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Effect of plasma treatment on polyester knitted fabrics: Part II — Moisture management properties

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This study focuses on the moisture management properties of plasma-treated polyester knitted fabrics (spun, continuous filament, micro denier and hollow fibre). The effect of different loop lengths and the impact of oxygen plasma treatment on the moisture management properties of the fabric has also been studied. The moisture management properties are better for the plasma-treated fabric and also for the fabric having highest loop length. The moisture management properties of the fabric have been improved with the oxygen plasma treatment.

Keywords: Knitted fabrics, Moisture management properties, Oxygen plasma, Plasma-treatment, Polyester

1 Introduction

Various plasma applications are dependent upon the characteristics of the plasma, which consists of the mixture of ions, electrons, neutrals, excited molecules and photons. Plasma can be classified as hot-temperature or low-temperature plasma. Hot-temperature plasma includes solar coronas and nuclear fusion generated by the thermonuclear reaction. Their temperature is about 100 million degree centigrade when this reaction is sustained. However, in low-temperature plasmas (non-equilibrium and non-thermal), the electron temperature is much higher than ion temperature. The high-energy electrons and low-energy molecular species can initiate reactions through electrical discharge without excessive heat, causing substrate degradation.

Low-temperature plasma has been used in a wide variety of engineering applications, such as surface etching and material processing, including textile processes. Low-temperature plasma is particularly suited to textile processing, because most textile materials are heat sensitive polymers. Low-temperature plasma treatments are conducted under low pressure or atmospheric pressure[1-4]. Das *et al*.[5] reported a study on the important role of fibre diameter and its cross-section on the moisture transmission properties through fabrics. Duru and Candan[6] reported that the type of the fibre and stitch length has a substantial influence on the liquid transfer properties of fabric. Haghi[7] analysed that there is a rise in air humidity between the skin and the fabric if liquid water (sweat) does not dissipate quickly. This "heat" sensation that triggers sweating is caused by the increased humidity preventing rapid liquid evaporation. Therefore, the body reacts with improved sweating to disintegrate the excess thermal energy. Thus, a fabric's incapability to dissipate liquid water appears to be the important factor that causes an uncomfortable feeling to the wearer. Hence, for a particular application, it is essential to design high performance fabric, which provides good moisture transmission through clothing. Das *et al*.[8] observed that when there is an increase in the number of hydrophilic groups, the water vapour permeability and absorbency of the fabric increase, but it has an adverse effect on the liquid moisture transmission behaviour of the material. Abidi *et al.*[9] has treated the cotton fabrics in plasma using N_2, O_2 and Ar gases. The result shows an excellent water repellency of the fabrics. Rashidi *et al*.[10] found that surface resistivity of cotton and polyester is reduced after plasma treatment. Maalek and Holme[11] studied the plasma treatments that lead to surface erosion of the cotton fibres, which generates a weight loss. Yasuda *et al.*[12] studied the effect of air plasma treatment on fibre and

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fabrics using non-polymerizable gases. It was found that weight loss increased with an increase in exposure time. There are various studies in the field of polyester fabric, knitting structures, plasma treatment using various gases, comfort properties, wicking, MMT. In this work, oxygen is used for plasma treatment of various fabric samples, and moisture management properties are studied for both the treated and the untreated fabric samples.

2 Materials and Methods

The single jersey knitted fabrics has been manufactured from the various polyester yarns such as continuous filament, spun, micro denier and hollow fibre with 111 dtex and 166 dtex. And all the samples were manufactured with the loop length of 0.25 cm, 0.27 cm and 0.29 cm. All the fabric samples were treated with the plasma as mentioned in Part I[13].

2.1 Moisture Management Properties

The moisture management properties of the fabric samples were tested by the SDL Atlas MMT (AATCC TM 195). The samples were evaluated by placing them between the upper and the lower horizontal sensors, each having seven concentric pins. Predetermined amounts of the test solution were dropped on the center of the upper surface of the fabric sample. The test solution moves in three different directions, spreading radially on the top surface, movement through the fabric sample from the top surface to the bottom surface and spreading radially on the bottom surface. During the test, the changes in the electrical resistance of the samples were measured and recorded. The untreated fabric specimen in the form of 8cm × 8cm size square was washed, cleaned and dried before the experiment. Specimens were conditioned in the standard atmosphere using a controlled environment chamber where a relative humidity of 65±2% and temperature of 25±1°C for 25 h were maintained. The instrument parameters were adjusted as per the direction given in the operation manual. At the time of testing, the sample was kept between the upper and lower sensors of the apparatus. The test was then initiated from the software, and testing and data collection were continued as a fully automatic process. During the testing, the pump was kept on for a period of 20 s and data gathering lasted for 120 s. After the test, the computer generated a graphical view of water content *vs* time for visualisation. The software also generated the calculated results of various indices of water management property of the sample. The results from the software are available both in numerical and graphical formats. The numerical output obtained from the software is called the profile, which gives the numerical values of various moisture management indices of all the specimens tested for a sample put in a tabular form. The software has another option, where multi measurement profile of test results with indices is available as grade instead of absolute values[14-18].

2.2 Data Analysis

To identify the significance of difference between different fabric samples and moisture management properties after plasma treatment, two-way ANOVA was used. The differences were considered to be significant if P-value was equal to or less than 0.05.

3 Results and Discussion

3.1 Effect of Plasma Treatment on Wetting Time

The wetting time values in seconds of the top (WT_t) and bottom surfaces (WT_b) of the fabric samples are given in Table 1. It shows the time taken for the top and bottom surfaces of the fabric to begin

Table 1 — Wetting time values (s) of polyester knitted fabrics of different loop lengths

Sample	0.25cm loop length				0.27 cm loop length				0.29 cm loop length			
	Before plasma WT_t s	After plasma WT_t s	Before plasma WT_b s	After plasma WT_b s	Before plasma WT_t s	After plasma WT_t s	Before plasma WT_b s	After plasma WT_b s	Before plasma WT_t s	After plasma WT_t s	Before plasma WT_b s	After plasma WT_b s
CF (111 dtex)	2.961	1.825	2.452	1.755	2.368	1.532	2.032	1.365	2.028	1.332	1.732	1.175
CF (166 dtex)	3.056	1.965	2.856	1.853	2.82	1.356	2.384	1.546	2.617	1.028	2.046	1.406
Spun (111 dtex)	1.567	0.153	1.234	0.149	1.121	0.082	0.834	0.062	0.814	0.068	0.734	0.057
Spun (166 dtex)	1.634	0.187	1.548	0.187	1.234	0.064	1.023	0.073	0.956	0.044	0.845	0.063
MD (111 dtex)	2.653	1.716	2.951	1.623	2.103	1.156	2.356	1.162	1.834	0.863	2.011	0.712
MD (166 dtex)	2.483	1.357	2.376	1.217	1.976	0.734	1.894	0.874	1.845	0.568	1.765	0.674
HF (111 dtex)	2.253	1.616	2.653	1.533	1.953	1.237	2.233	1.173	1.845	0.762	1.838	0.892
HF (166 dtex)	2.243	1.312	2.156	1.117	1.854	0.952	1.956	0.835	1.762	0.826	1.82	0.658

Subscript (t) stands for top surface and (b) stands for bottom surface.

to wet after the commencement of the test. It can be seen that the wetting time for both face and reverse sides of the fabrics changes with different yarn and its linear density and the plasma treatment. The results indicate that the wetting time of the top surface is higher than that of the bottom surface for all the fabric samples. The wetting time for the 166 dtex continuous filament polyester fabric is good and it has a good absorbency.

It is also observed that the plasma-treated fabric samples show a significant improvement in the absorbency when compared with the untreated fabric samples. Also, the effect of O_2 plasma is found prominent, showing the considerable reduction in as compared to untreated fabric. It directly shows that treated fabric samples absorb water at a faster rate compared to the untreated fabric sample. Wrobel *et al.*[19] stated that the wetting time of plasma-treated fabric considerably drops in comparison to untreated fabric and the best results are obtained by treatment in nitrogen, oxygen and air plasma.

3.2 Effect of Plasma Treatment on Absorption Rate

The absorption rates of the top and bottom surface of fabric, before and after plasma treated, are given in Table 2. It is clearly seen that the absorption rates are dependent on the linear density and the plasma treatment. As the linear density increases, the absorption rate also increases and the plasma-treated fabrics show reduced absorption timing for all the samples that has improved the rate of absorption in lesser time. Ömeroğulları and Kut[20] observed an increase in the hydroxyl group and the surface roughness, which thereby shows an improvement in the hydrophilic properties of the oxygen plasma-treated polyester fabric. Due to the increase in the hydrophilic property, the plasma-treated fabric absorption rate is faster. Karaca *et al.*[21] have explained in their study that there is a significant increase in the rate of absorption in a very less time comparatively of the plasma-treated fabric, whereby the absorption performance is attributed to the etching effect. Sójka-Ledakowicz and Kudzin[22] have observed that the atmospheric water vapour gets absorbed by the plasma-treated fabric due to the more hydrophilic nature of the surface fibres, which is due to the broad peaks formed due to hydroxyl groups (–OH and >C-O or >C-O) to the plasma-treated surface of the fabric.

3.3 Effect of Plasma Treatment on Water Spreading Speed

The water spreading speed test results for the untreated and treated fabrics are given in Table 3. A comparison of the spreading speed values clearly reveals that the spreading speed increases as the linear density increases. It is noted earlier that in the plasma-treated fabrics the wetting time decreases, consequently spreading speed for the wetting of the treated fabric is higher as compared to that of the untreated fabric. Kaynak and Babaarslan[23] states that the coarser filaments yarns have higher value for plane transfer capability of the liquid moisture due to its large macro pores. Therefore, fabrics with coarser filaments, transfer liquid moisture more rapidly through the surface of the fabric. Wang and Wang[24]

Table 2 — Absorption rates (%/s) of before and oxygen plasma-treated polyester knitted fabrics of different loop lengths

Sample	0.25cm loop length				0.27cm loop length				0.29cm loop length			
	Before plasma AR_t %/s	After plasma AR_t %/s	Before plasma AR_b %/s	After plasma AR_b %/s	Before plasma AR_t %/s	After plasma AR_t %/s	Before plasma AR_b %/s	After plasma AR_b %/s	Before plasma AR_t %/s	After plasma AR_t %/s	Before plasma AR_b %/s	After plasma AR_b %/s
CF (111 dtex)	37.431	30.114	39.581	32.585	39.47	31.9	40.23	34.6	40.94	32.42	41.5	32.585
CF (166 dtex)	39.271	32.967	41.254	35.144	41.32	34.76	43.65	37.54	41.36	38.76	42.5	35.144
Spun (111 dtex)	23.912	18.431	32.777	28.532	25.342	23.621	33.967	30.052	24.75	23.82	31.56	29.35
Spun (166 dtex)	28.524	15.264	33.567	25.881	30.139	14.625	35.743	27.921	29.467	15.11	36.367	25.881
MD (111 dtex)	34.118	26.919	37.476	29.712	33.94	28.149	39.033	31.39	34.3	29.356	40.032	32.443
MD (166 dtex)	33.595	25.193	36.431	28.431	35.123	26.136	37.502	29.844	36.57	27.32	38.46	28.252
HF (111 dtex)	34.743	28.452	35.853	29.634	35.587	29.754	36.24	30.23	36.254	30.372	37.548	31.53
HF (166 dtex)	35.221	28.94	37.475	30.427	36.347	29	37.982	31.744	37.112	30.25	38.32	32.36

Table 3 — Water spreading speed (mm/s) of before and oxygen plasma-treated polyester knitted fabrics of different loop lengths

Sample	0.25 cm loop length				0.27 cm loop length				0.29 cm loop length			
	Before plasma SS_t mm/s	After plasma SS_t mm/s	Before plasma SS_b mm/s	After plasma SS_b mm/s	Before plasma SS_t mm/s	After plasma SS_t mm/s	Before plasma SS_b mm/s	After plasma SS_b mm/s	Before plasma SS_t mm/s	After plasma SS_t mm/s	Before plasma SS_b mm/s	After plasma SS_b mm/s
CF (111 dtex)	10.012	10.564	10.013	10.545	9.934	9.98	9.634	9.58	9.236	9.645	8.836	8.624
CF (166 dtex)	9.834	10.285	9.615	10.277	9.512	9.85	9.215	9.627	8.432	8.941	8.114	8.523
Spun (111 dtex)	16.523	16.146	16.102	15.238	16	15.428	15.32	14.845	15.67	15.244	15.075	14.525
Spun (166 dtex)	17.158	17.942	17.216	17.983	16.382	17.213	16.165	16.735	16.151	16.592	17.216	16.01
MD (111 dtex)	10.837	11.069	10.739	11.099	10.104	11.355	9.326	10.734	9.885	10.037	9.305	9.772
MD (166 dtex)	12.717	13.238	12.956	13.294	11.617	11.822	11.994	11.533	11.163	11.528	11.731	11.013
HF (111 dtex)	11.567	12.193	11.34	12.248	10.85	11.858	11.536	12.265	10.125	11.522	10.743	12.367
HF (166 dtex)	12.533	13.075	12.023	12.746	11.554	12.539	11.112	11.864	11.281	12.121	10.843	11.35

Table 4 — Maximum wetted radius (mm) of before and oxygen plasma-treated polyester knitted fabrics of different loop lengths

Sample	0.25 cm loop length				0.27 cm loop length				0.29 cm loop length			
	Before plasma MWR_t mm	After plasma MWR_t mm	Before plasma MWR_b mm	After plasma MWR_b mm	Before plasma MWR_t mm	After plasma MWR_t mm	Before plasma MWR_b mm	After plasma MWR_b mm	Before plasma MWR_t mm	After plasma MWR_t mm	Before plasma MWR_b mm	After plasma MWR_b mm
CF (111 dtex)	32	25	32	25	33	27	33	27	33	27	33	27
CF (166 dtex)	33	26	33	26	34	27	34	27	34	26	33	27
Spun (111 dtex)	20	10	20	10	22	11	22	11	22	10	22	10
Spun (166 dtex)	21	10	21	10	21	10	21	10	22	11	22	11
MD (111 dtex)	30.5	23.3	30.5	23.3	30.5	23.3	30.5	23.3	30.5	23.3	30.5	23.3
MD (166 dtex)	29	20	29	20	29	20	29	20	29	20	29	20
HF (111 dtex)	31	26	31	26	32	27	32	27	32	26	32	26
HF (166 dtex)	32	27	32	27	32	27	32	27	32	27	32	27

has clearly stated that the polyester fabric on treatment with the oxygen plasma creates micro pits on the surface, thereby improves the water absorption time due to the improved hydrophilic properties.

3.4 Effect of Plasma Treatment on Maximum Wetted Radius

In this study, the MWR of the fabrics wetted with the same amount of liquid for both the treated and untreated fabrics have been investigated. The results for all the fabrics are given in Table 4. It may be seen that the MWR is lower for the plasma-treated fabrics. Leroux *et al.*[25] have stated that the plasma-treated polyester fabric produces carboxylic group at the fabric surface and generates oxidation, which thereby increases the wettability and surface energy of the fabric. Because of the wettability and hydrophilic character created by the plasma-treated polyester fabric, some of the liquid gets absorbed and penetrates into the fibre structure, which would result in lower moisture spreading along the fabric. Karaca *et al.*[21] states that the plasma-treated fabric shows low maximum wetted radii due to the increased surface area caused by the etching effect. Hence, a lower value of MWR for the plasma-treated fabric means a less clammy touch, a less chilly sensation and thus, overall better comfort close to the skin.

Table 5 — AOTI (R%) and OMMC of before and oxygen treated polyester knitted fabrics of different loop lengths

Sample	0.25 cm loop length				0.27 cm loop length				0.29 cm loop length			
	Before plasma		After plasma		Before plasma		After plasma		Before plasma		After plasma	
	R (%)	OMMC	R (%)	OMMC	R (%)	OMMC	R (%)	OMMC	R (%)	OMMC	R (%)	OMMC
CF (111 dtex)	323.56	0.683	211.77	0.577	315.62	0.652	203.57	0.526	295.17	0.604	185.52	0.525
CF (166 dtex)	243.19	0.624	195.31	0.571	225.06	0.587	178.46	0.558	205.67	0.542	159.04	0.502
Spun (111 dtex)	588.53	0.745	527.45	0.678	556.53	0.713	504.52	0.632	537.56	0.686	484.64	0.614
Spun (166 dtex)	529.02	0.841	496.67	0.794	485.23	0.802	478.48	0.736	453.65	0.724	431.32	0.673
MD (111 dtex)	320.76	0.675	250.52	0.603	302.67	0.632	226.33	0.539	287.53	0.582	195.52	0.511
MD (166 dtex)	398.23	0.742	323.33	0.663	344.36	0.707	318.63	0.621	314.27	0.672	283.74	0.585
HF (111 dtex)	437.56	0.735	354.21	0.659	383.84	0.686	321.54	0.612	349.43	0.624	271.55	0.582
HF (166 dtex)	488.26	0.689	402.35	0.624	462.84	0.62	374.84	0.584	432.72	0.588	337.63	0.542

Table 6 — Statistical comparison

Source of Variation	Sum of square value (SS)	Degree of freedom (df)	Mean square value (MS)	F-Value	P-Value	F crit
Fabric samples	0.0637	4	0.0151*	55.479	0.0015	6.388
OMMC	0.0147	1	0.0127*	46.574	0.002	7.709
Error	0.0011	4	0.0003			

*Significant for $\alpha < 0.05$.

Since the treated fabrics have the lowest MWR values for the top and bottom surface of the fabrics, it reflects good moisture transport property and a dry feeling as a result.

3.5 Effect of Plasma Treatment on Fabric's AOTI and OMMC

Overall moisture management capacity (OMMC) is dependent upon the absorption rate, one-way liquid transport index and liquid spreading speed. Table 5 shows the values of Accumulative one-way transport index (AOTI) and OMMC. These values are compared with the grading scale (0–0.2 very poor, 0.2–0.4 poor, 0.4–0.6 good, 0.6–0.8 very good, >0.8 excellent)[26]. From the results, it can be stated that continuous filament polyester fabrics of both untreated and treated fabric shows low OMMC value. The plasma-treated spun polyester fabrics (166 dtex) are in the 'very good' category in terms of moisture management capacity; however, all the other fabrics fall under the 'good' category. Regarding the AOTI, all the fabrics are rated as 'very good', except the untreated and treated spun polyester fabric which is rated as 'excellent'[27].

3.6 Statistical Data Analysis

To evaluate the statistical data of result, two-way analysis of variance (ANOVA) has been used to find out the significance of the plasma treatment on the overall moisture management capacity of different types of polyester fabrics. To find out whether the results are significant or not, p values are taken into account. The results of the two-way ANOVA are given in the Table 6. The values given in the table reveal that the continuous filament polyester, spun polyester and micro denier polyester are significant factors for the OMMC with $p<0.05$ respectively.

4 Conclusion

Plasma treatment plays an important role in moisture-related comfort properties of clothing. This study focuses mainly on the effect of different linear density of different polyester fabrics on the moisture management properties of both the plasma-treated and untreated fabrics. The results show that as the linear density increases, the maximum absorption rate increases, whereas the wetting time of the plasma-treated spun polyester is very low. MWR and overall moisture management of the plasma treated fabrics decrease. Linear density and plasma treatment influence the moisture management properties of the fabric significantly. It is concluded that as the linear density increases, the wetting time, maximum absorption rate and MWR increase. This means that with increase in linear density, more time is required to wet a knitted fabric. The OMMC can serve as an indicator of the moisture behavior of the fabrics. Most of the fabrics, in general, are in the 'very good' category and only few are in the 'good' category in terms of moisture management capacity.

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