Effects of Filament Linear Density on the Comfort Related Properties of Polyester Knitted Fabrics

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Abstract
One of the most important developments seen in the synthetic fibre industry is absolutely producing microfibres. Microfibres provide many distinguishing properties for different end uses. In this study, the effects of filament linear densities on the comfort related properties of polyester knitted fabrics were investigated. For this aim, microfilament polyester textured yarns of 110 dtex with 0.33 dtex, 0.57 dtex and 0.76 dtex filament linear densities and conventional polyester textured yarns of 110 dtex with 1.14 dtex and 3.05 dtex filament linear densities were knitted. Dynamic liquid moisture management, air permeability, water vapour permeability and thermal properties of the fabrics were tested. Consequently it is seen that fabrics with coarser filaments have a better capability of transferring liquid moisture. Lower air permeability results are observed with finer filaments, while there is no considerable difference among the samples for water vapour permeability. Also higher thermal resistance results are obtained for samples of coarser filaments.

Key words: microfilament, knitted fabric, dynamic liquid moisture management, air permeability, water vapour permeability, thermal resistance.

Introduction
Due to increasing performance demands from textile products, the synthetic fibre industry has seen very important developments such as producing microfilaments. Many researchers defined the microfilament as a filament finer than 1 dtex or 1 denier [1 - 8]. Microfilaments provide light weight, softness, good drapability and many distinguishing properties for different end uses. Knitted fabrics offer an important freedom of movement to the users distinctively from their woven counterparts. Unrestricted movement of knitted fabrics and distinguishing properties of microfilaments has caused a market demand for knitted microfilament garments. On the other hand, by the reason of being the most widely used synthetic fiber type, polyester microfilament knitted fabric is frequently utilised in a wide range of knitwear applications, including sportswear and underwear. For next-to-skin end uses, comfort is the foremost property in purchasing. In the literature, there are some studies which deal with the performance properties of microfibre knitted fabrics. Some of them [9 - 12] focused on the performance properties of knitted fabrics produced from staple type microfibres. On the other hand, a limited number of studies revealed the performance and comfort properties of knitted fabrics produced from microfilament yarns. It is seen that microfilament polyester fabric had higher water transportability, water absorbency, water holding capacity and lower drying time than conventional filament polyester fabric [13, 14]. In the case of thermal comfort and water vapour permeability properties, some studies revealed contrary results to each other [14 - 16]. On the other hand, with respect to spirality, bursting strength, abrasion resistance and pilling resistance, consistent results cannot be obtained in the literature [13, 17]. Apart from these studies, the present one investigates the comfort related properties of polyester filament knitted fabrics on the basis of filament linear densities. For this aim, the dynamic liquid moisture management property, air permeability, water vapour permeability and thermal conductivity properties of the fabrics were tested.

Materials and methods
In this study, microfilament polyester textured yarns of 110 dtex with 0.33 dtex, 0.57 dtex and 0.76 dtex filament linear densities and conventional polyester textured yarns of 110 dtex with 1.14 dtex and 3.05 dtex filament linear densities were used in order to investigate the effects of filament linear density on the comfort related properties of microfilament knitted fabrics. In doing so, we examined the effect of filament fineness for both micro and conventional linear densities. Cross-sectional SEM (Scanning Electron Microscopy) views of the yarns at the same magnification are seen in Figure 1 (see page 90).

The sample yarns were knitted in a single jersey structure by a 3.5” gauge and 22 fein sample circular knitting machine with one feeder at a 20 ± 2 rev/min production speed and same machine settings. Surface views of the fabrics at 40 times magnification are seen in Figure 2 (see page 90).

It is seen from Figure 2 that the sample fabrics have different structural views despite being knitted with the same production parameters. This is a probable result of different bulkiness properties of the sample yarns, which have different filament linear densities. All fabric samples were conditioned according to ISO 139 before the tests, performed in a standard atmosphere of 20 ± 2 °C and 65 ± 4% humidity. Fabric thickness, fabric surface mass, the number of stitches per unit length and stitch length properties of the sample fabrics were determined according to ISO 5084: 1996, TS EN 12127: 1999, TS EN 14971: 2006 and TS EN 14970: 2006 [18 - 21], respectively. Fabric structural properties are given in Table 1 (see page 91). It is seen from Table 1 that the loop length is same for all samples because of the same production parameters, whereas the other structural parameters are different among samples, because sample yarns behave differently from each other due to having different filament linear densities in the yarn cross section. The samples of yarns with coarser filaments exhibit higher contraction in the fabric structure, causing a lower num-
ber of stitches per unit length and fabric surface mass.

Liquid moisture management properties were determined by an SDL Atlas MMT (Moisture Management Tester) test device according to AATCC 195: 2010. Liquid moisture management properties of textile fabrics [22]. Air permeability properties of the fabrics were tested by SDL Atlas Digital air permeability tester according to ISO 9237:1995 Determination of the permeability of fabrics to air [23]. A 20 cm² test area was used and a 100 Pa air pressure applied during the test. Thermal resistance and thermal absorptivity properties of the sample fabrics were determined by an Alambeta Test Device. Water vapour permeability properties were tested by a Permetest Test Device. In order to understand the statistical importance of filament linear density for fabric comfort related properties, ANOVA was performed. For this
aim the statistical software package SPSS 17.0 was used to interpret the experimental data. All test results were assessed at a 95% confidence interval.

## Results and discussion

In this experimental study, comfort related properties of polyester knitted fabrics such as dynamic liquid moisture management, air permeability, water vapour permeability and thermal conductivity properties were investigated as a function of the filament linear density of the component yarn.

### Dynamic liquid moisture management

Perspiration plays an important role in the cooling mechanism of the human body and occurs in two ways: insensible perspiration and sensible perspiration (sweating). For human comfort, to eliminate dampness, clinginess and stickiness, it is crucial to realise the fabric behaviour during liquid contact. Consequently transferring liquid moisture from the surface of the skin to the atmosphere is the foremost comfort property for next-to-skin use. There are many test methods to evaluate the liquid contact behaviors of fabrics such as wetting, wicking, liquid absorption and liquid strike through. Two important phenomena occur simultaneously during contact between liquid moisture and fabric for transferring the liquid moisture from the surface of the skin to the atmosphere: firstly in the plane transfer of liquid moisture, and secondly through plane transfer of liquid moisture. The MMT device measures different properties for dynamic liquid moisture management. In this study, we decided to consider the in-plane transfer of liquid moisture, termed ‘the spreading speed’, and through plane transfer of liquid moisture, termed ‘one way transport capability’, by means of an MMT device. The spreading speed and one way transport capability results of the MMT test device are seen in Figures 3 and 4, respectively.

The MMT test device measures the spreading speed of liquid moisture on the top and bottom surfaces. Figure 3 exhibits the bottom and top spreading speed properties of the samples. According to the MMT device’s grading scales, all samples have a “very fast” spreading speed. In spite of this grading, it is seen from Figure 3 that the spreading speed of liquid moisture increases by rais-

### Table 1. Structural properties of samples.

| Samples | Fabric thickness, mm | Mass per square meter, g/m² | Loop length, mm | Number of wales per cm | Number of courses per cm |
|---------|---------------------|-----------------------------|----------------|-----------------------|------------------------|
| 0.33 dtex | 0.50 | 111 | 2.9 | 16 | 18 |
| 0.57 dtex | 0.57 | 109 | | 14 | 16 |
| 0.76 dtex | 1.14 dtex | 100 | 88 | | |
| 1.14 dtex | 3.05 dtex | 88 | | | |

### Table 2. ANOVA for dynamic liquid moisture management properties.

| Top spreading speed | Sum of squares | Degree of freedom | Mean square | F | Significance |
|---------------------|----------------|------------------|-------------|---|--------------|
| Filament linear density | 76.141 | 4 | 19.035 | 388.707 | 0.000 |
| Within groups | 0.881 | 18 | 0.049 | | |
| Total | 77.022 | 22 | | | |

| Bottom spreading speed | Sum of squares | Degree of freedom | Mean square | F | Significance |
|-----------------------|----------------|------------------|-------------|---|--------------|
| Filament linear density | 64.754 | 4 | 16.189 | 456.728 | 0.000 |
| Within groups | 0.638 | 18 | 0.035 | | |
| Total | 65.392 | 22 | | | |

| One way transport capability | Sum of squares | Degree of freedom | Mean square | F | Significance |
|------------------------------|----------------|------------------|-------------|---|--------------|
| Filament linear density | 28403.929 | 4 | 7100.982 | 2.766 | 0.059 |
| Within groups | 46206.372 | 18 | 2567.021 | | |
| Total | 74610.301 | 22 | | | |
The one way transport capability property denotes the ability of the fabric to transfer liquid moisture from one side of the fabric to the other. In other words, a higher one way transport capability means that sweat can be easily and quickly transferred from the skin to the outer surface of the garment to keep the skin dry.

As exhibited in Figure 4, the one way transport capability is higher for coarser filaments. The samples, except 0.33 dtex filament linear density, have “excellent” one way transport capability according to the MMT grading scale, while the 0.33 dtex sample has a lower grading of “very good” according to the MMT scale. But the difference among the samples is not so obvious. There is a slight increase in one way transport capability as the filaments get coarser. This situation is a result of having larger macro pores for fabrics produced with coarser filaments. Furthermore the effect of filament linear density on the one way transport capability is not significant (p = 0.059) statistically, as seen in Table 2. One way transport capability and the spreading speed are increased with higher filament linear density values. High one way transport capability and spreading speed means a high capability of transferring the liquid through the fabric [26, 27]. As a consequence of test results, it can be concluded that fabrics with coarser filaments tend to keep the skin dry more than those of finer ones.

**Air permeability**

Air permeability is often used in evaluating and comparing the comfort property of fabrics. The influence of filament linear density on air permeability is evident from Figure 5. Air permeability values are increased with coarser filaments, as seen in earlier studies [17, 28]. In the case of microfilament linear density (0.33, 0.57 and 0.76 dtex), air permeability values of samples are close to each other. In regard to conventional filament

Table 3. ANOVA for air permeability

| Filament linear density | Sum of squares | Degree of freedom | Mean square | F         | Significance |
|-------------------------|---------------|------------------|-------------|-----------|--------------|
| 3.05 dtex               | 1.195×10⁷     | 4                | 298894.614  | 209.004   | 0.000        |
| Within groups           | 60057.500     | 42               | 14299.702   |           |              |
| Total                   | 1.256×10⁷     | 46               |             |           |              |

Table 4. ANOVA for water vapour permeability

| Filament linear density | Sum of squares | Degree of freedom | Mean square | F         | Significance |
|-------------------------|---------------|------------------|-------------|-----------|--------------|
| 0.33 dtex               | 19.128        | 4                | 4.782       | 2.681     | 0.083        |
| Within groups           | 21.402        | 12               | 1.783       |           |              |
| Total                   | 40.529        | 16               |             |           |              |

**Figure 6. Water vapour permeability of samples.**

**Figure 5. Air permeability of samples.**

ing the filament linear density for both the top and bottom surfaces. Especially for the 3.05 dtex sample, both the top and bottom spreading speed values are considerably higher than those of other samples. As seen from Figure 1, yarns with finer filaments have a high number of micro pores between the filaments. On the other hand, if Figure 2 is observed, it is seen that fabrics with finer filaments have a bulky and compact structure of small macro pores between the yarns. Especially the 3.05 dtex sample has a lower number of loops in the unit area and also considerably larger macro pores between the yarns than other samples. Rapid in plane transfer of the liquid for samples which have coarser filaments can be explained by large macro pores, because during liquid contact the macro pores are responsible for the rapid diffusion of liquid. In a short time duration, the macro pores absorb liquid rapidly [24] and the measurement duration of the MMT device is 120 seconds, whereas in a long time duration, the micro channels are responsible for reaching the maximum height with a slow diffusion rate [24, 23]. Consequently our samples with coarser filaments, which have large macro pores, have higher in plane transfer capability of liquid moisture. In other words, fabrics with coarser filaments transfer liquid moisture through the fabric surface more rapidly. According to statistical analysis, filament linear density has a significant effect on both the top (p < 0.000) and bottom (p < 0.000) spreading speed properties at a 95% confidence interval.

**Table 2.** Statistic results of filament linear density on water vapor permeability and air permeability.

| Filament linear density | Water vapor permeability, % | Air permeability, mm/s |
|-------------------------|-----------------------------|------------------------|
| 0.33 dtex               | 35                          | 4000                   |
| 0.57 dtex               | 30                          | 3000                   |
| 0.76 dtex               | 25                          | 2000                   |
| 1.14 dtex               | 20                          | 1000                   |
| 3.05 dtex               | 15                          | 500                    |
The thermal properties of a garment are important to determine its suitability for use in different environmental conditions. For this assessment, the protection capability of the garment from environmental thermal conditions is of prime importance. This property can be identified from the thermal resistance. In addition, the feeling of warm or cool sensed by the wearer is also an important thermal comfort descriptor for next-to-skin use. The measurement of this sense is explained by thermal absorptivity. Thermal resistance and thermal absorptivity properties of the samples are illustrated in Figures 7 and 8, respectively.

As seen from Figure 6, the sample fabrics exhibited similar levels of water vapour permeability. In addition, according to the statistical analysis in Table 4, there is an insignificant effect of filament linear density on water vapour permeability (p = 0.083).

**Water vapour permeability**

Water vapour permeability is an important property that indicates the fabric transfer capability of water vapour from the inner to outer side of the fabric. If sufficient water vapour transfer does not exist, the wearer feels uncomfortable due to the high temperature of the microclimate inside the fabric as well as dampness as a result of condensation. The water vapour permeability test results are given in Figure 6.

As seen from Figure 1, yarns with coarser filaments have large pores between the filaments than finer ones. In addition, Figure 2 exhibits the inter yarn porosity of fabrics, where larger inter yarn porosity is seen for fabrics with 1.14 dtex and 3.05 dtex filament linear density. Air passes through the larger pores more easily than those of smaller pores due to the strong relation between air permeability and porosity in knitted fabrics [29]. As the filament linear density decreases, the number of filaments in the yarn cross sections increases. Thus the specific surface area of filaments increases. This situation causes a higher drag resistance to air flow through the fabric. Consequently air permeability decreases with finer filaments. Samples of microfilament linear density values of 0.33, 0.57 and 0.76 dtex have close and low air permeability values, whereas those of conventional filament linear density of 1.14 and 3.05 dtex have higher air permeability values. Also the statistical analysis exhibited in Table 3 indicates the significant effect of filament linear density on air permeability (p < 0.000).

**Thermal resistance and thermal absorptivity**

The thermal properties of a garment are important to determine its suitability for use in different environmental conditions. For this assessment, the protection capability of the garment from environmental thermal conditions is of prime importance. This property can be identified from the thermal resistance. In addition, the feeling of warm or cool sensed by the wearer is also an important thermal comfort descriptor for next-to-skin use. The measurement of this sense is explained by thermal absorptivity. Thermal resistance and thermal absorptivity properties of the samples are illustrated in Figures 7 and 8, respectively.

In Figure 7, the lower thermal resistance of the 0.33 dtex sample than those of other filament linear densities is obvious, as the other samples show higher thermal resistance values. In addition, for the samples, except that of 0.33 dtex filament linear density, there is a slight increase in thermal resistance as the filaments get coarser, which is a probable result of the increase in the total pore dimension for coarser filaments, because air is held in the inter fibre and inter yarn pores, and the thermal conductivity of air is lower than that of textile fibres. As a consequence, fabrics which have more pores in the structure, where more air is held, have higher thermal resistance [28, 30 - 32]. The increase in the pores is particularly evident from Figure 1, which deals with inter fibre pore dimensions, and Figure 2, which deals with inter yarn pore dimensions. This means that finer filaments have worse protection capability for the wearer against environmental conditions. Besides this, the effect of filament linear density on ther-
nal resistance is statistically significant ($p = 0.034$), as seen in Table 5.

In the case of the thermal absorptivity of the sample fabrics, which are exhibited in Figure 8, it is seen that there is a minor decrease in thermal absorptivity due to the increase in filament linear density. The surface character of the fabric greatly influences this sensation. A rough fabric surface reduces the area of contact appreciably, and a smoother surface increases the area of contact and heat flow, thereby creating a cooler feeling [28, 30]. It is a well-known fact that fabrics produced from microfilaments have a soft touch and smooth surface, which is a probable reason for the higher thermal absorptivity or cool feeling of microfilament fabrics. On the other hand, filament linear density has no significant effect on the warm-cool feeling of these fabrics according to statistical analysis ($p = 0.365$).

**Conclusions**

In this study, we intended to investigate the effect of filament linear density on the comfort related properties of polyester filament knit fabrics. According to experimental results, a noteworthy effect of filament linear density is observed on dynamic liquid moisture management properties. Rapid in plane and through plane transfer of liquid is observed for samples which have coarser filaments. Especially 3.05 dtex filament linear density samples exhibit considerably different liquid transfer values. This situation may be attributed to the fact that the macro pores absorb liquid rapidly in a short time duration [24, 25]. Lower air permeability values are obtained for samples with microfilament linear density values, whereas those with conventional filament linear density have higher air permeability. In the case of water vapour permeability, there is no considerable effect of filament linear density on the water vapour permeability of the samples. With respect to thermal properties, the sample which has the lowest filament linear density of 0.33 dtex has the lowest thermal resistance. The other samples which have coarser filaments in the fabric structure have similar and also higher thermal resistance values than the 0.33 dtex sample. In the case of thermal absorptivity, the 0.33 dtex sample differs from others with a higher value. Besides, for the rest of the samples, there is a slight increase in thermal absorptivity with a decrease in filament linear density by the reason of the soft touch and smooth surface.

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