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Effects of fiber cross-section shape on thermal comfort properties of polyester interlock fabrics

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ABSTRACT

In this study, some dimensional and thermal comfort properties, i.e. thermal resistance, water vapor permeability, and air permeability properties of interlock fabrics knitted from different cross-section shaped polyester fibers were investigated. Four polyester yarns of different fiber cross-section shapes (hollow-round, round, triangular, and W-shape) were used to produce the samples. From the results, it was found that the triangular and W-type fibers had higher fabric density values due to the denser and closer fiber settlement. The highest bursting strength value belonged to the sample knitted from hollow-round yarn, which had also the highest yarn-breaking load value. The samples knitted from both round cross-section polyester yarns had significantly higher air permeability and thermal resistance values than the other samples due to the lower fabric density values of these fabrics. On the other hand, the water vapor permeability values of the fabrics from triangular and W-type fibers were slightly higher than the others because of their lower thicknesses.

Keywords
fiber cross-section,
hollow-round,
polyester,
round,
thermal comfort,
triangular,
W-shape

1 Introduction

As natural resources decrease, synthetic yarns become more popular owing to the increase in the global demand for textile products. Polyester fiber is one of the most widely consumed of all fibers. However, polyester fiber does not have natural fibers' good appearance and handling characteristics. Additionally, polyester fiber has hydrophobic and electrostatic nature. The polyester fiber has many positive properties like moisture management, lightweight, high strength, durability, dimensional stability, abrasion resistance, insulation, and quick drying [1].

Polyester fibers are used in many areas such as military clothing, automotive industry, hygiene products, industrial applications, protective clothing, filters, construction materials, geotextiles, agriculture, and home textiles, besides daily wear. To obtain better moisture transport, softness, and handling, researchers have been working on modifying polyester, especially by changing the fineness, surface, and cross-sections of fibers [2]. In this way, it will be possible to combine the good properties of synthetic fibers with the preferred properties of natural fibers.

The cross-sectional shape of filaments has an essential effect on the bending rigidity, abrasion resistance, handle, dyeing, friction, thermal comfort, strength, and surface properties of synthetic yarns. The fiber's cross-sectional shape and its related results also affect the properties of yarns and fabrics which are produced from them. Until recent years, the fibers were most commonly produced as round cross-sections. But nowadays, instead of the round cross-section new versions of fibers are preferred in order to improve and develop fiber 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 the fibers can be easily changed by the shape or size of the nozzle holes. The thickness and cross-section shape of fibers is determined by the size and shape of the nozzle holes, respectively.

Karaca and Özçelik [3] examined the properties of round, hollow-round, triangular and hollow triangular cross-section shaped fibers and stated that solid fibers are more durable and flexible, while hollow fibers are harder. Matsudaira et al. [4] determined that polyester fabric becomes soft and deformable with an increase in the space ratio in the fiber cross-section; however, it does become inelastic and unrecoverable.

The requirement for fabrics is not only related to mechanical and dimensional properties, but also to comfort properties. As it is known, the normal internal body temperature for human beings is 37 °C. If any difference happens from this value, the rates of heat loss or heat production change to keep the body temperature at this level. When the thermoregulation is unable to control the body temperature, humans are possible to feel discomfort or sickness. For heat balance, the heat energy produced by the metabolism must be equal to the rate of heat transferred from the body.

During heavy activities or in very hot weather conditions, the body produces lots of heat energy, then the body temperature increases, more blood is routed from the core to the skin, and skin temperature increases. In order to reduce this high temperature, the body perspires in liquid or vapor form. Reversely, with the changing from a warm to a cold environment, skin becomes cool, and blood is routed from the skin to the core, where it is warmed before flowing back to the skin. Therefore, core temperature decreases and shivering may occur to increase body temperature.

The thermal comfort of clothing is determined by the movement of air, heat and moisture in a fabric structure [5]. Air permeability is an indicator of how well air passes through the fabric. The flow of omitted gases from human body to the environment and inward flow of fresh air towards human body make the air permeability, a hygienic character of textiles [6]. It is an important parameter for the selection of fabrics for different end usage areas. Many factors may affect air permeability, such as the fiber material and cross-section shape, yarn count, twist and crimp, fabric density, thickness, porosity, structure, and the finishing processes [7]. Studies on the structural factors influencing the air permeability of fabrics assume that airflow takes place in the spaces between yarns. Therefore, the inter-yarn pore is an important parameter influencing the openness of the fabric structure [8].

Thermal resistance is a measure of the insulation value and it shows the resistance of fabric against heat flow [9]. Under certain climatic conditions, thermal resistance is an important parameter for body comfort that is influenced by fiber shape, yarn properties, and fabric structure. Additionally, it depends more on the air gaps within the structures than on the material composition.

The water vapor permeability of fabric indicates the capacity of the fabric to transmit water vapor from the skin to the environment [10]. Water vapor transmission happens through the air spaces between the fibers. The lower water vapor permeability prevents evaporative cooling of the skin, and thus stored heat cannot be dissipated from the body. Then this may lead to uncomfortable conditions for the wearer [11].

Some of the studies performed on fiber cross-sectional shape have focused on its effects on fiber processing behavior, fiber properties [3,6], and the thermal comfort behavior of woven fabrics produced from different cross-section shaped fibers [8,12,13]. Xu and et al. [14] presented one application of automated measurement using image processing techniques that extracts basic shape features from fiber cross sections. Sai Sangurai et al. [15] studied the effect of the polyester filament cross-section and the lycra content variation on the moisture management properties of rib knitted fabrics. They found that fabrics having trilobal polyester filament had better liquid transportation properties than the fabrics from circular polyester filament. Fewer researches have proven the effects of fiber cross-sectional shape on various fabric properties. The aim of this study is to investigate the changing of the dimensional and thermal comfort properties of interlock fabrics when the cross-section shapes of polyester yarn are changed.

2 Materials and methods

Interlock knitted fabrics were produced with polyester filament yarns which have four different cross-section shapes. Yarn count was 135 dtex and 48 filaments and the shapes of the cross-section were hollow-round, round, triangular, and W-shape, as seen in Figure 1. During the yarn production, just the shape of nozzle holes was changed while all the other parameters were kept constant.

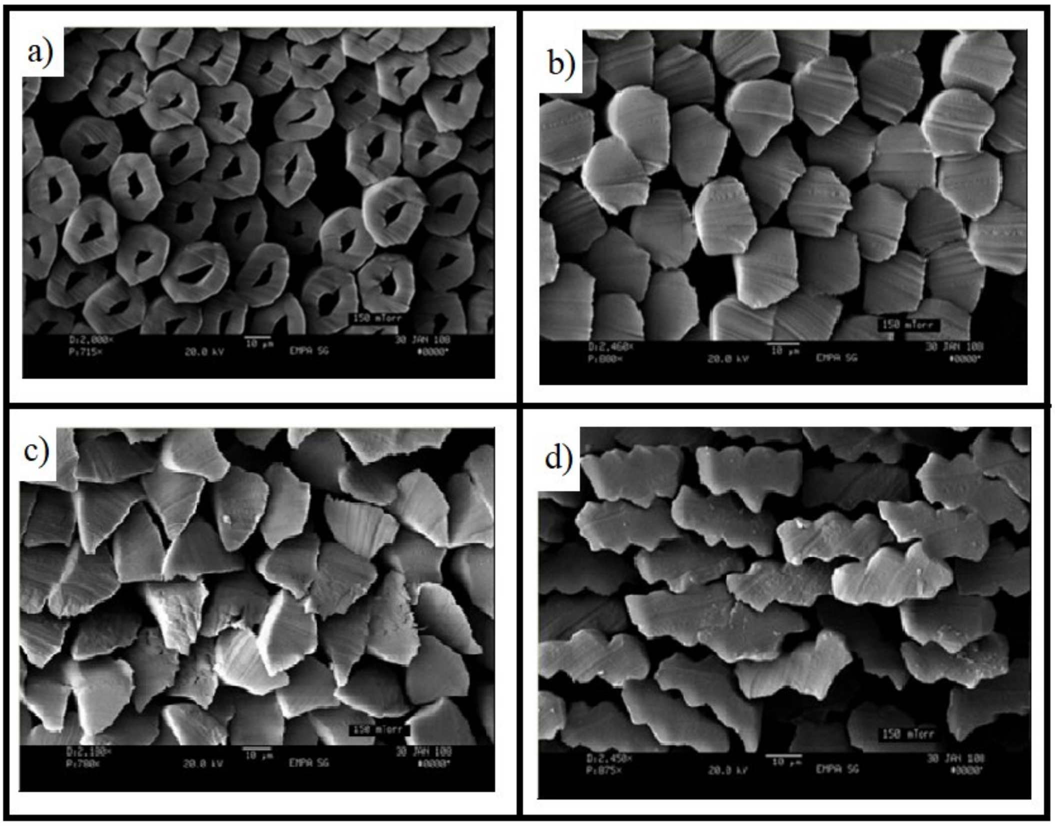

Fig. 1 Cross section shapes of fibers (a) hollow-round; (b) round; (c) triangular; and (d) W-shape.

The interlock fabrics were knitted on an E18 and D30” Fouquette circular knitting machine using a medium tightness factor and take-down tension values. After the dry relaxation process, some dimensional properties, bursting strength, and thermal comfort properties were measured. The measured parameters, their symbols and units, related measuring standards, and used instruments are listed in Table 1. Whole measurements were completed under standard atmospheric conditions.

During the evaluation of the results, fabric density was taken into consideration as an important parameter. The fabric density of the fabrics was determined using the FD = G / T equation: Here, FD is fabric density (g/m^3), G is mass per unit area of the fabrics (g/m^2), and T(m) is fabric thickness.

Table 1. Tested parameters, their units and test methods.

Parameter	Symbol (unit)	Related standard	Test device
Yarn breaking load	YBL (N)	TS 245 EN ISO 2062	Lawson Hemphill CTT
Mass per unit area	G (g/m^2)	TS 251	
Thickness	T (mm)	ISO 8301	SENSORA Alambeta
Fabric density	FD (g/cm^3)		calculated
Bursting strength	BS (kPa)	TS393	TMI Group, EC37
Air permeability	AP ($l/m^2/s$)	TS 391 EN ISO 9237	Textest FX 3300
Thermal resistance	Rct (m^2K/W)	ISO 8301	SENSORA Alambeta
Water vapor permeability	WVP (%)	ISO 11092	SENSORA Permetest

3 Results

The results of the experiments and statistical analyzes are shown in Table 2. In this table, the mean values of the measurements for each parameter are marked with the letters ‘a’, ‘b’ and ‘c’ according to the statistical evaluations. Here the letter ‘a’ shows the lowest and ‘c’ shows the highest values for each parameter. If the difference between the mean values of the different yarns is insignificant, they are marked with the same letter. For example, the thickness values of hollow and full round-shaped fibers are at the ‘b’ level. This means that the difference between them is statistically insignificant and their thickness is higher than other fibers.

Table 2. Specifications of interlock fabrics.

Code	Cross-section	YBL	G	T	FD	BS	AP	Rct	WVP
H	Hollow-round	6.48	176.4 a	0.98 b	180.0 a	1368.16 c	5109 b	0.0215 b	48.67 a
R	Round	6.15	183.4 b	0.98 b	186.7 a	1180.62 a	5427 b	0.0200 b	50.13 a
T	Triangular	5.97	175.8 a	0.87 a	202.1 b	1180.34 a	4430 a	0.0170 a	55.37 b
W	W-shape	6.41	188.2 c	0.87 a	216.3 b	1260.70 b	4495 a	0.0170 a	55.93 b

As visible in Figure 2, showing the relation between fabric density and thickness, the samples produced from both round-shaped fibers have higher thicknesses and lower fabric density values. Because of the different cross-sectional shapes, the packaging of the fibers is significantly different from each other.

The yellow circles in Figure 3 show the air gaps between filaments in the yarn structure. As depicted here, both round fibers have more air gaps between the fibers. However, for the other two cross-section shapes, the air gaps are smaller and fewer. Therefore, triangular and W-shape fibers have a denser and closer settlement inside the yarn. Finally, the fabric density of samples from these fibers will be higher.

Fig. 2 Relations between the fabric density and thickness.

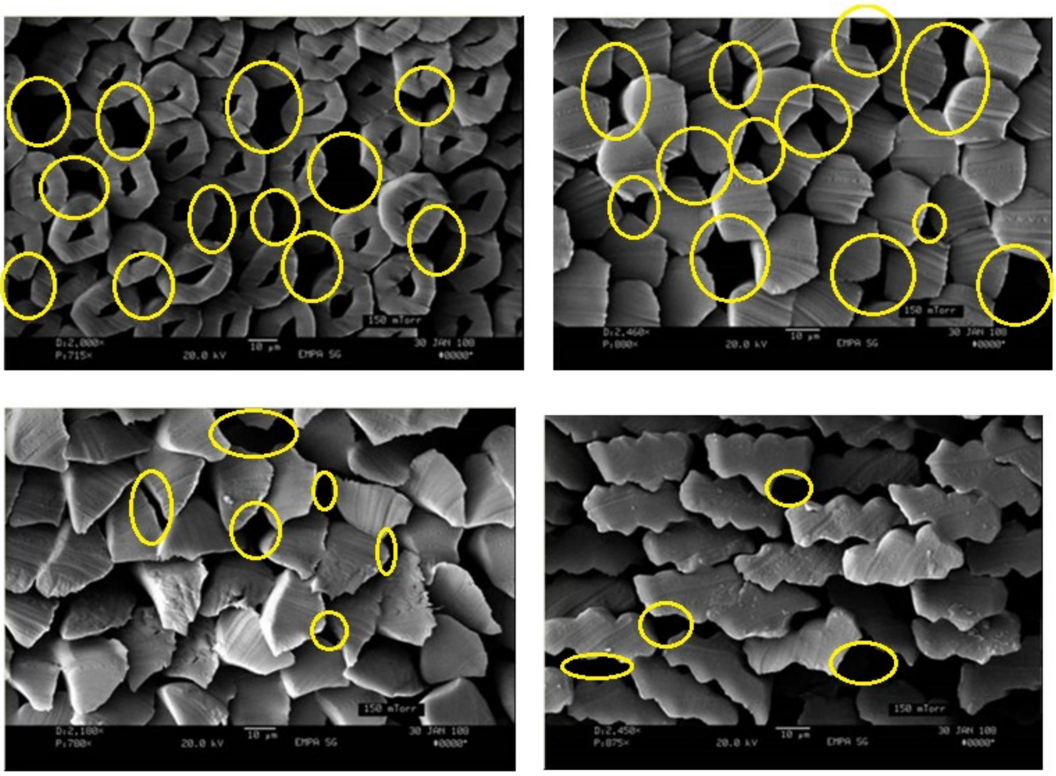

Fig. 3 Air gaps between filaments in the yarn structure for hole fiber types.

The fabric mass per unit area is one of the critical parameters for fabric properties. It is seen that from figure 4, the areal weight of the fabric from W-shaped fibers is the highest among the whole fibers, because it has the highest fabric density value. When the fabrics knitted from both round-shaped fibers are compared, it is visible that the fabric from the hollow-round fibers has a lower areal weight. Although the diameters are the same, this is an expected result due to the air channel inside the hollow fiber.

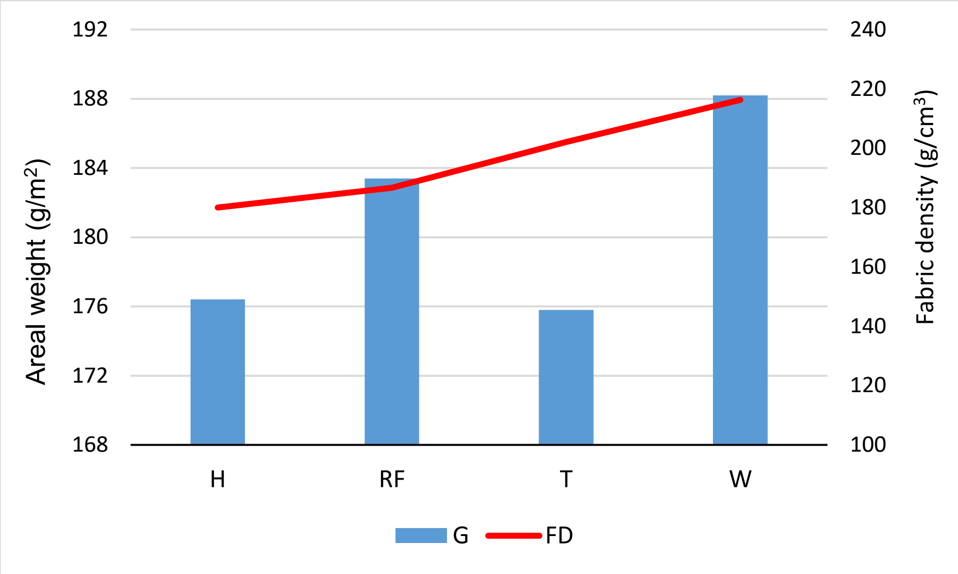

Fig. 4 Relations between the fabric areal weight and fabric density.

The bursting strength is the force that must be exerted perpendicular to the fabric surface to break off the fabric [16]. The value helps to determine the quality of the fabric and how safe it is for different applications. It is an important factor that can affect the elasticity and general strength of a fabric. The bursting strength of knitted fabrics is significantly dependent on fabric structure, fiber shape, blend, and yarn breaking load. The statistical evaluation has shown that the highest bursting strength value belongs to the sample knitted with hollow fibers, followed by W-shaped fibers. These results are thought to be due to the breaking load of the yarns. The relation between bursting strength of the fabric and yarn breaking load is given in Figure 5. As expected, a higher yarn breaking strength gives higher fabric bursting strength.

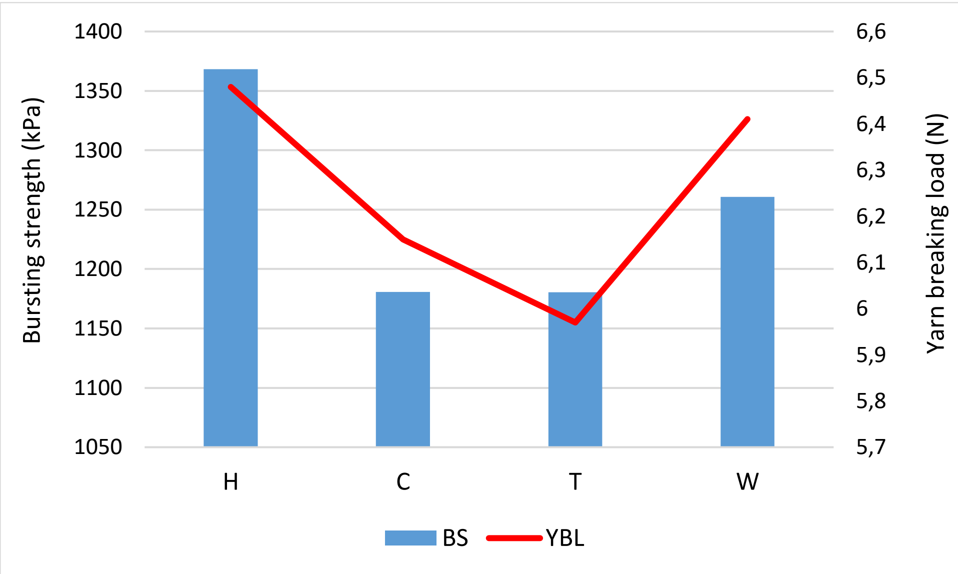

Fig. 5 Relations between the fabric bursting strength and the breaking loads of the yarns.

The results show that the samples knitted from both round-shaped fibers have significantly higher air permeability, because these fabrics have lower fabric density values of these fabrics than others. As can be seen from Figure 6, showing the correlation of air permeability and fabric density, the air permeability value decreases with an increase in fabric density.

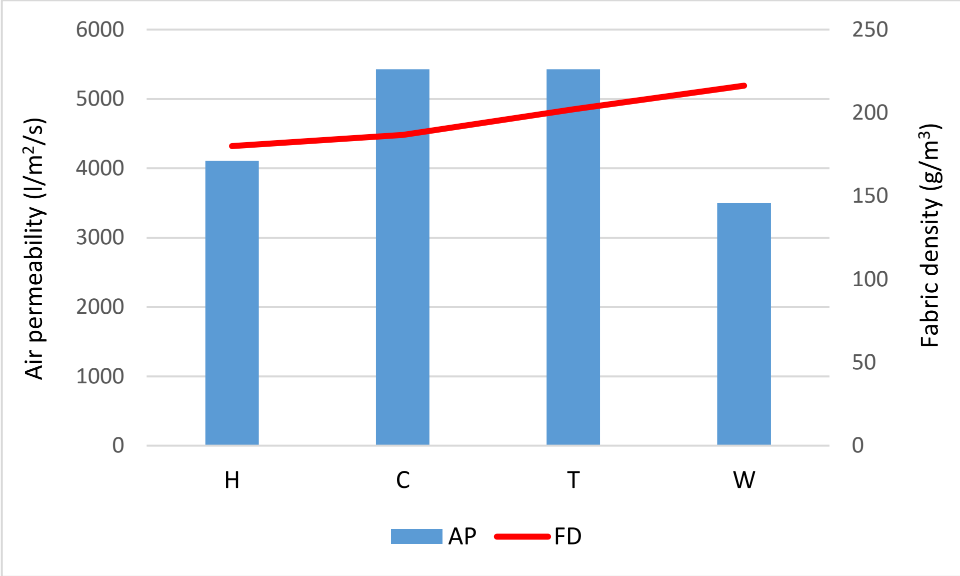

Fig. 6 Relations between the fabric air permeability and fabric density.

The relation between the thermal resistance and fabric density is given in Figure 7. It was observed that the sample knitted from hollow-round fibers has the maximum thermal resistance value, as it is expected. Because of the air channels inside fibers, the amount of entrapped air increases in the structure. Additionally, fabrics from both round fibers have significantly higher thermal resistance values. This is due to the high air gaps in the yarn structure and therefore the low density of the fabric. The greater amount of air in their structure causes higher insulation, as stated in previous studies [6,17,18].

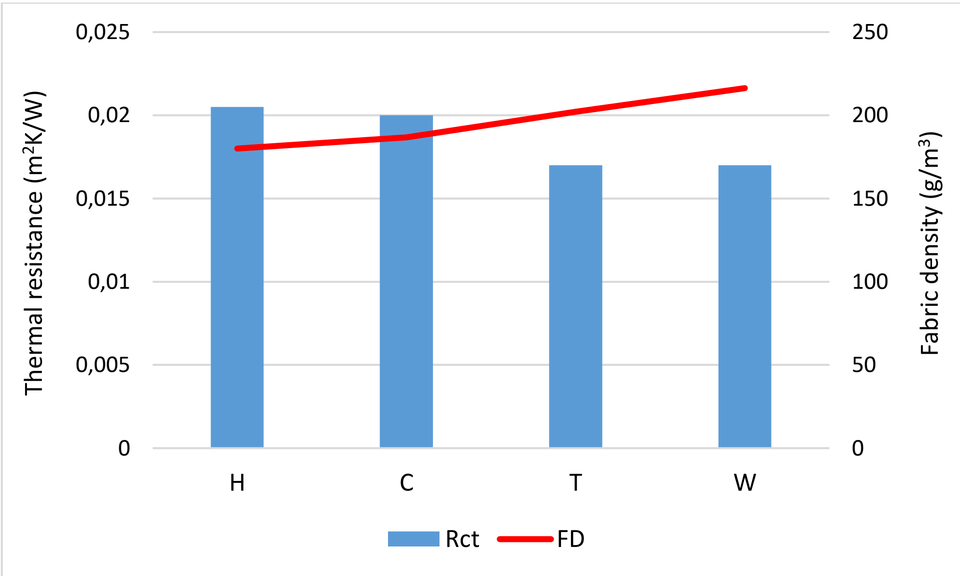

Fig. 7 Relations between the fabric thermal resistance and fabric density.

The test results given in Figure 8 show that the water vapor permeability values of the fabrics produced from triangular and W-shape fibers are significantly higher than the other fabrics. This result is thought to be due to two reasons. The first is that the thickness of these two fabrics is lower than that of circular cross-section fabrics, as seen from the graph correlating water vapor permeability and fabric thickness. As mentioned in a previous study [8], it is more difficult to transport water vapor through a thick and tight fabric than in the opposite case, because these fabrics have less air gaps for water vapor diffusion. Secondly, and more importantly, water vapor could easily pass through the thin channels formed between the fibers due to their irregular cross-sectional shape because of the capillary effect.

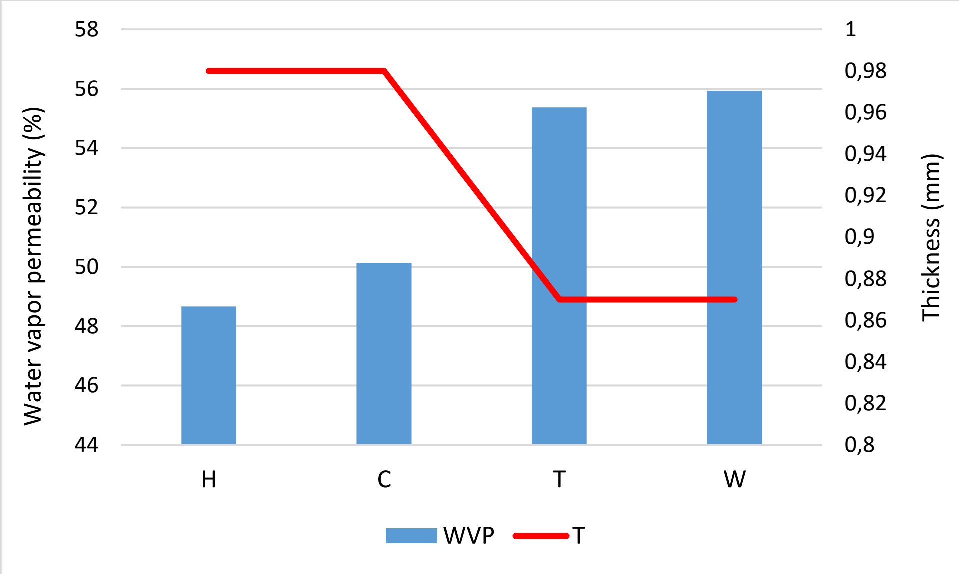

Fig. 8 Relations between the fabric water vapor permeability and fabric density.

4 Conclusion

The aim of this study was to investigate the effect of the cross-section shapes of polyester yarn on the dimensional and thermal comfort properties of interlock fabrics. As can be seen from the results, due to the denser and closer fiber settlement of the triangular and W-shape fibers, they have higher fabric density and less air permeability values. The water vapor permeability values of the fabrics from triangular and W-shape fibers are higher compared to the others because of lower thicknesses and capillary effect. The sample from hollow fibers has the highest bursting strength and thermal resistance values, because these fibers have a higher yarn-breaking load and more air channels inside the fibers.

Conflicts of Interest

The authors declare no conflict of interest.

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