	Surfaces	**1**	**2**	**3**	**4**	**5**
Wetting time	Top	≥120	20–119	5–19	3–5	<3
		No wetting	Slow	Medium	Fast	Very Fast
	Bottom	≥120	20–119	5–19	3–5	<3
		No wetting	Slow	Medium	Fast	Very Fast
Absorption rate	Top	0–10	10–30	30–50	50–100	>100
		Very slow	Slow	Medium	Fast	Very Fast
	Bottom	0–10	10–30	30–50	50–100	>100
		Very slow	Slow	Medium	Fast	Very Fast
Max. wetted radius	Top	0–7	7–12	12–17	17–22	>22
		No wetting	Small	Medium	Large	Very large
	Bottom	0–7	7–12	12–17	17–22	>22
		No wetting	Small	Medium	Large	Very large
Spreading speed	Top	0–1	1–2	2–3	3–4	>4
		Very slow	Slow	Medium	Fast	Very Fast
	Bottom	0–1	1–2	2–3	3–4	>4
		Very slow	Slow	Medium	Fast	Very Fast
AOTI	Top	<–50	–50 to 100	100–200	200–400	>400
		Poor	Fair	Good	Very good	Excellent
OMMC	Bottom	0.0–0.2	0.2–0.4	0.4–0.6	0.6–0.8	>0.8
		Poor	Fair	Good	Very good	Excellent

the principle of heat flux sensing. The relative water vapour permeability (RWP) of the sample is calculated by the ratio of heat loss from the measuring head with fabric (q_s) and heat loss from the measuring head without fabric (q_o) as below equation [35, 36].

$$RWP = (q_s / q_o) \times 100\ \% \qquad (1)$$

Air permeability of fabrics was measured based on EN ISO 9237 standard using SDL Atlas Digital Air Permeability Tester Model M 021 A. Measurements were performed by application under 100 Pa air pressure per 20 cm^2 fabric surface. Averages of measurements from 10 Averages of measurements from 10 different areas of fabrics were calculated [37].

Statistical analysis

A completely randomized three-factor analysis of variance (ANOVA) was performed to determine the effect of fibre cross-sectional shape, incorporated TiO_2 amount (%) of weft yarns and the weft density on drapery fabrics' thermal comfort, moisture management, water vapour permeability and air permeability properties. The means were compared using SNK tests. The treatment levels were marked by the mean values, and levels marked by a different letter (a, b, c) reveal that they were significantly different. The statistical evaluations were done by using the SPSS 23 Statistical software package.

RESULTS AND DISCUSSIONS

Thermal properties

Thermal properties were evaluated in terms of bar graphs and statistical results. Figures 2 to 5 indicate the bar charts of thermal conductivity, thermal absorptivity, thermal resistivity, and fabric thickness respectively. According to figure 2, thermal conductivity results do not fluctuate prominently regarding to fibre cross-sectional type. Maximum thermal conductivity value was obtained from A8 coded fabric samples while minimum value was found among A17 coded fabric samples. Figure 3 indicates thermal absorptivity values where the maximum value was obtained from A6 coded fabrics and the minimum value was found among A9 samples. Concerning fibre cross-sectional shape, samples of yarns having hollow fibres display slightly higher thermal absorptivity results compared to those having round and W cross-sectional fibres. Thermal resistance results (figure 4) reveal a fluctuating trend among the fabric samples. Samples of yarns having "w" cross-sectional fibre reveal higher thermal resistance values compared to those having round and hollow fibres. There is not a prominent trend for the fabric thickness results (h) regarding fibre cross-sectional shape according to figure 5. Additionally, it is observed that although fabric thickness results are expected to be directly parallel with the thermal resistance results, the graphs may differ slightly due to the varying thermal conductivity results.

Three-Way ANOVA was utilized to investigate the significant effect of weft density, fibre cross-sectional shape and TiO_2 (%) amount on the thermal properties of the produced drapery fabrics at a significant ratio of 0.05 (table 5). Besides ANOVA results, Student-Newman-Keuls (SNK) multi-comparison tests (to evaluate the significance different of subgroups regarding TiO_2 (%) amount and fibre cross-sectional shape) were also conducted for the comparison of means of thermal properties (table 6). Regarding to ANOVA results; fibre cross-sectional shape and weft density were significant factors in thermal conductivity at a significance level of 0.05. The interaction of TiO_2 and fibre cross-sectional shape was also a significant factor in thermal conductivity at a significance level of 0.05. When thermal diffusivity is considered; it can be observed that fibre cross-sectional shape and weft density had a significant effect on this parameter at a significant level of 0.05. Thermal absorptivity was significantly influenced by fibre cross-sectional shape and the weft density at a significance level of 0.05. Fibre cross-sectional shape, weft density and the interaction of TiO_2 and fibre cross-sectional shape parameters had significant effect on the thermal resistivity of fabrics. Sample thickness was significantly influenced by fibre cross-sectional shape, weft density and the interaction of fibre cross-sectional shape and weft density at a significance level of 0.05. The peak heat flow density ratio (*p*) and peak heat flow density (*q*) were significantly influenced only by the fibre cross-sectional shape. Since TiO_2 (%) was not a significant factor for thermal comfort results according to ANOVA tests, SNK tests were performed only for fibre cross-sectional shape parameters (table 6). According to SNK results, minimum thermal conductivity was obtained from samples with hollow pet yarns while maximum value was found among the samples with W cross-section PET yarns. This may be attributed to the high insulation properties of hollow pet yarns. It is mentioned in Karaca et al.'s study [14] that when it is geometrically considered, the pore volume in the yarns produced from hollow fibres will be greater than that in yarns produced from solid fibres of the same fibre count because of the greater outer dimension of the hollow fibres which will lead to a higher unit weight and thicker fabric structure hence higher insulation in the fabrics produced from these fibres. Considering thermal diffusivity, the minimum value was obtained from samples of hollow yarns while the maximum value was obtained from w section yarns. Thermal absorptivity values of samples from yarns of hollow fibres were higher than samples from yarns of round and w sectional fibres which were observed under the same subset at a significance level of 0.05. This means that samples made of hollow fibres will give a cool feeling while samples made of round and w sectional fibres will give a warmer feeling. Thermal resistivity results of the samples made of hollow and round fibres were observed under the same subset at a significance level of 0.05 and lower than those with "w" fibres. Normally since samples with "w" cross-sectional

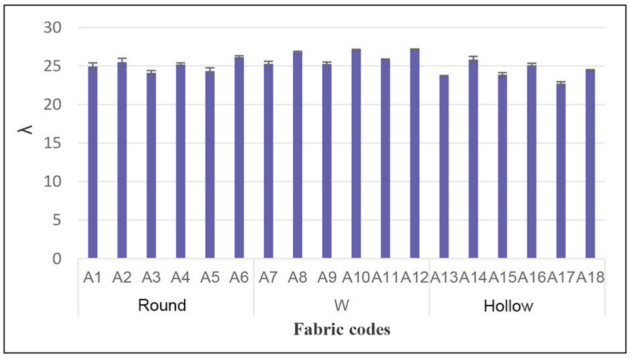

Fig. 2. Thermal conductivity $(W \cdot m^{-1} \cdot K^{-1}) \cdot 10^{-3}$

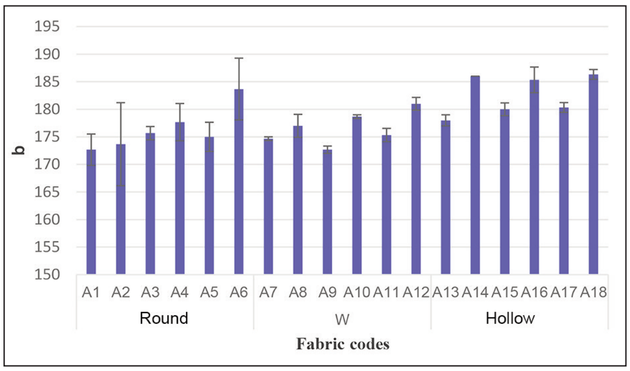

Fig. 3. Thermal absorptivity $(W \cdot s^{1/2})/m^2 \cdot K$

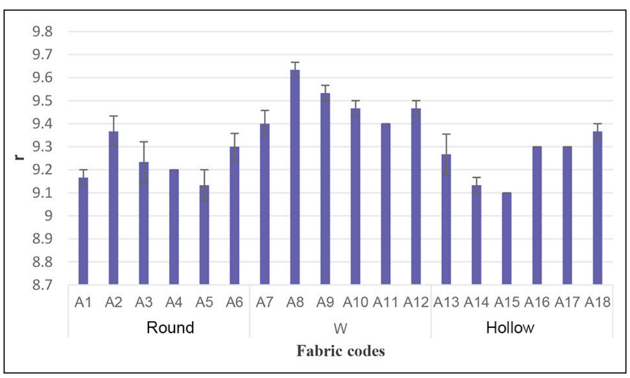

Fig. 4. Thermal resistivity $(m^2 \cdot K)/W \cdot 10^{-3}$

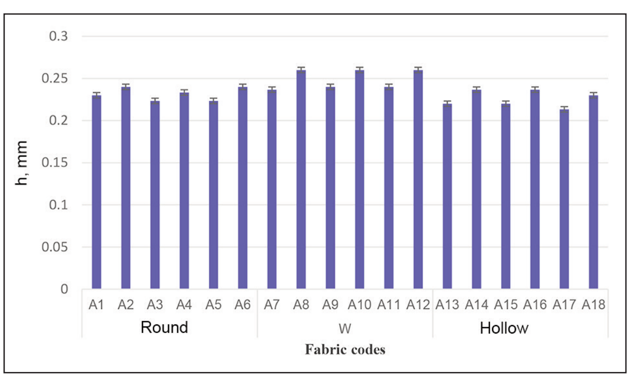

Fig. 5. Fabric thickness (mm)

shaped fibres had the maximum thermal conductivity, these samples are expected to reveal the minimum thermal resistivity. However, the result is not as expected. This may be due to the fabric thickness value. Regarding fabric thickness, the Fabric thickness of samples with yarns of hollow fibres indicated higher values compared to their counterparts with yarns of round and "w" sectional fibres. Considering the peak heat flow density ratio; samples of yarns made of "w" cross-sectional fibres indicated the lowest value while samples with yarns made of hollow fibres revealed the maximum value. Additionally, samples with yarns made of round fibres were not statistically different from their counterparts with "w" and "hollow" fibres at a significance level of 0.05. Regarding peak heat flow density, samples of pet yarns with "w" section fibre revealed the lowest value while samples of pet yarns with "hollow" and "round" cross-sectional fibres indicated the maximum value which was observed under the same subset at a significance level of 0.05.

Moisture management properties

It has been observed in many studies that moisture management properties of the fabrics are influenced by fabric structure, yarn structure and fibre structure. Synthetic fibres such as polyester are hydrophobic, which means that their surface has few bonding sites for molecules. Hence they are expected to remain dry, with good moisture transportation and release [36]. The moisture management performance of the fabrics was evaluated in terms of wetting time (s), absorption rate (%/s), the spreading spread (mm/s) for the top (SS_t) and bottom surfaces (SS_b), the accumulative one-way transport index (AOTI) and overall moisture management capacity (OMMC) using bar graphics. Additionally, a completely randomised three way-ANOVA test was performed to investigate the significant effect of TiO_2 (%) amount, fibre cross-sectional shape and weft density on moisture management properties of drapery fabrics (table 7). SNK tests were also evaluated for the comparison of means (table 8). Each result was discussed within each related part.

Wetting time (WT_t, WT_b)

According to figure 6, Maximum top wetting time and bottom wetting time results were obtained from A3 coded samples while minimum top wetting time was found among A2 coded samples and minimum bottom

Table 5

ANOVA RESULTS FOR THERMAL PROPERTIES

Main source	λ $(W·m^{-1}·K^{-1})·10^{-3}$	α $(m^2·s^{-1})·10^{-6}$	b $(W·s^{1/2})/m^2·K$	r $(m^2·K)/W·10^{-3}$	h (mm)	p	q $(W/m^2)·10^3$
TiO_2 (%)	0.25	0.06	0.12	0.63	0.24	0.61	0.50
Fibre cross-sectional shape	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***	**0.04***	**0.00***
Weft density	**0.00***	**0.00***	**0.00***	**0.00***	**0.00***	0.66	0.61
TiO_2 * Fibre cross-sectional shape	**0.00***	0.09	0.72	**0.01***	0.05	0.26	0.57
TiO_2 * weft density	0.78	0.86	0.60	0.36	0.79	0.85	0.91
Fibre cross-sectional shape * weft density	0.23	0.89	0.70	0.47	**0.03**	0.86	0.76
TiO_2 * fibre cross-sectional shape * weft density	0.10	0.86	0.70	**0.00***	0.76	0.62	0.78

Note: * significantly important.

Table 6

SNK RESULTS FOR THERMAL PROPERTIES

Parameter: Fibre cross sectional shape	λ $(W·m^{-1}·K^{-1})·10^{-3}$	α $(m^2·s^{-1})·10^{-6}$	b $(W·s^{1/2})/m^2·K$	r $(m^2·K)/W·10^{-3}$	h (mm)	p	q $(W/m^2)·10^3$
Hollow	24.27 a	0.17 a	182.66 b	9.24 a	0.22 a	1.44b	0.59 b
Round	25.03 b	0.20 b	176.38 a	9.23 a	0.23 b	1.42 ab	0.58 b
W	26.22 c	0.22 c	176.55 a	9.48 b	0.24 c	1.40 a	0.56 a
Parameter: Weft density	**λ $(W·m^{-1}·K^{-1})·10^{-3}$**	**α $(m^2·s^{-1})·10^{-6}$**	**b $(W·s^{1/2})/m^2·K$**	**r $(m^2·K)/W·10^{-3}$**	**h (mm)**	**p**	**q $(W/m^2)·10^3$**
24	24.44 a	0.01 a	176.03 a	9.28 a	0.22 a	1.43 a	0.59 a
28	25.90 a	0.02 a	181.03 a	9.35 a	0.24 a	1.44 a	0.58 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

Table 7

ANOVA RESULTS FOR MMT PROPERTIES								
Main source	**WT_t**	**WT_b**	**Abs_t**	**Abs_b**	**SS_t**	**SS_b**	**Accumulative Transfer Index**	**OMMC**
TiO_2 (%)	**0.02***	0.06	0.06	0.96	0.17	0.58	0.06	0.61
Fibre cross-sectional shape	**0.04***	**0.00***	0.37	0.91	**0.01***	0.73	**0.00***	0.07
Weft density	0.14	**0.02***	**0.00***	0.77	**0.04***	0.31	0.70	**0.02***
TiO_2 * Fibre cross-sectional shape	**0.02***	0.18	**0.00***	0.73	0.13	0.72	**0.00***	0.37
TiO_2 * weft density	0.32	0.30	0.12	0.58	0.21	0.63	**0.01***	0.79
Fibre cross-sectional shape * weft density	**0.02***	**0.00***	0.49	0.16	**0.01***	0.35	**0.01***	0.91
TiO_2 * Fibre cross-sectional shape * weft density	0.31	0.65	**0.00***	0.27	0.20	0.23	0.07	0.62

Note: * significantly important.

Table 8

SNK RESULTS FOR TOP WETTING TIME, BOTTOM WETTING TIME, TOP SPREADING SPEED AND ACCUMULATIVE TRANSFER INDEX OF DRAPERY SAMPLES						
Parameter		**WT_t**	**WT_b**	**SS_t**	**AOTI**	**OMMC**
TiO_2	0.3	1.5 a	4.01a	4.37a	1774.09 a	0.72 a
	1.2	1.80 b	5.72a	3.22a	1768.76 a	0.72 a
	1.8	1.73 b	4.70 a	2.60 a	1857.93 a	0.71 a
Fibre cross sectional shape	Round	1.52 a	6.28 b	5.04 b	1542.60 a	0.70 a
	W	1.81 b	4.23 a	2.51 a	1910 b	0.72 a
	Hollow	1.70 ab	4.01 a	2.65 a	1947 b	0.73 a
Weft density	24	1.75 b	5.53 b	2.60 a	1793.82 a	0.70 a
	28	1.61 a	4.15 a	4.20 b	1806.61 a	0.73 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05

wetting time was found among A7 coded samples. Wetting time results of top surfaces are generally close to each other however there is a fluctuating trend for bottom wetting results regarding fibre cross-sectional shape. Fabric samples of yarns with round cross-sectional fibres revealed higher wetting time for bottom surfaces compared to their counterparts with hollow and w cross-section fibres. This may indicate that samples of yarns with hollow and w cross-sectional fibres have an easy drying advantage. *SNK* results (table 8) also reveal that fabric samples of polyester yarns added with different TiO_2 (%) amounts and fabric samples of yarns with different fibre cross-sectional shapes possessed different WT_t and WT_b results at a significance level of 0.05. Considering the TiO_2 (%) amount, samples of yarns with 1.2 % TiO_2 and 1.8 % TiO_2 substance revealed the same WT_t results which were higher than the result of samples with 0.3 % TiO_2. Regarding to fibre cross-sectional shape, fabrics of weft yarns with round fibre sectional shape indicated the lowest WT_t value while fabrics of yarns with "w" cross-sectional shape indicated the highest WT_t value. Additionally, fabrics of yarns with round fibres revealed higher WT_b values compared to those with "w" and "hollow" fibres at a significance level of 0.05.

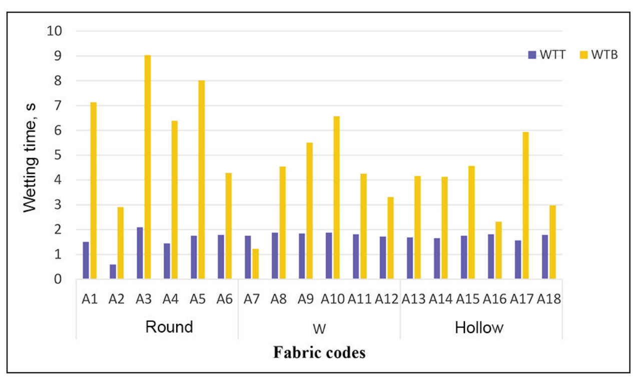

Fig. 6. Wetting time

Absorption rate (%/s)

The absorption rate (%/s) values reveal the average moisture absorption ability of the top and bottom surfaces of fabric in the pulp time. According to figure 7, the maximum top absorption rate was found among A1 coded fabrics whereas the minimum value was obtained from A3 coded fabrics. Bottom absorption rate (%/s) values do not fluctuate prominently among the samples. Additionally, there is not a clear trend of top absorption rate results regarding fibre cross-sectional shape. As it is observed, since top absorption rate values are higher than bottom absorption rate values, it may be anticipated that there is not so much liquid diffusion from next-wet surfaces to the opposite side. Hence the liquid may accumulate on the top of the fabric instead of the bottom side. Since the fibre cross-sectional shape, TiO_2 amount (%) and the weft density factors were non-significant on top and bottom absorption rate values, *SNK* tests were not performed.

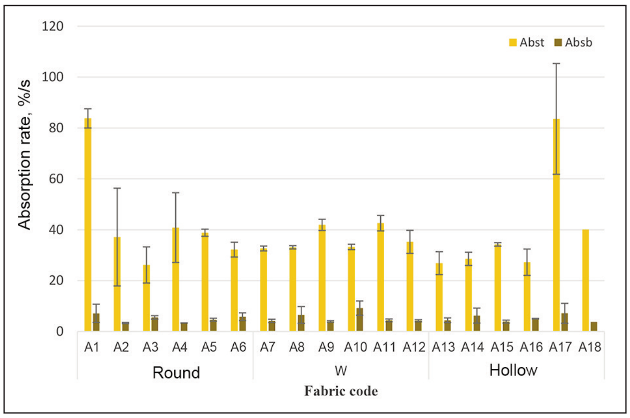

Fig. 7. Absorption rate (%/s)

Spreading Speed (SS_t, SS_b)

Figure 8 indicates the spreading speed of the drapery sample. According to figure 8, minimum SS_t was obtained from A3 coded fabrics of yarns with round fibres as 2.21 mm/s and minimum SS_b was obtained from A9 coded fabrics of yarns with hollow fibres as 3.02 mm/s. According to MMT grade indices displayed in table 4, these two fabrics have medium SS_t and SS_b values. On the other hand, maximum SS_t was obtained from A2 coded fabrics of yarns with round fibre as 12.88 mm/ss and SS_b value was obtained from A7 coded fabrics of yarns with "w" cross-sectional fibres as 9.50 mm/sec which means the fabrics have very fast SS_t and SS_b according to MMT grade indices. Additionally, it is generally observed that SS_b results of fabrics are higher than

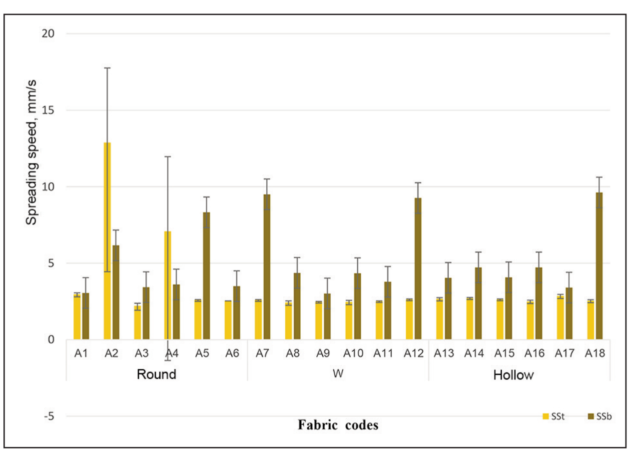

Fig. 8. Spreading speed (mm/s)

SS_t results. *SNK* test results (table 8) also revealed that fabrics of yarns with different fibre cross-sectional shapes possessed different SS_t results. Fabrics of yarns with round cross-sectional fibres indicated higher SS_t results compared to samples made of yarns with "W" and hollow cross-sectional fibres which were observed under the same subset at a significance level of 0.05.

Accumulative One-Way Transport Index (AOTI)

One way transportation capability may also be described as one-way liquid moisture transfer from the fabric's inner surface to the outer surface. This parameter describes how easily a fabric can transport moisture absorbed from its conducting surface to the other side by providing a moisture feel reduction which is a sign of fabric comfort. It was mentioned in the literature that polyester fibres can pass moisture from the inner to the outer surface due to its tendency to transport moisture instead of absorbing it. Figure 9 indicates the accumulative one-way transport index of drapery samples. According to figure 9, the highest value was found among A15 coded fabrics whereas the minimum value was obtained from A4 coded fabrics. Although the *AOTI* results of fabrics with round fibres were generally lower than their counterparts with "w" cross-sectional and hollow fibres, it may be observed that whole samples have *AOTI* above 400 value which means the fabrics have excellent *AOTI* according to MMT grade indices (table 4). Fibre cross-sectional shape factor, the interaction of fibre cross-sectional shape and TiO_2 amount (%), the interaction of fibre cross-sectional shape and weft density and the interaction of TiO_2 amount (%) and the weft density factors had a significant effect on *AOTI* results at a significance level of 0.05. *SNK* results (table 8) also possessed those fabrics with different fibre cross-sectional shapes that possessed different *AOTI* at a significance level of 0.05. Minimum *AOTI* was obtained from fabrics with round fibres while maximum value was obtained from samples with hollow and w section fibres which were observed under the same subset at a significance level of 0.05.

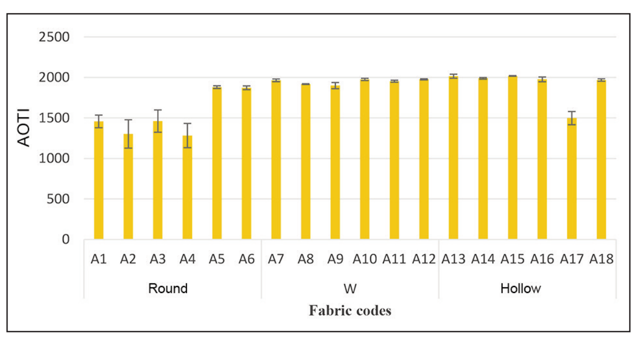

Fig. 9. Accumulative One-way Transport Index

Overall Moisture Management Capacity (OMMC)

Figure 10 reveals the *OMMC* results of fabric samples. There is not a prominent trend for *OMMC* results of the samples regarding to fibre cross-sectional shape of weft yarns. The highest *OMMC* value was obtained from A8 coded samples as 0.75 whereas the minimum *OMMC* value was obtained from A9 coded sample as 0.66. Since all the samples have *OMMC* values between 0.6 and 0.8, they are in the very good grade according to MMT grade indices (table 4). According to the ANOVA test, *OMMC* values were significantly influenced only by the weft density factor (table 7).

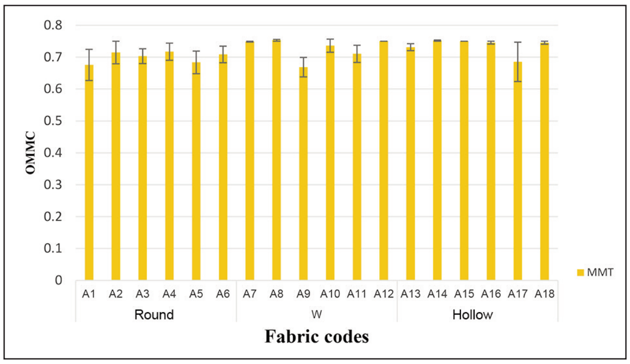

Fig. 10. OMMC results

Air permeability

Figure 11 indicates the air permeability results of the drapery samples. The highest air permeability was obtained from A3 coded fabrics at 335 mm/sec while minimum air permeability was found among A12 coded fabrics at 92.36 mm/sec. As a general evaluation, there is not a prominent trend for the air permeability results concerning the fibre cross-sectional shape of drapery samples. However, the samples of yarns with a “w” cross-sectional shape reveal slightly lower results compared to their counterparts with hollow and round fibres. Another remarkable result about the bar graph, when the results are related to the weft densities of the samples (table 2), it is understood that owing to the high number of interlacements among the fabric, drapery samples with 28 weft density indicated lower air permeability results which do not allow air to pass through freely and easily. Three-way ANOVA test (table 9) was conducted to investigate the effect of fibre cross-sectional shape, amount of TiO_2 (%) and the weft density on air permeability results of samples. According to the results, all three main factors and the interactions of these main sources were significant parameters on the air permeability properties of the samples at a significance level of 0.05. SNK results (table 10) also indicated that samples of yarns produced with different TiO_2 (%) amounts and samples of yarns with different fibre cross-sectional shapes possessed different air permeability results. Regarding to amount of TiO_2 (%) in the yarns of the samples, minimum air permeability was obtained from the samples with the amount of 0.3 and 1.8 TiO_2 (%) which were observed under the same subset at a significant level of 0.05. On the other hand, the highest air permeability was obtained from the samples of yarns with the amount of 1.2 TiO_2 (%). When the fibre cross-sectional shape is taken into consideration, it is observed that samples having “W” cross-sectional shape fibres have the lowest air permeability value while samples having round and hollow cross-sectional shape fibres which were observed under the same subset provided the maximum air permeability value at significant level of 0.05.

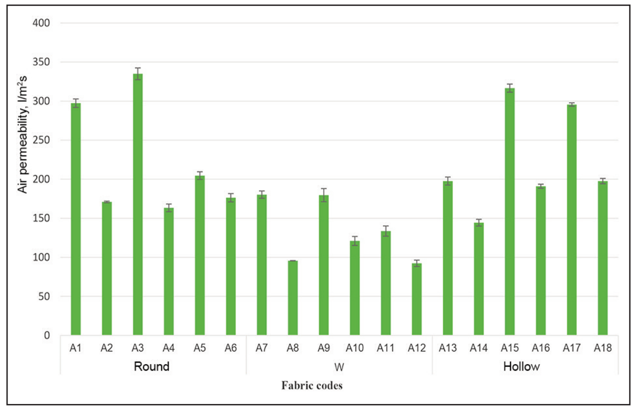

Fig. 11. Air permeability

Table 9

ANOVA RESULTS FOR AIR PERMEABILITY	
Main source	**Air permeability**
TiO_2 (%)	0.00*
Fibre cross-sectional shape	0.00*
Weft density	0.00*
TiO_2 * Fibre cross-sectional shape	0.00*
TiO_2 * weft density	0.00*
Fibre cross-sectional shape * weft density	0.00*
TiO_2 * Fibre cross-sectional shape * weft density	0.00*

Note: * Significantly important.

Table 10

SNK RESULTS FOR AIR PERMEABILITY		
Parameter		**Air permeability**
TiO_2	0.3	181.11 a
	1.2	217.20 b
	1.8	183.24 a
Fibre cross sectional shape	Round	226.30 b
	W	134.55 a
	Hollow	221.43 b
Weft density	24	239.42 a
	28	148.96 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

Relative water vapour permeability (RWP), absolute water vapour permeability (AWP)

Water vapour permeability results were evaluated in terms of relative water vapour permeability (*RWP*)

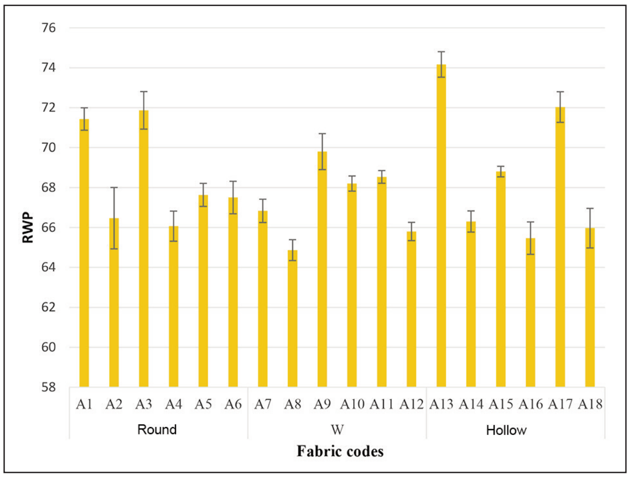

Fig. 12. Relative water vapour permeability (%)

and absolute water vapour permeability (*AWP*) which were obtained from the Permetest device. Figure 12 reveals the relative water vapour permeability results of the samples. According to figure 12: the highest relative water vapour permeability result (%) was obtained from A13 coded samples, while the minimum value (%) was obtained from A8 coded samples. There is not a prominent trend for *RWP* results regarding to fibre cross-sectional shape of drapery samples however when the weft densities are considered, it is understood that samples with higher weft density (28 thread/cm) indicated lower *RWP* (%) compared to their counterpart with lower weft density (24 thread/cm) as an expected result. When the absolute water vapour permeability (figure 13) is considered, A8 coded samples revealed the maximum and A13 coded samples revealed the minimum absolute water vapour permeability (Pa.m^2/w) contrary to the relative water vapour permeability results. Additionally, there is not a prominent difference between the absolute water vapour permeability of the samples produced from yarns of fibres with different fibre cross-sectional shapes. Three-way ANOVA was conducted to investigate the effect of fibre cross-sectional shape, incorporated TiO_2 amount (%) and weft density parameters on the relative (%) and absolute water vapour permeability (Pa·m²/w) values of the samples. According to the ANOVA table (table 11), the incorporated TiO_2 (%) amount was a significant factor in *AWP* but a non-significant factor in the *RWP* value of the samples. Fibre cross-sectional shape and weft density were significant factors in the *RWP* and *AWP* values of the samples. All interactions of these three factors except the interaction of TiO_2 (%) and weft density factors were also significant on *RWP* and *AWP* results. Samples made of yarns with different fibre cross-sectional shapes revealed different *RWP*, and *AWP* results at a significant level of 0.05 (table 12). The minimum *RWP* value was obtained from samples with "w" cross-sectional-shaped fibres. The *RWP* values of samples with "round" and "hollow" fibres which were observed under the same subset at a significance level of 0.05 were higher than those with "w" cross-sectional

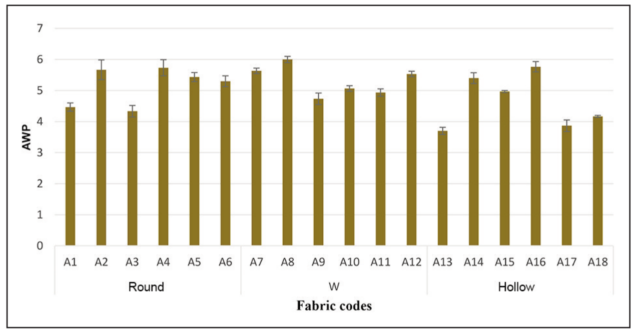

Fig. 13. Absolute water vapour permeability (Pa·m^2·w^{-1})

shaped fibres. *AWP* value of samples with hollow cross-sectional shaped fibres was lower than those with "w" and round cross-sectional shaped fibres which were observed under the same subset at a significance level of 0.05. *SNK* results also indicated that samples of yarns with different TiO_2 amounts (%) possessed different *AWP* results at a significance level of 0.05 (table 12). Fabric samples of yarns with 1.8 TiO_2 (%) revealed lower *AWP* results than those of yarns with 0.3 and 1.2 TiO_2 (%) at a significance level of 0.05.

Table 11

ANOVA RESULTS FOR WATER VAPOR PERMEABILITY		
Main source	**RWP**	**AWP**
TiO_2 (%)	0.49	**0.01***
Fibre cross-sectional shape	**0.00***	**0.00***
Weft density	**0.00***	**0.00***
TiO_2 * Fibre cross-sectional shape	**0.00***	**0.00***
TiO_2 * weft density	0.08	**0.00***
Fibre cross-sectional shape * weft density	**0.00***	**0.02***
TiO_2 * Fibre cross-sectional shape * weft density	**0.00***	**0.00***

Note: * Significantly important.

Table 12

SNK RESULTS FOR WATER VAPOR PERMEABILITY			
Parameter		**RWP**	**AWP**
TiO_2	0.3	68.34 a	5.14 b
	1.2	68.36 a	5.10 b
	1.8	67.91a	4.87a
Fibre cross sectional shape	Round	68.49 b	5.15 b
	W	67.33 a	5.31 b
	Hollow	68.78 b	4.64 a
Weft density	24	70.12 a	4.67 a
	28	66.29 a	5.40 a

Note: The different letters next to the counts indicate that they are significantly different from each other at a significance level of 0.05.

CONCLUSION

This study has been conducted to investigate the effect of fibre cross-sectional shape and the utilized

TiO_2 (%) amount during yarn extrusion on some thermal comfort, moisture management, air permeability and water vapour permeability of drapery fabrics produced at different weft densities. As all yarn and drapery fabric production conditions were kept the same, a difference in fabric comfort properties of drapery fabrics was attributed to fibre characteristics, utilized TiO_2 and the fabric weft density. According to ANOVA results, fibre cross-sectional shape and weft density were significant factors in thermal conductivity at a significance level of 0.05. TiO_2 (%) was not a significant factor for thermal properties. Considering all thermal properties, the difference in the number of contact points of samples with different fibre cross-sectional shapes revealed different results. Fabric samples with round fibres revealed higher wetting time for bottom surfaces compared to their counterparts with hollow and w cross-sectional shape fibres. This may indicate that samples of yarns with hollow and w cross-sectional shape fibre have an easier drying advantage compared to those with round shape fibres. Whole samples have an accumulative one-way transport index above 400 value which means the fabrics have excellent accumulative one-way transport index according to MMT grade indices. All the samples have OMMC value between 0.6 and 0.8 which mean they are in a very good grade according to MMT grade indices (table 4). OMMC values were significantly influenced only by the weft density factor according to the ANOVA test. All three main factors; the effect of fibre type, amount of TiO_2 (%) and weft density and the interactions of these main sources were significant parameters on air permeability properties of the samples. The incorporated TiO_2 (%) amount was a significant factor in AWP but a non-significant factor in the RWP value of the samples. Fibre cross-sectional shape and weft density were significant factors in the RWP and AWP values of the samples. As a general evaluation of the study, considering all test results including thermal properties, MMT, water vapour and air permeability of drapery fabrics, it is observed that the amount of TiO_2 (%) does not have a prominent influence on the above-mentioned comfort properties. However, the fibre cross-sectional shape' effect is generally significant in most of the thermal and comfort properties of drapery fabrics. Hence new fibre designs to be used as warp or weft yarns of drapery fabrics may be improved by considering fibre additive materials in further studies for satisfying comfort properties.

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