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Intermingling pressure level effect on micro polyester melange knitted fabric properties

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This study aims at investigating the effects of intermingling pressure level on properties of melange fabrics made of multifilament micro polyester yarns. For this purpose, unit weight, thickness, moisture management, transfer and surface properties of fabrics have been measured, and fabric porosity is analysed by image analysis methods. In addition, image analysis techniques are also used to determine the effect of intermingling pressure level on the visual properties of melange fabrics. Results show that the intermingling pressure level has statistically significant effects on the unit weight, fabric thickness, air permeability, fabric porosity and fabric's visual properties.

Keywords: Intermingling, Image analysis method, Melange fabric, Micro polyester, Multifilament, Textured yarn

1 Introduction

Polyester is one of the most widely used synthetic fibres in yarn production. The fabrics produced from polyester yarns have high elasticity and strength, good durability, soft handle, light weight, high wrinkle-resistance, and easy washing and drying properties[1,2]. Synthetic fibres, such as polyester, are generally textured. Texturing is a method that changes the fibre's texture (physical appearance of the fibre) and gives natural fibre properties to the continuous filaments. The prime purpose of texturing synthetic filament yarn is to create a bulky structure[3]. Moreover, the texturing process also imparts elasticity, resilience, porosity, better handling, air permeability and comfort properties like warmth, insulation, and moisture absorption to flat continuous filament yarns without destroying its continuity. The geometrical structure determines these properties and can be changed by giving crimps, curls, waviness, loops, coils, or crinkles to continuous filaments. Since 1950s various commercial texturing methods, such as edge-crimping, gear crimping, knit-de-knit, stuffer box, false twist and air-jet texturing have been introduced[4-6]. Except air-jet texturing, all other texturing processes utilize the thermoplastic nature of polymers and have four main steps, viz deforming, heating, cooling, and relaxing. False twist texturing has become the most widely used method for producing textured yarn over the years. False twist texturing process involves drawning, twisting, heat-adjusting of the twisted form and de-twisting, and is performed using friction discs.

The false twist textured yarns consist of continuous filaments with crimp that lack of inter-filament cohesion[4]. Textured yarns can be used with this form as 'unintermingled yarn' or it is used as 'intermingled yarn' after intermingling process. Intermingling is an optional process used to hold together filaments in the structure of textured yarns. It is achieved by passing the textured yarn through the turbulent zone of an air jet intermingling nozzle which is positioned in the path of the yarn. This creates intermittent, knot-like entangled nodes along the yarn and increase the inter-filament cohesion significantly[7]. This process helps to reduce the chances of broken filaments locking up during processing or building up fluff that would disrupt production[8]. Intermingled yarn is well defined in Textile Terms and Definitions, Tenth Edition, published by the Textile Institute. However, synonyms of this term such as mingled, co-mingled, interlaced, tangled or entangled yarns are still used in the industry[4,5].

Intermingling process specification factors are air pressure, yarn speed and yarn tension[4]. Intermingling and its process parameters have significant effects on yarn and fabric properties. It is found that many studies have been dealt to investigate these effects on yarn properties[7,9-20]. On the other hand, there are few studies which analyze the effects on fabric properties[21-24]. Ucar *et al.*[21] investigated the effects of

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two important parameters, viz number of knots and draw-ratio, in intermingled nylon-elastomeric yarns, on the physical and comfort properties of hosiery knit products. Ozkan *et al.*[22] aimed to assess the effects of intermingled yarns surface structure caused by difference in number of nips, on the knitted fabrics' color parameters with spectral photometer. In another study, Ozkan *et al*.[23] examined the effect of filament yarn's number of nips on bending rigidity of knitted fabric. Bilisik and Demiryurek[24] analyzed the effects of interlacement and yarn sets on the tensile behavior of air-entangled textured polyester fabrics using regression model.

In this study, it is aimed to examine the effects of intermingling pressure level on properties of fabrics produced from multifilament melange micro polyester yarns. For this purpose, physical, moisture, comfort, transfer, and surface properties of fabrics are analysed. In this respect, unit weight, thickness, roughness, air permeability and moisture management properties of fabrics are measured, and fabric porosity is determined by image analysis method. In addition, the effect of intermingling pressure level on the visual (surface appearance) properties of melange fabrics, which are known to be very important for aesthetic design and customer purchase preference, is analysed using image analysis techniques.

2 Materials and Methods

2.1 Materials

Single jersey knitted fabrics produced from melange 100% micro polyester POY (partially oriented yarn) were used for the study. Multifilament yarn having linear density 150 denier and 288 filaments (150 denier f 288), the content of which is 144 ecru and 144 black filaments, was used. The yarn containing different colored fibres is called melange yarn. Melange yarns were used in the study because it is thought that the pressure level changes the fibre distribution in the yarn structure and therefore affects the visual properties. Due to its increasing popularity year by year, microfibres were preferred in the multifilament yarn production. Fibres, having the fineness in the range of 0.1–1.0 dtex, are termed as microfibres[25]. When compared with conventional fibres, microfibres provide luxurious appearance, improved physical and handle properties, and high level of wearing comfort for fabrics[26].

The texturing process of yarns was performed using the false twist friction discs. The intermingling device was located after the second drawing roller and the yarns were interlaced by the effect of air pressure in this device. Normally, 1-6 bar air pressure is applied during the intermingling process for textured yarns produced from standard fineness fibres. On the other hand, low air pressure, approximately 0.4 bar, is applied for micro filament application to reduce broken filaments and tight spots and facilitate downstream processing[4]. In this study, intermingled textured yarns were produced under 0.2 bar, 0.5 bar, 0.8 bar and 1.0 bar intermingling pressure levels to evaluate the effect of the air pressure. For better comparison, textured yarn without intermingling was also produced. Properties of yarns are given in Table 1. Single jersey knitted fabrics were produced from intermingled yarns using the same machine settings with 12 courses and 11 wales per cm and 4.0 mm loop lengths.

2.2 Methods

Fabric unit weight and fabric thickness were measured to determine physical properties of fabrics. Fabric unit weight was measured according to EN 12127:1997. Fabric thickness was measured by R&B cloth thickness tester under 5 g/cm^2 pressure. Multi-directional liquid transmission properties were measured by SDL Atlas MMT test device in accordance with AATCC Test Method 195-2009. Wetting time /top-bottom (s), absorption rate/ top-bottom (%/s), maximum wetted radius/top-bottom (mm), spreading speed/top-bottom (mm/s), Accumulative One-way Transport Index (AOTI), and Overall Moisture Management Capability (OMMC) of the fabrics were measured by this device. AOTI and OMMC are most widely used indexes among these. AOTI is the difference between the area of the liquid moisture content curves of the top and bottom surfaces of a specimen with respect to time. AOTI index shows the cumulative moisture difference between two surfaces of fabric and it is calculated using the water content on the fabric top surface and bottom surface *vs*. time. With an increased AOTI

Table 1 — Properties of yarns

Intermingling pressure level bar	Linear density dtex	No. of interlaces / m (under no tension)	Breaking strength cN	Elongation %
0 (unintermingled)	177	0	617.05	21.70
0.2	181	62	469.75	12.46
0.5	182	87	517.94	13.95
0.8	182	93	532.84	15.12
1.0	182	88	492.12	13.35

value, the transmission of liquid from the skin to the environment will be easier and faster. Minus and low AOTI values indicate that the fabric gets wet quickly and removes the liquid late. OMMC is an index of the overall capability of a fabric to transport liquid moisture. The higher this value, the better will be the fabric's liquid transmission performance. OMMC is calculated by combining three measured attributes of performance, viz the liquid moisture absorption rate on the bottom surface (AR_B), AOTI, and the maximum liquid moisture spreading speed on the bottom surface (SS_B)[27]. The air permeability tests were made with 100 Pa pressure drop and 20 cm² test area in accordance with ISO 9237:1995 using Textest FX 3300 air permeability tester. Porosity of the fabrics was determined by image analysis method. Image processing is a signal processing method in which the input of the system is an image and output is an image or the property of this image. Digital image is composed of a finite number of elements called pixels. An image can be defined as a two-dimensional function as f (x,y), here x and y coordinates of the function determine the intensity or gray level of the image at that point[28,29]. Images may be in the form of color image, gray level image or binary image. Every pixel is defined with three values, which are Red (R), Green (G) and Blue (B) in color image. In this study, at the first step, color digital images of fabrics were captured by a digital camera integrated to a microscope (Olympus SZ61) with ×10 magnifying lens. Then, images were converted to gray level using the MATLAB image processing toolbox at the second step. Gray level images consist of 256 gray tones. Zero gray level value denotes black and 255 gray level value denotes white color in the gray scale. At the third step, to calculate fabric porosity, gray level images were converted into binary image using a suitable threshold value by separating pore regions. The value of the pixels higher than the defined threshold value was converted into white pixels and lower ones were converted into black pixels using the Otsu method with MATLAB image processing toolbox according to following equation[29]:

$$g(x,y) = \begin{cases} 1 \; f(x,y) \geq \text{Threshold value} \\ 1 \; f(x,y) < \text{Threshold value} \end{cases} \quad \ldots (1)$$

In binary image, white pixels represent pore areas and black pixels represent yarns [Fig. 1(a)]. The porosity of fabrics (%) was calculated as the ratio of total number of white pixels to total number of pixels of the image.

Fabric roughness is defined as protrusions that disrupt the fabric's surface smoothness and is one of the most crucial parameters for fabric handle properties and prediction of clothing tactile comfort. Mitutoyo SJ 301 surface roughness tester was used for the measurements of fabric roughness. The surface roughness tester is a stylus type and evaluates surface textures with a variety of parameters. The stylus of the SJ–301 detector unit traces the minute irregularities of surface. Surface roughness is determined from the vertical stylus displacement produced during the detector traversing over the surface irregularities. Arithmetic mean of absolute values of the roughness profile deviations (Ra) is the most commonly used parameter for analyzing the surface roughness.

In the context of study, image-processing techniques were also used to analyse the effects of intermingling pressure level on fabric visual properties. For this purpose, entropy (randomness) properties of fabrics were determined. Entropy is a statistical measure of randomness that can be used to characterize the texture of the input image and is defined as sum (p.*log2(p), where p contains the normalized histogram counts returned from imhist[29]. Entropy can be thought as a measurement of the sharpness of the histogram peaks[30]. This parameter is a measure of disorder and higher entropy illustrates the greater the disorder. For determining surface randomness, the surface images of the fabrics were taken with a scanner as a first step. Scanner was used instead of a microscope to obtain the image in a larger area (with original size and fixed light source). At the second step, images were converted to gray level using the Matlab image processing toolbox and entropy was determined from gray level images. Also, histograms of images were analyzed. And, at the last step, gray level images were converted into binary image using a suitable threshold value, which is the same for all images. Entropy was also calculated for binary images[31]. Images used for surface randomness are given in Fig. 1(b).

3 Results and Discussion

In this study, effects of intermingling pressure level on the properties of single jersey knitted fabrics produced with textured micro polyester yarns have been evaluated. For this purpose, Analysis of Variance (ANOVA) at $\alpha = 0.05$ significance level is performed, and bar charts and 95% confidence interval graphs are used to visualize the results.

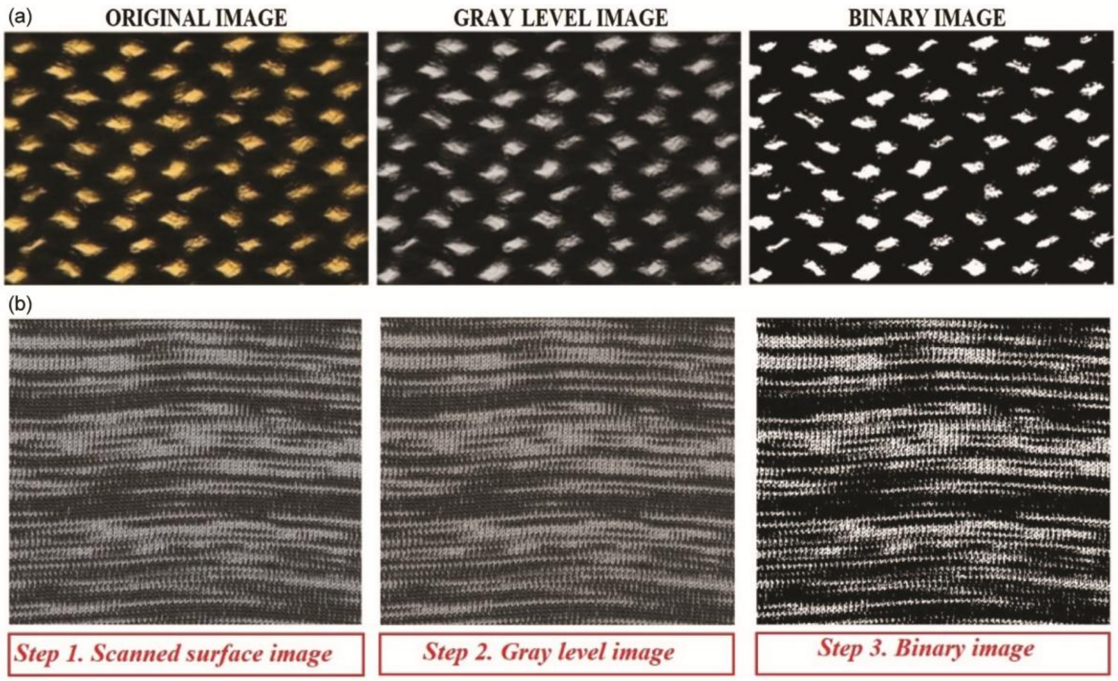

Fig. 1 — Steps of image analysis for (a) fabric porosity, and (b) surface randomness

Table 2 — OMMC and AOTI values and significance level

Pressure level, bar	OMMC	Sig.	AOTI, %	Sig.
Unintermingled	0.6125		131.8171	
0.2	0.6532		159.5900	
0.5	0.5735	0.255	107.3238	0.080
0.8	0.5810		197.3119	
1.0	0.5365		79.6747	

3.1 Physical Properties

The mean values and significance levels of fabric unit weights and fabric thicknesses are given in Table 2, and 95% confidence interval plots for fabric unit weight (g/m^2) and thickness (mm) are given in Fig. 2. When the unit weight and thickness values of the fabrics are examined, it is observed that the effect of intermingling pressure level is statistically significant at α=0.05 (p=0.025 for fabric unit weight, p=0.000 for fabric thickness) and fabrics, produced from unintermingled yarns, have the highest values for both fabric structural parameters. Pair-wise comparison shows that fabrics produced from unintermingled yarns have quite different values from the others and the differences between 0.5, 0.8 and 1.0 bar are not statistically significant for fabric unit weight and thickness.

During the knitting process, 3-10 cN tension is applied on the yarns[32,33] and a certain amount of elongation occurs under this tension. For yarns used in the study, when the load-extension curves are examined, it is observed that all the yarns remain in

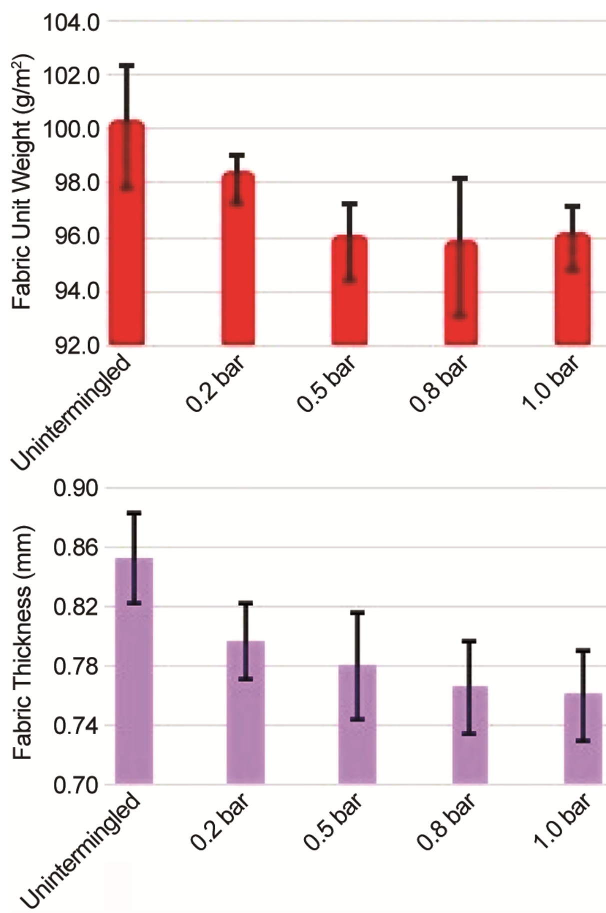

Fig. 2 — Unit weight and thickness values of fabrics

the elastic region (1st region) under this given tension. Moreover, unintermingled yarns have the highest elongation values [34]. Therefore, when the tension is removed after the knitting process and the fabric is completely relaxed, it is expected that unintermingled yarns have the highest elastic recovery. As a result of this situation, it is thought that fabrics produced from these yarns have greater unit weight. For fabric thickness, it is thought that the knots are not caused greater thickness values, as the yarns made of microfibres and intermingled at low pressures. Since intermingling pressure level has an inverse effect on yarn diameter[5], with the decrease in yarn diameter fabric thickness decreases. As a result of this situation, while intermingling pressure level increases, the fabric thickness measured under 5 g/m^2 pressure decreases.

3.2 Comfort and Transfer Properties

MMT test device measures many parameters related to the moisture management properties of fabrics. Among these parameters, OMMC and AOTI give a general information about fabric moisture comfort. While OMMC indicates the all capacity of the liquid moisture, AOTI shows the cumulative moisture difference between two surfaces of the fabric. The results of OMMC and AOTI and significance levels are given in Table 2. It is found that intermingling pressure level does not have statistically significant ($\geq$0.05) effect on OMMC and AOTI values, since raw material and knitting type are the most important factors in terms of moisture management, as well as other properties[35-38].

OMMC values of fabrics range between 0.57 and 0.65 and AOTI values range between 79.67% and 197.32%. When a general evaluation is made for fabrics produced from intermingling micro polyester yarn, it is possible to say that OMMC and AOTI values are quite good[27,37].

Air permeability is one of the most important transfer properties of fabrics and depends on passing the air through fibres, yarns and fabric structure. Fabric porosity is a crucial parameter which directly affects air permeability of fabrics. Within the context of the study, porosities of fabrics are analysed by image analysis. Air permeability and porosity values are given in Fig. 3. The statistical results indicate that intermingling pressure level is statistically significant for air permeability and fabric porosity. For both air permeability and porosity, fabrics produced from unintermingled yarns have the lowest values, while fabrics produced from 0.8 bar intermingled yarns have the highest. Pair-wise comparison results show that there is no statistically significant difference between 0.8 bar and 1.0 bar for both air permeability and porosity. It is thought that, due to higher yarn diameter and lower fabric porosity, fabrics produced with unintermingled yarns have the lowest air permeability values. It is known that yarns which are unintermingled have the highest diameters and considered that they have the lowest porosity and hence air permeability values as a result of this situation. When the correlation coefficient between air permeability and fabric porosity is calculated, it is found equal to 0.91.

3.3 Surface and Visual Properties

Fabric roughness is related to the tactile properties of fabrics, such as prickle, harshness, warmness and coolness. Ra (μm) values change in the range 35.2-37.1 for course direction and 21.5-26.1 for wale direction. According to the ANOVA results, the effect of intermingling pressure level is not statistically significant for course and wale directions of the fabrics (p=0.945 for course direction, p=0.724 for wale direction). It is possible to say that due to the low air pressure, intermingling points do not change the roughness of fabric significantly and these points are located randomly not only on the fabric surface but also in the fabric interior structure. Also, other factors such as linear density of yarns, interlacing points, knitting structure and setting values have an important effect on surface roughness and they are same for all fabrics used in the study.

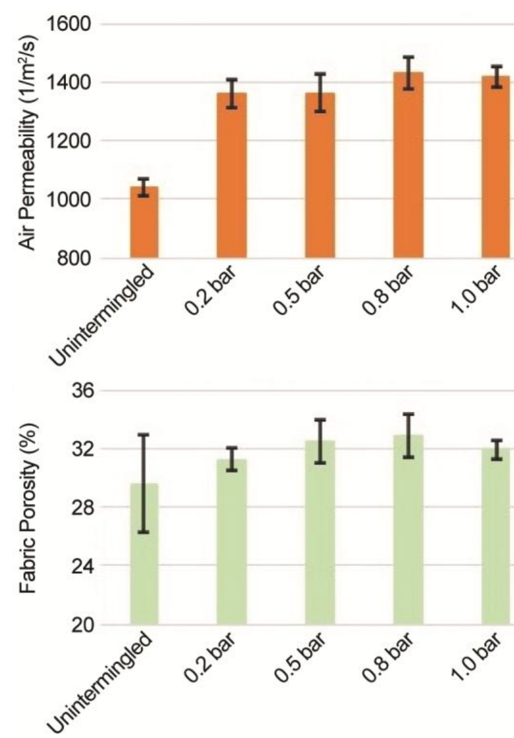

Fig. 3 — Air permeability and porosity values of fabrics

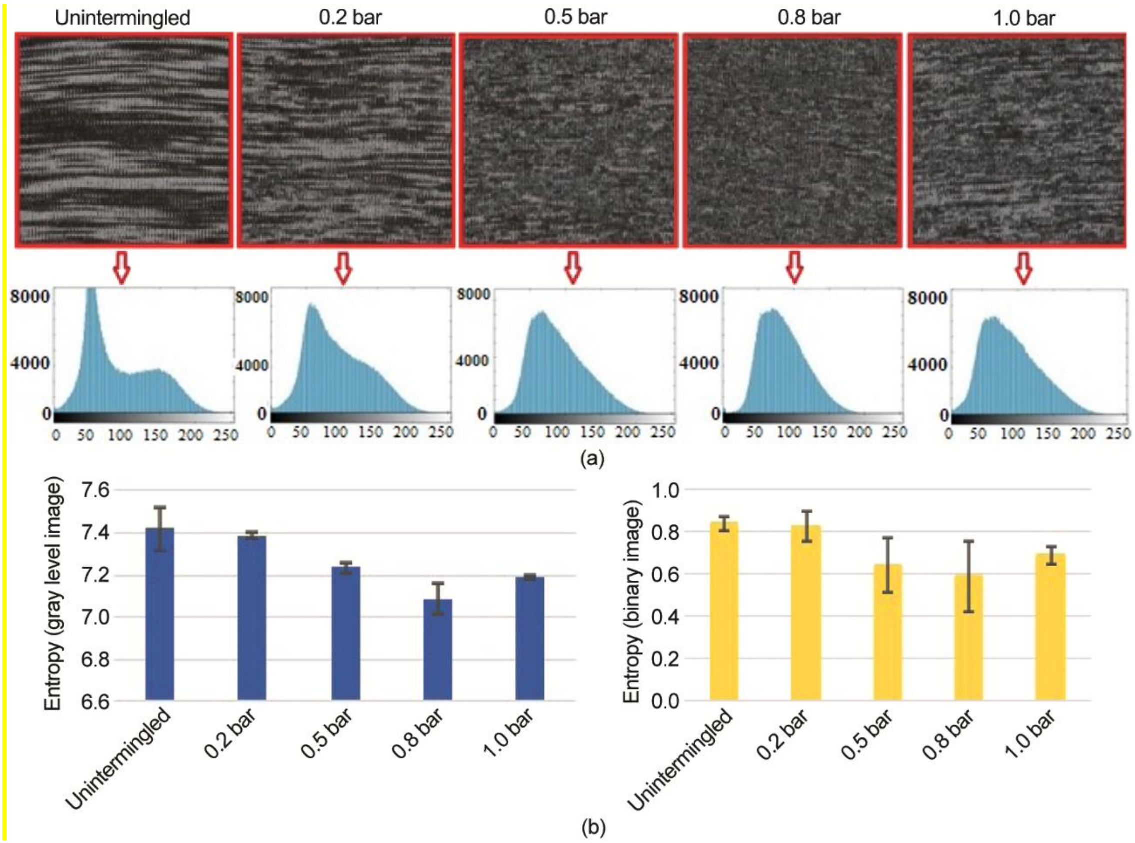

Fig. 4 — (a) Fabric surface images and gray level histograms and (b) entropy (randomness) values of fabric surfaces

Surface images of the fabrics and histograms of images are shown in Fig. 4(a). As it can be seen from the figure, it is observed that intermingling pressure level has an important effect on visual properties of the fabrics, even if all other structural parameters are same for all fabrics. It is possible to say that fibre distribution in the yarn cross-section is highly affected even with a slight change in air pressure since the yarn is made of microfibres. When histograms of surface images are analysed, it is found that the fabrics produced from unintermingled yarns have the highest histogram irregularity, and as a result the highest surface randomness is observed. Entropy values obtained from histograms also confirm this result [Fig. 4(b)]. According to entropy values, it is concluded that intermingling pressure level has statistically significant effect on fabric surface appearance and fabrics produced by yarns with 0.8 bar intermingling pressure level have the most homogenous surface effect for both binary and gray level images. And it is possible to say from histograms, as the histograms approximate the normal distribution, that the visual effects of the fabrics become more homogeneous.

4 Conclusion

The findings show that the intermingling pressure level has statistically significant effect on unit weight, thickness, air permeability, porosity and visual properties of the fabrics. When the results are examined in terms of physical properties, it is found that the fabrics produced from unintermingled yarns have the highest unit weight and thickness values. Moreover, according to pair-wise comparison results, the differences among 0.5, 0.8 and 1.0 bar are not statistically significant in terms of fabric structural parameters. When a general evaluation is made for moisture comfort properties, results indicate that Overall Moisture Management Capability (OMMC) and Accumulative One-way Transport Index (AOTI) values are quite good for fabrics produced from intermingled micro polyester yarn, which means that the transmission of the liquid from the skin to the environment will be quickly. On the other hand, ANOVA results indicate that intermingling pressure level has no effect on OMMC and AOTI values. This situation is also observed for fabric roughness. It is thought that structural parameters, such as raw material, linear density of yarns, interlacing points, knitting structure and setting values, are more important in terms of these properties. For air permeability and porosity properties, the lowest values belong to fabrics produced from unintermingled yarns and the highest values belong to fabrics produced from 0.8 bar intermingling pressure level yarn. Fabric surface images, histogram analysis and entropy results verify that intermingling pressure level has an important role for visual properties of fabrics made of melange yarns, and 0.5 and 0.8 bar pressure levels are found ideal for homogeneous surface effects. Therefore, it is possible to say that intermingling pressure level will play very important role in fabric visual properties and aesthetic design, and different surface effects can be obtained with only changing intermingling pressure levels for the fabrics produced with melange yarns, even if all other parameters are the same. According to the findings of this study, in terms of many fabric properties, 0.8 bar intermingling pressure level may be offered as the optimum levels for production of melange multifilament yarns with 150 denier linear density and 288 filaments.

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