Evaluation of Luster, Hand Feel and Comfort Properties of Modified Polyester Woven Fabrics

Rong Zhou, Xueli Wang, Jianyong Yu, Zhenzhen Wei, Yu Gao

Donghua University, Shanghai, Shanghai CHINA

Correspondence to:
Xueli Wang email: wxl@dhu.edu.cn

ABSTRACT

This paper reports a hollow copolyester fiber modified with polyethylene glycol and sodium-5-sulfo-bis-(hydroxyethyl)-isophthalate, abbreviated as ECDP-H, which has the potential to be a replacement for cotton. The objective evaluation of luster (contrast glossiness) and Kawabata Evaluation System for Fabrics (KES-F) (four Primary Hand Parameters and the Total Hand) of ECDP-H, PET and cotton fabrics are studied in order to investigate the cotton-like appearance of the ECDP-H. The results of moisture regain and dynamic moisture absorption values obtained indicate that the hydrophilicity of the ECDP-H fabric is better than that of PET fabric. The thermo-physiological performance for three fabrics is determined using air and water vapor permeability, wicking, warm-cooling feeling, thermal resistance and vapor resistance. The results show that the ECDP-H fabric has better hand and comfort properties than cotton.

Keywords: copolyester, cotton-like, luster, KES, thermos-physiological performance

INTRODUCTION

Cotton fibers are extensively used in all kinds of textile applications and accepted by consumers for their natural hand, moisture transport and unique luster or 'cotton look' [1]. However, cotton supply lags demand because of limited cotton cultivated land resources. This drives demand for a new material possessing similar appearance and properties as cotton. The global polyester market is facing the challenge of overcapacity; as a result, a cotton-like synthetic fiber probably is an effective solution. Poly (ethylene terephthalate) (PET) is the most widely used synthetic fiber for textile applications due to excellent mechanical properties, good chemical durability, easy-care properties, and reasonable price [2]. However, dazzling luster, rigid hand feel and low moisture limit its application in garment fabric [3, 4].

Many researchers have proposed that profiled synthetic fibers having excellent capillary effects be used for sportswear fabrics, such as 4 channel cross-section CoolMaX® by Dupont, Y-shaped cross-section Triactor® by Toyobo and hollow cross-section Thermolite® by INVISTA, etc. [3, 4]. However, fabrics made from these fibers have low moisture regain and a waxy hand feel compared to cotton fabrics. Chemical modification is a frequently-used tool to improve these properties of polyesters, including surface treatment, blending and copolymerization [5, 6]. Previous studies show that the effects of coating, plasma, UV/O_3 irradiation and corona discharge modification decrease with number of washes [7, 8], and blending modification might lead to difficulties during fiber spinning. Therefore, copolymerization could be possible method to overcome the defects of PET. Studies concerning PET modification by grafting sodium-5-sulfo-bis-(hydroxyethyl)-isophthalate (SIPE) indicate that is results in an improvement of the dyeability and hydrophilicity of PET fibers [9-11]. Several studies have been reported on the preparation of copolyesters improving hydrophilicity by introducing low levels of diols [12, 13], diacids [14-17] and polyethylene glycol (PEG) [18-20]. However, a study of the luster, hand and comfort properties of fabrics made from modified copolyesters with hollow fiber cross-sections has not been done to date.

In this paper, fabric made from hollow cross-section copolyester (ECDP-H) modified with SIPE and PEG was studied along with fabrics of cotton and PET. The luster and hand of the fabrics were evaluated using a fabric glossiness measuring instrument and the Kawabata Evaluation System for Fabrics, respectively. Furthermore, the thermo-physiological comfort properties were determined through moisture regain, air permeability, wicking property, warm-cool feeling, water-vapor transmission (WVT), dry thermal resistance (R_{ct}), the vapor resistance (R_{et}) and vapor permeability index (I_{mt}) measurements.

EXPERIMENTAL

Sample Preparation

The yarns studied (normal cotton, PET and ECDP-H staple fibers) were supplied by Jiangsu Dasheng Group CO., Ltd China. The characteristic parameters of the fibers and yarns are listed in *Table I*. The cross-section and longitudinal morphology of ECDP-H fiber, obtained using an optical microscope (XP-200B), are shown in *Figure 1*.

TABLE I. Characteristic parameters of fibers and yarns.

Samples		Cotton	PET	ECDP-H
Fibers	Average length (mm)	35.6	38.1	38.6
	Average fineness (dtex)	2.02	1.4	1.57
	Strength (cN/dtex)	2.23	5.91	3.7
	Elongation (%)	5.91	30.38	24.07
Yarns	Yarn count (tex)	18.4	18.7	18.3
	Strength (cN/dtex)	14.8	31.1	18.6
	Elongation (%)	5.1	11.9	10.1
	Twist/(10 cm)	81.9	78.8	80.8

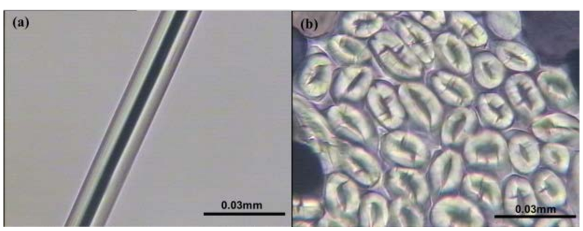

FIGURE 1. The optical microscope images of the ECDP-H (a) longitudinal morphology and (b) cross-section.

The fabric construction was 1/2 twill, which is widely used in many kinds of fabrics. A rapier machine was used to manufacture the fabrics and the pure yarns mentioned earlier were used as both warp and weft. The fabrics were soaped at 60°C for 30 min and washed to remove dust from the spinning and weaving process, and then dried at 50°C in an electric heat oven until they totally dried. Subsequently, the fabrics were pressed flat using an electric iron. The parameters and mechanical properties of the fabrics are presented in *Table II.*

TABLE II. Characteristic parameters of fabrics.

Samples		Cotton	PET	ECDP
Thickness(mm)		0.54	0.48	0.51
Density	Warp (ends/cm)	50.1	50	50.8
	Weft (picks/cm)	35.8	35.6	36.2
Breaking strength (N)	Warp	808.7	1158.4	640.2
	Weft	556.1	635.2	354.2
Breaking elongation (%)	Warp	27.66	32.51	36.81
	Weft	12.47	23.09	24.06

The Objective Evaluation of Fabric Luster

The luster of the fabrics was measured using a Fabric Glossiness Measuring Instrument (YG 814-II). A schematic diagram of fabric glossiness test is shown in *Figure 2*. Typically, the samples were exposed to incident light at a 60^o angle, then specular reflection lighting at 60^o and diffuse reflection lighting at -30^o simultaneously. The contrast glossiness (G_c) was calculated by following equation:

$$G_c = \frac{G_S}{\sqrt{|G_S - G_R|}} \quad (1)$$

where G_s is the intensity of specular reflect light and G_R is the intensity of diffuse reflection light.

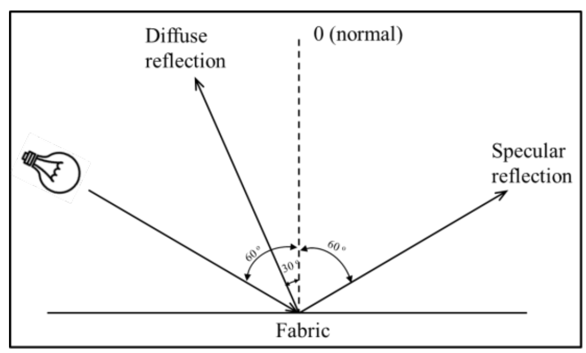

FIGURE 2. Schematic diagram of fabric glossiness test.

Hand Evaluation

The Kawabata Evaluation System for Fabrics (KES-F) was used to characterize the primary hand value (HV) and total hand value (THV) of fabrics. The KES-F system includes a shear/tensile tester, bending tester, compression tester and surface tester.

Moistur Absorption Ability

Moisture Regain

The moisture regains (MR) of fabric samples were calculated according to the Eq. (2).

$$\text{MR (\%)} = \frac{W_2 - W_1}{W_1} \times 100\% \quad (2)$$

Where W_1 is the weight of the dried samples and W_2 is the weight of samples staying in the standard conditions room for 24 h.

Dynamic Moisture Absorption for Fabrics

In order to evaluate the relationship between moisture absorption and time, dynamic moisture equilibrium curves were obtained. The samples were weighed every 5 minutes for 3h at standard conditions after drying at 105°C for 2h in an air-circulating oven.

Thermo-Physiological Performance

Air and Water-Vapor Permeability

The air permeability was measured using a digital fabric air permeability tester (YG461E) at air pressure of 100 Pa applies to a 20 cm^2 area of the samples at 10 different positions.

Water-vapor transmission (WVT) was determined by the desiccant cup method. The desiccant, anhydrous calcium chloride powder, previously dried at 160°C for 3h, was put into the measuring cup, which was covered by the fabric and sealed using a rubber band placed under the fabric. The measuring cup was weighed and then put into the testing environment (38°C, 90% relative humidity and airflow rate of 0.3~0.5 m/s). After 0.5 h, the measuring cup was removed and reweighed. The water-vapor transmission of the fabric was calculated by Eq. (3):

$$\text{WVT} = \frac{24 \times \Delta m}{S \times t} \quad (3)$$

where WVT is the rate of water-vapor transmission ($g/m^2 \cdot d$); t is the testing time (h); Δm is the difference between two weighings of the same measuring cup (g) and S is the water-vapor permeable area (m^2).

Wicking Properties

The fabrics were vertically dipped into water at 50 mm depth and then the absorbed water height was obtained after 30 minutes. This was repeated 5 times and average values are reported.

Warm-Cool Feeling of Fabric

A KES-F7 Thermo Labo II was used to measure the maximum transient thermal flow (q_{max}) of fabric over a very short time. The q_{max} value represents the warmth and coolness that are instantaneously felt as soon as a fabric first touches human skin. The temperatures of the two sides of the fabric, which created a temperature gradient, were 35°C and 25°C. The duration of each q_{max} test of fabric was 0.2 seconds.

Steady State Vapor and Heat Transmission

A Sweating Guarded Hotplate (YG606G) was used to measure the vapor and heat transfer properties of fabrics. Vapor permeability index (I_{mt}), which is a parameter relating thermal resistance (R_{ct}) and vapor resistance (R_{et}), and calculated by Eq. (4).

$$I_{mt} = \frac{S \times R_{ct}}{R_{et}} \quad (4)$$

The factor S=60Pa/K, the I_{mt} is a dimensionless parameter with value between 0 and 1.

All experiments above were carried out under standard conditions (temperature 20±1°C, relative humidity 65±2 %).

RESULTS AND DISCUSSION

The performance of these three fabrics is grouped into four categories for discussion: (i) luster properties; (ii) evaluation of hand; (iii) moisture absorption and (iv) thermo-physiological performance.

Luster Property of Fabrics

In general, the major reflection of synthetic fibers is specular reflection due to the circular cross-section and uniform fineness, giving a dazzling luster for their fabrics, which is not preferred by the consumers. Cotton fiber has a natural curl leading to partial diffuse reflection, and the waist shaped cross-section of fibers leads the reflection light to be inward refraction and outward diffuse reflection, resulting in the soft gloss of cotton fabrics.

TABLE III. The luster value of these three fabrics.

Samples	cotton	PET	ECDP-H
G_s	57	60	56
G_R	71	61	67
G_c	8.6	7.8	8.3

It is found in *Table III* that the contrast gloss values (G_c) of cotton and ECDP-H fabrics are higher than that of PET for fabrics of the same construction, indicating that the G_c is related to the morphology of the fibers. As *Table III* illustrates, the specular reflection gloss value (G_s) of PET is highest while the diffuse reflection gloss value (G_R) is the lowest due to the circular cross-section and uniform fineness. Because of the waist shaped cross-section and irregular curls, the diffuse reflection gloss value of the cotton fabric is higher than those of the PET and ECDP-H fabrics. The hollow cross-section of ECDP-H leads to fibers with a layered structure, resulting in multiple reflections and refraction of the light in the fiber and increasing diffuse reflection. Thus, the luster property of ECDP-H fabric is better than that of the PET fabric.

Hand Evaluation of Fabrics

The primary hand values listed in *Table IV* are calculated by regression of the formula for women's medium-thick fabrics [21].

TABLE IV. Primary and total hand values for fabrics.

		Cotton	PET	ECDP-H
Primary hand parameters	Stiffness	5	5.23	6.34
	Smoothness	4.76	4.44	5.46
	Fullness and softness	5.44	5.38	5.34
	Soft feeling*	2.2	1.74	2.44
THV		3.15	3.07	3.55

*this is not a primary hand. This expression was added as a semi-primary hand because this feeling was important for ladies' dress fabric.

The primary hand is illustrated as follows [22]:

1) The stiffness is a feeling related to bending stiffness, which can be affected by weaving density. As seen in *Table IV*, the stiffness value of both PET and the ECDP-H fabrics are higher than that of cotton, because of the rigid chains and the regular molecule arrangement of the chemical structure of polyester. This is a desirable property for suit type fabrics. Moreover, the ECDP-H has the largest stiffness value, probably due to the hollow structure of the fibers.

2) The smoothness is a mixed feeling resulting from smooth, limber and soft feelings. The results in *Table IV* indicate that the ECDP-H fabric has the best primary hand of smoothness, due to the introduction of the PEG soft segments into the copolyesters.

3) The fullness and softness is a feeling consisting of bulky, rich and well-formed feelings, which are closely related to compression/recovery response and the warm feeling associated with increasing thickness. The fullness and softness values of the three fabrics are similar due to similar fabric constructions.

4) The soft feeling is a mixed feeling consisting of bulky, flexible and smooth feelings. The order of soft feeling values is ECDP-H＞Cotton＞PET, which can be explained by the cross-section of the fibers.

The Total Hand Value (THV) is calculated using the assumption that these fabrics fall into the Women's Winter Suits category. As seen in *Table IV*, the ECDP-H fabric has the best total hand feel among the three fabrics, indicating that the fabric made of ECDP-H fibers is more suitable for Women's Winter Suits than cotton and PET fabrics.

Moisture Regain and Dynamic Moisture Absorption

As seen in *Table V*, the moisture regain of ECDP-H is improved to 1.8%, much higher than the pure PET (0.4%), due to the sulfonated group SIPE and ether bonds in the PEG, which can combine with water molecules by hydrogen bonding [23]. Further, the introduction of the isophthalic acid units in SIPE and the flexible chain of the PEG result in fewer crystalline regions and more amorphous regions in the macromolecules, which allows the water molecules easier entry into the co-polyester macromolecules.

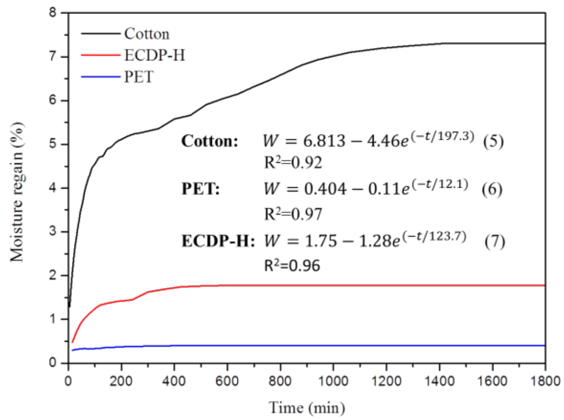

FIGURE 3. Dynamic moisture absorption curves of fabrics.

Figure 3 shows the dynamic moisture absorption of the three fabrics from a dry state to standard atmospheric conditions. The regression Eq. (5), Eq. (6), and Eq. (7) in *Figure 3* for the moisture regain versus time can be deduced according to the Fick' s Law during the moisture absorption process, where *W* is the moisture regain of fabrics, *t* is the time of moisture absorption and the *R* is the confidence level. The general trend of the moisture absorption process is divided into two phases. In the first phase the moisture absorption velocities are quite high and pure cotton fabric has the highest moisture absorption velocity (gradient). Over time, the moisture regain for the fabric levels off .

The Thermo-Physiological Performance of Fabrics

Air and Water Vapor Permeability

Air permeability is one of the comfort parameters that are affected by the structure of fibers and fabrics. As seen in *Table V*, the values of air permeability are almost the same for the three fabrics, which could be due to the same yarn count and weaving processes.

The value of water vapor transmission (WVT) is the permeability to water vapor of a moisture gradient between the two sides of fabric, which could provide some relevant information on the fabric "breathability". *Table V* shows the WVT values of three fabrics. Expectedly, the value of ECDP-H fabric is higher than that of pure PET fabric, but lower than that of cotton fabric, which could be explained by the hollow structure and moisture absorption of fibers.

Wicking Property

Wicking is an important factor in determining the comfort of clothing for active wear. For all fabrics (seen in *Table V*), the warp wicking height is much higher than the weft wicking height, because more fibers are in parallel in the warp direction leading to higher capillary effects. The results of wicking test show that PET fibers have lower moisture absorption compared with that of the cotton fibers. However, ECDP-H, the profiled modified copolyester, has the best water absorption performance among three fabrics. This can be attributed to the hollow cross-section of the ECDP-H fibers, which tends to transfer liquid quickly through the channel cross section by capillary effects [24].

Warm-Cooling Feeling (q_{max})

The q_{max} values of three fabrics are given in *Table V*. Theoretically, the bigger the value of q_{max}, the greater the heat flow between the fabric and the skin and the cooler the fabrics feel. It is found that the q_{max} values of cotton and ECDP-H fabrics (0.156 and 0.150 $J/cm^2 \cdot s$, respectively) are much higher than that of PET fabric (0.128 $J/cm^2 \cdot s$), which is probably because the moisture regain of cotton and ECDP-H fabrics are much higher than PET fabric. In general, for the same fabric construction parameters, if the moisture content of the fabric is higher, the cool feeling is stronger (20).

Thermal Resistance, Vapor Resistance and Water-Vapor Permeability Index

The test results for thermal resistance (R_{ct}), vapor resistance (R_{et}) and I_{mt} are listed in *Table V*. It can be seen that the PET fabric has the lowest R_{ct} value. For textile materials, the still air in the fabric structure has great influence on the thermal conductivity of fabric, and still air has a much lower thermal conductivity value (0.025 W/mK) than any of the fibers. The fabrics of cotton and the ECDP-H fibers with hollow structures have more still air in the structures than the PET fabric, thus both the cotton and ECDP-H fabrics exhibit higher thermal resistance than the PET fabric. In addition, the thermal conductivity value of water is 0.6 W/mK [25], much larger than any of the fibers. Since the moisture regain of cotton (7.4%) is much higher than ECDP-H (1.8%), ECDP-H fabric shows good thermal resistance compared to cotton fabric.

According to previous studies, the values of vapor resistance (R_{et}) are strongly related to the thickness, porosity and moisture regain of the fabric [26]. Since the porosity of the fabric has a positive correlation to the air permeability, and the three fabrics in this study have similar air permeability and thickness, the moisture regain has a major influence on the vapor resistance. Therefore, the order of R_{et} value for three fabrics is as follows: PET fabric > ECDP-H fabric > cotton fabric.

The value of the water-vapor permeability index (I_{mt}) characterizes the physiological effect of clothing through the relationship between thermal resistance and vapor resistance. Theoretically, when I_{mt} equals 0, the thermal resistance and the vapor resistance of garment correspond to an air layer of the same thickness and when I_{mt} equals 1, the garment is completely devoid of water-vapor permeability [27]. On the basis of the study by Verdu [28], a fabric is considered to provide optimum thermal comfort when the value of I_{mt} is around 0.3. As can be seen in *Table V*, the water-vapor permeability of ECDP-H fabric is good (0.32), slightly higher than cotton fabric (0.31) and much higher than PET fabric (0.25), a higher value I_{mt} indicating the fabric allows sweat evaporation and avoids moisture accumulation.

TABLE V. Parameters of thermo-physiological performance for fabrics.

	Cotton	PET	ECDP-H
Moisture regain (%)	7.4	0.4	1.8
Air permeability (mm/s)	161.8	161.12	162.9
WVT ($g/cm^2 \cdot h$)	0.52	0.48	0.51
Wicking height (warp)	11.8	10.8	14.1
Wicking height (weft)	11.3	10	13.5
q_{max}	0.156	0.128	0.15
$R_{ct} \cdot 10^3$ (m^2 K/W)	24.3	22.7	25.1
R_{et}(m^2 Pa/W)	4.66	5.53	4.73
I_{mt}	0.31	0.25	0.32

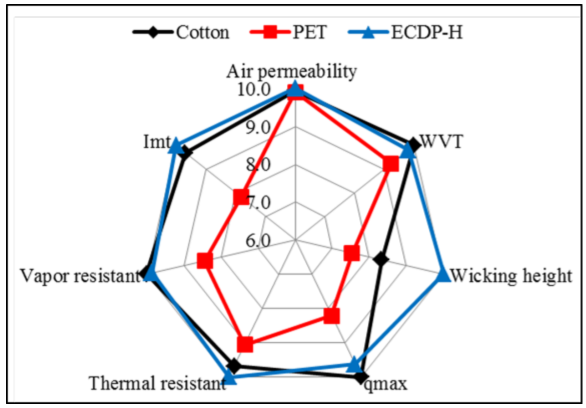

FIGURE 4. Radar plot for comparisons of fabrics comfort properties.

A comparison of the performance among the three fabrics using a radar plot is illustrated in *Figure 4*. The most relevant comfort properties were included in this plot with scales from 0 to 10. The ratings were calculated by dividing the corresponding values by the best obtained value for that specific property. When a lower value indicates better performance with respect to a given property, (e.g. vapor resistance), the rating is expressed as the reciprocal ratio [27]. It is found from *Figure 4* that both ECDP-H and cotton fabrics show an improved performance balance over PET fabric. All the fabrics show very similar performance in the air, vapor and moisture permeability, which is due to similar structure for all fabrics. In addition, without considering the moisture regain, the ECDP-H fabric has the best comprehensive comfort properties.

CONCLUSION

The result of objective evaluation of luster shows that the contrast gloss value of ECDP-H fabric is much better than PET and similar to cotton fabric, indicating that the ECDP-H looks like cotton. The ECDP-H fabric is the most suitable for Women's Winter Suits among three fabrics from the results of Total Hand Feel test due to the soft segments and hollow PEG fiber structure. Moisture regain and dynamic moisture absorption show that the ECDP-H fabric has much better hydrophilicity than PET and its moisture regain is 4.5 times that of PET; both properties have a major influence on fabric comfort properties. Thermo-physiological performance measured through multiple tests shows that ECDP-H fabric is much better than PET and better than cotton in wicking and I_{mt} aspects. ECDP-H fabric is even superior to cotton in hand and thermo-physiological properties indicating excellent potential as a cotton-like alternative for garment applications.

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AUTHORS' ADDRESSES

Xueli Wang
Rong Zhou
Jianyong Yu
Zhenzhen Wei
Yu Gao
Donghua University
Renmin North Road NO.2999
Shanghai, Shanghai 200000
CHINA