Indian Journal of Fibre & Textile Research
Vol. 47, March 2022, pp. 45-58

Influence of plasma treatment on moisture management of bamboo charcoal composite fabrics for hospital application

P Kandhavadivu[a] & M Parthiban

Department of Fashion Technology, PSG College of Technology, Coimbatore 641 004, India

To enhance the moisture transmission properties of hospital bed linen, a tri-layer weft knitted fabric has been developed from the fibres, like lyocell, bamboo charcoal and micro polyester, and tested for comfort properties. The tri-layer fabric exhibits good water vapour permeability, water absorbing tendency, wicking tendency and faster drying rate. To enhance these functional properties, the fabric is subjected to plasma treatment. Optimization of plasma treatment parameters is attempted by using Box-Benkhen experimental design, considering the process parameters, such as time, distance between electrodes and current. The plasma-treated and untreated fabrics are tested for moisture management properties, such as water absorbency, water vapor permeability, wickability – transverse and vertical, drying time and SEM analysis. From the test results, it is observed that the plasma-treated fabric has improved moisture management and drying properties

Keywords: Bamboo charcoal fibre, Comfort properties, Drying rate, Hospital bed-linen, Lyocell, Micro-polyester, Moisture management, Plasma treatment, Tri-layer fabric

1 Introduction

Among the vast category of medical textile products, hospital textiles, like bed linens, uniforms and mattresses, are expected to fulfill hygienic and comfort properties, such as air-flow, moisture management, thermal conductivity, wettability, wickability and anti-microbial activity. The commercially available hospital bed sheets are made of fibres, like cotton, polyester and their blends. The moisture absorbency and heat transportation properties of these plain woven fabrics are not sufficient to transmit the body fluids and body heat which creates a damp atmosphere conducive for the growth of micro-organisms, like bacteria, fungi and virus. Thus, the high-frictional and less-absorbent plain woven cotton bed sheets are the main cause for the frictional festers and pressure ulcer in patients[1].

Multi- layered fabrics consist of different layers of the fabrics which has the ability to complement and maximize the essential comfort properties of the fabric for specific end use. Various research works have been carried out to analyze the functional properties of layered fabrics. Behera *et al*.[2] produced bi-layer interlock knitted structures using 100% polypropylene and 100% cotton spun yarn and studied the transmission behaviors of air, water and heat in order to assess their suitability for sportswear.

Basal and Ilgaz[3] developed a spacer fabric for pressure ulcer prevention using different combinations of engineered polyester, polypropylene, cotton and viscose fibres by face-to-face velour weaving technique and recommended channeled polyester, cotton and polypropylene as the most promising fibre types for pressure ulcer prevention. Sharabaty *et al*.[4] studied the wettability characteristics of polyester, cotton and multilayered polyester/cotton fabrics to manage human perspiration and found that wicking coefficient of multilayered fabrics is better than cotton fabrics. Ye *et al*.[5] developed warp knitted spacer fabric from PES multifilament and monofilament yarns for cushion applications; analyzed the pressure distribution, air permeability, and heat resistance of the fabrics; and concluded that these spacer fabrics could be used to substitute PU foam, especially in the case where the comfort and recycling are highly required.

Field sensor is a very popular high performance fabric from Toray, which employs a multilayer structure that not only absorbs perspiration quickly but also transports it up to the outer layer of the fabric very rapidly using principle of capillary action. It is composed of coarser denier yarn on the inside surface (in direct contact with the skin), and the fine denier hydrophobic polyester yarn in a mesh construction on the outer surface to accelerate quick evaporation of sweat[6]. Another multi layered fabric developed using high-tech polyester yarns with specially designed ‘W’ shape cross-section speeds up fabric’s ability to

[a]Corresponding author.
E-mail: vadivu67@yahoo.co.in

transport water away from the skin. Its increased surface area increases the evaporation rate and these fabrics exhibit quick drying properties[7].

For a long time, the textile industry has been searching for a rapid way to modify textile polymer surfaces to improve their wettability and adhesion without altering the mechanical properties of the textile structure. Several studies have showed that plasma treatment results in surface modification by way of surface etching, surface activation, cross-linking and chain scission[8]. It offers numerous advantages over the conventional chemical processes. Plasma surface modification does not require the use of water and chemicals, resulting in a more economical and ecological process. The enormous advantage of plasma processes concerns the drastic reduction in effluent treatment, so it can be considered as an environmentally benign technology[9].

Atmospheric plasma treatments are used to modify polymer surfaces using plasma gases composed of a mixture of charged particles (electrons and ions), excited atoms (free radicals and meta-stable molecules) and photons[10-11]. Many process variables in the plasma treatment, such as type of the gas used, energy applied, flow rate, pressure applied and time of treatment, influence the surface characteristics of the fabric[12-14]. Masaeli *et al.*[13] varied the treatment time and power in low pressure plasma process to improve the wettability and observed the functional changes with the use of certain gas combinations. McCord *et al.*[12] studied the effect of atmospheric pressure plasma on polypropylene and nylon fabrics at different gas flow rates of combination of He and O_2 gases and analyzed the results using scanning electron microscope (SEM) imaging. The main advantage of plasma treatment is that the process parameters are chosen in such a way that they do not alter the bulk properties of the treated fabric[12,13,15,16].

Gotoh and Yasokowa[17] treated the polyester fabrics by atmospheric pressure plasma (APP) to enhance hydrophilic behavior of the fibre surfaces. Zdenka Pers *et al.*[18] have done a research work to study the surface properties and sorption characteristics of differently treated regenerated cellulose fabrics. In the case of viscose fibre treatments, Vrabic *et al.*[19] showed that, after argon plasma treatment, the wettability and water retention of viscose fibres were improved markedly. This result was attributed to the formation of polar groups on the fibre surfaces[20,21]. In the same way, Zemljic *et al.*[22] showed that oxygen plasma treatment of viscose fabric induced a decrease in the water contact angle (y) from 66° to 15° and increased the ability of the fabric to absorb chitosan, resulting in an improved antimicrobial activity.

This research work deals with design and development of multi-layered knitted fabric for hospital textile applications using fibres like lyocell, bamboo charcoal and micro polyester and analyse its comfort characteristics. To further enhance the functional properties, the tri-layer composite fabric was subjected to plasma treatment. Lyocell fibre used in the tri-layer composite fabric is breathable, absorbent, comfortable to wear and guarantees optimum conditions for the skin. Polyester microfibre provides better thermo regulation, better moisture management, vapour transmission, softer handle, higher fabric density, better cover and lower flexing resistance[7].

Cho and Cho[23] have recorded that, since the bamboo charcoal fibre contains activated carbon, which is efficient in adsorbing odorous volatile compounds produced by micro-organism, thereby reducing the odor, it is used in hospital textiles for adsorption of wound odor. Thenmozhi *et al.*[24] analyzed cotton, bamboo / cotton and bamboo charcoal bed linens for their suitability as hospital textiles by applying anti-microbial and blood repellant finish and it was found that anti-microbial activity, blood repellency and odor resistance are higher for bamboo charcoal fabrics than those for 100% bamboo /cotton union fabrics or 100% cotton fabrics.

2 Materials and Methods

A tri-layer composite fabric with the composition of bamboo charcoal- micro polyester- lyocell was developed. The fabric parameters are: count–bamboo charcoal 30^sNe, micro- polyester 28^s Ne, lyocell 29^sNe; GSM– 300; CPI–40; and WPI–26. To further enhance the moisture transmission properties of hospital bed linen, the fabric sample was subjected to plasma treatment using Hydro Pneo vac technologies plasma chamber with compressed air as a reactive source. Plasma processing parameters used were distance between the electrode, time of exposure and current. Box-Behnken experimental plan was adopted for plasma treatment with 3 factors at 3 levels with 15 runs. The plasma treated and untreated fabrics were left under controlled climate conditions (20 ± 2 °C, 65 ± 2 % R.H.) for 24 ± 2 h and tested for moisture management properties, such as water absorbency, water vapor permeability, wickability – transverse and vertical, drying time and SEM analysis.

2.1 Production of Tri-layer Knitted Fabric

Tri-layer composite knitted fabric was produced in three fibre combinations, such as bamboo charcoal / micropolyester / lyocell using a double jersey knitting machine. Weft knitting machine with two sets of needles has the ability to create two individual layers of fabric that are held together by tucks. Such a fabric is referred as a double-faced fabric, also called as tri-layer fabric. Sequence of operation in knitting tri-layer fabric is given in the Fig. 1. The tri-layer fabric was knitted on a weft knitting machine with 72 feeders, 18 gauze, 32” diameter double jersey knitting machine.

The tri-layer composite weft knitted fabric produced is generally soft, and possesses certain exceptionally good functional characteristics, such as moisture absorbency, where the moisture from the body is absorbed by the base layer, passed through the connecting layer and gets evaporated from the top layer. In bamboo charcoal / micro polyester / lyocell knitted fabric, the base layer contains bamboo charcoal yarn, so that the wetness is transferred away from the body of the patient. The top layer is made of lyocell to ensure rapid absorption of water from the inner layer and faster drying. The connecting layer is made of micro polyester which inter-loops with the face and back alternatively, assisting in moisture transfer from the inner layer to the outer layer. Since micro polyester possesses high surface area, it acts as an efficient medium to transfer moisture from the inner layer to the outer layer and also provides structural stability to the composite fabric.

Atmospheric pressure plasma treatment (APP) was performed on the tri-layer fabric, using plasma pre-treatment equipment Hydro pneo vac technologies plasma chamber with compressed air as a reactive gas

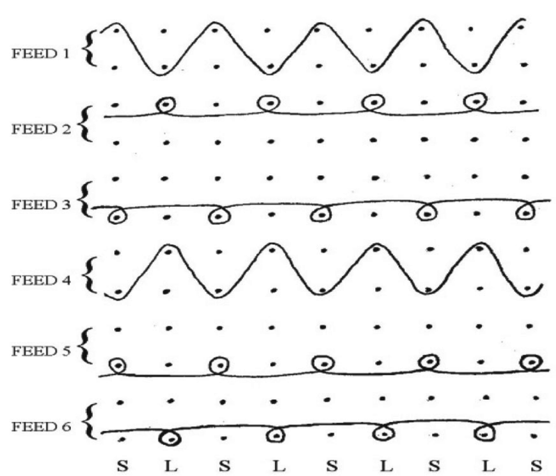

Fig. 1 — Knitting sequence of tri-layer fabric

source. APP was generated by means of high-voltage discharge inside the nozzle jet coupled with the stepped high-frequency pulse current power supply (plasma generator) through the high-voltage transformer.

Plasma discharge was generated at atmospheric pressure by two electrodes and a counter-electrode, all of which were covered by a dielectric ceramic material. The dielectric limits the amount of charge transported from one electrode surface to another via a single micro-discharge. Distribution of these micro-discharges (micro-streamers, filaments) over the entire electrode area results in a homogenous and stable plasma. Material processing was done by passing the substrate through the plasma gas present between the electrodes/counter-electrode gap. The machine parameters used were an electrical voltage of 15 kV, a frequency of 30 kHz, an electrode length of 0.5 m, an electrical power varying from 300 W to 1000 W, a treatment speed varying from 2 to10 m/min and air as gas discharge.

2.2 Box-Behnken Experimental Plan

A Box-Behnken statistical design with 3 factors, 3 levels, and 15 runs was selected for the optimization study. The experimental design consists of a set of points lying at the midpoint of each edge and the replicated center point of a multidimensional cube. In this study, the tri-layer composite fabric was subjected to different electrical powers, distance between electrodes and treatment time. The treatment time used were 60 s, 90 s and 120 s; electrical powers 1.2 mA, 1.4 mA,1.6 mA; and distance between electrodes 4 cm, 4,5 cm and 5 cm. The treatment was carried out twice, both sides of the tri-layer composite fabric were exposed separately to the plasma jet, amounting the total plasma pretreatment time (two sides of the fabric) to 120 s, 180 s and 240 s. The variables adopted to carry out the plasma process for tri-layer fabric using Box-Behnken statistical design are shown in Tables 1 and 2. The conditions were optimized by using contour plots (Design Expert software).

2.3 Statistical Analysis

The traditional approach for developing a formulation is to change one variable at a time. By this method, it is difficult to develop an optimized formulation, as the method reveals nothing about the interaction among the variables. Hence, a Box-Behnken statistical design with 3 factors, 3 levels and 15 runs was selected for the optimization study (Table 2). The independent and dependent variable are listed in Table 1. The polynomial equation generated by this experimental design (using Design Expert software) is as follows:

$$Y = b_0 + b_1\,A + b_2\,B + b_3\,C + b^{12}\,A\,B + b_{13}\,A\,C + b_{23}\,B\,C + b_{11}\,A^2 + b_{22}\,B^2 + b_{33}\,C^2 \qquad \ldots (1)$$

where Y_i is the dependent variable; b_0, the intercept; b_1-b_{33}, the regression coefficient; and A, B, and C, the independent variables that are selected from the preliminary experiments.

Table 1 — Optimizing parameters and levels

Parameters	Levels -1	Levels 0	Levels +1
Current, mA (A)	1.2	1.4	1.6
Distance between electrodes, cm (B)	4	4.5	5
Time, s (C)	60	90	120

Table 2 — Box-Behnken experimental design for optimization

Experiment	Current (A)	Distance between electrodes (B)	Time (C)
1	-1	1	0
2	-1	0	-1
3	0	1	-1
4	0	0	0
5	0	-1	1
6	-1	-1	0
7	1	-1	0
8	1	1	0
9	0	1	1
10	0	-1	-1
11	1	0	1
12	0	0	0
13	1	0	-1
14	-1	0	1
15	0	0	0

3 Results and Discussion

3.1 Responses for Experimental Design

The plasma treated tri-layer composite fabric samples have been tested for moisture management properties, such as absorption, wicking on both lyocell side and bamboo charcoal side of the composite fabric and drying rate as a single fabric. The results are given in Table 3.

3.2 Influence of Plasma Treatment on Absorbency

The ability of the fabric to absorb water is measured by spreading action as per AATCC 79:2000. A sample of size 20 cm × 20 cm was taken and a drop of water was allowed to fall on the flat fabric surface. Area was kept constant for finding out water spreading in seconds. The height of water drop was controlled by syringe, which contains one milliliter of water. The time taken to completely absorb one drop of water was measured for fabric samples.

Contour plot shown in Fig. 2(a) represents the absorbency rate (Bamboo charcoal side) of fabric specimen *vs.* distance between electrode, time and current. While considering the absorption rate on bamboo charcoal side of the fabric, the increase in exposure time, increases the absorption time. When the distance between the electrodes is around 4.4 cm, the time taken to absorb water seems to be high. At higher current, the absorption time decreases.

Table 3 — Moisture management properties of plasma treated tri-layer composite fabric

Current mA	Distance between electrode, cm	Time, s	Drying rate - RWR%	Vertical wicking, cm				Absorption rate, s		Transverse wicking, s	
				Lyocell side		Bamboo side		Lyocell side	Bamboo side	Lyocell side	Bamboo side
				Course wise	Wales wise	Course wise	Wales wise				
1.2	5	90	34.1	5.1	6.9	6.2	7	0.9	13.35	194.93	15
1.2	4.5	60	32	6.7	6.9	7.6	6.5	1.15	13.98	7.28	2.07
1.4	5	60	29.1	5.8	9	6.1	8.9	1.58	5	1.02	0.82
1.4	4.5	90	26.6	6.4	5.4	6.1	5.3	1.11	24.7	156.64	20.49
1.4	4	120	25.4	4.4	8.3	4.4	7.1	1.2	7.51	115.98	12.13
1.2	4	90	20	4.8	5.5	4.7	4.5	0.81	23.34	145.9	9.21
1.6	4	90	31.2	4.6	4.9	5.4	4.6	0.5	2.13	133.69	20.97
1.6	5	90	26.1	5.3	7.5	5.3	7	0.93	24.31	203.81	32.31
1.4	5	120	27	9.3	8.9	9.1	9.1	2.1	10.98	251.52	19.82
1.4	4	60	27.9	5.9	4.5	7.3	5	0.9	25.35	43.51	15.07
1.6	4.5	120	28.5	8.1	4.9	8.4	5.1	2.28	11.06	46.4	13.07
1.4	4.5	90	26.6	6.4	5.4	6.1	5.3	1.11	24.7	156.64	20.49
1.6	4.5	60	29.7	9.8	5.5	9.8	5.8	0.79	11.68	13.61	7.07
1.2	4.5	120	34	8.5	5.1	8.5	6	1.27	84	44.31	17.41
1.4	4.5	90	34	8.5	5.1	8.5	6	1.27	84	44.31	17.41

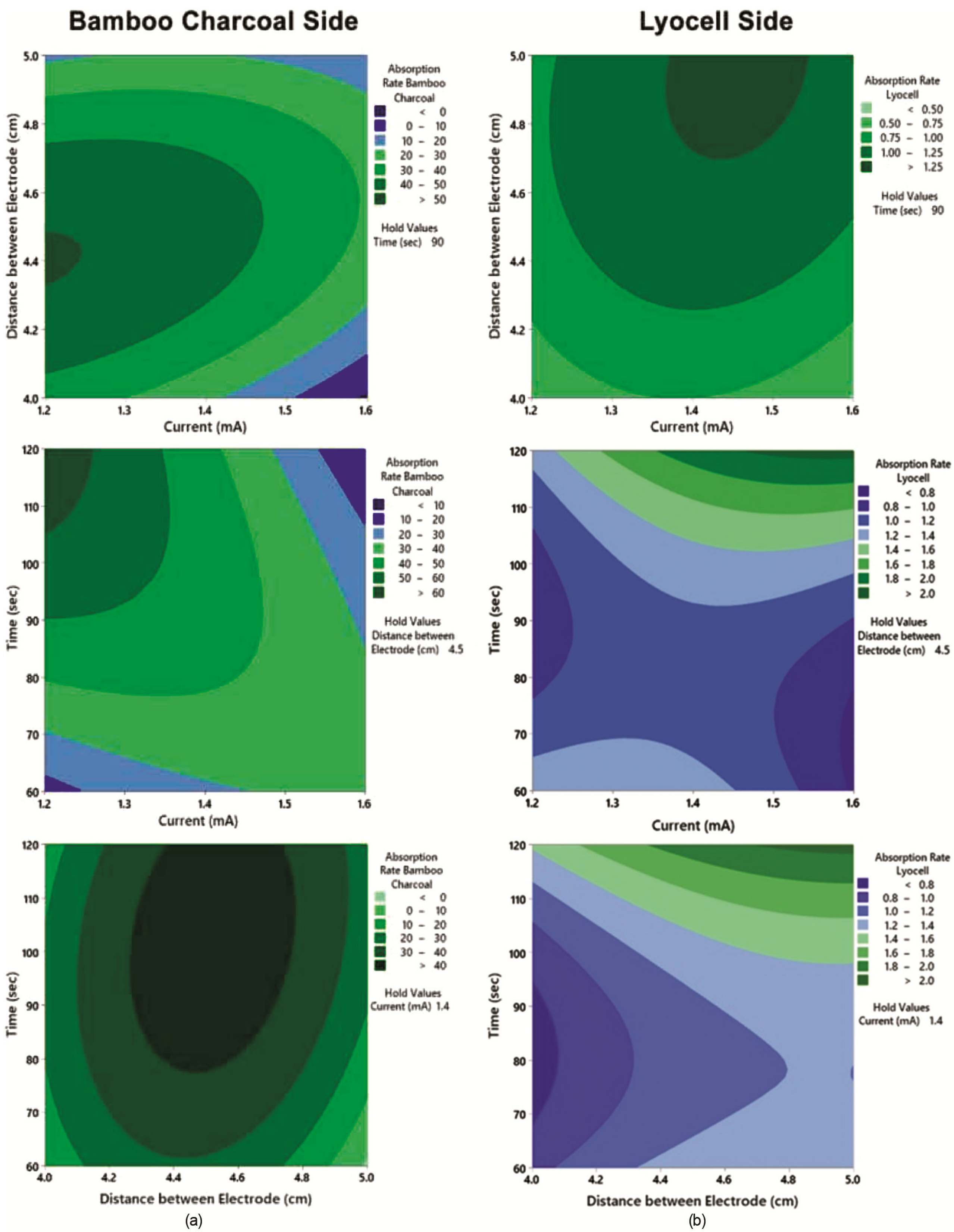

Fig. 2 — Influence of process parameters on absorbency rate (a) bamboo charcoal side and (b) lyocell side

Contour plot shown in Fig. 2(b) represents the absorbency rate (lyocell side) of fabric specimen *vs.* distance between electrode, time and current. The absorption rate of the fabric on lyocell side is greatly influenced by the process parameters. The increase in distance between the electrodes increases the absorption time. Time between 70 s and 90 s results in good absorption at lower distance between the electrodes. Increase in current increases absorption time at lower time, whereas at higher time the effect of current is not significant.

There is a strong polar attraction between fibre molecules and water due to the highly hydrophilic nature of lyocell. Its higher water retention and liquid holding capacity may be due to the strong hydrophilic attraction between water and lyocell fibres and water retention in the inter fibrillar spaces of the fibres, whereas being hydrophobic in nature bamboo charcoal and micro polyester do not form bonds with water molecules, but due to its positive contact angle (75^{o}), liquid surface is dragged very smoothly, which offers high transfer in case of micro polyester. So, when a small proportion of micro polyester is added in the system, it acts as a channel to the water and forms capillary and enhances the transfer phenomena. Hence lyocell based tri-layer fabrics exhibit very good water absorbency, resulting in immediate transfer of moisture to the outer layers. This property is essential to keep the patient dry and to avoid problem created due to wet skin.

When the absorbency rate of control sample and plasma treated samples are compared, in the control sample, the time taken to absorb moisture is low (1.6 s) for the lyocell side of the fabric when compared to the Bamboo charcoal side of the fabric (5 s). After plasma treatment, the absorbency improved considerably. The increase is more in the case of Bamboo charcoal side (1.8 s) when compared to lyocell side (0.8 s). It can be noted that longer plasma exposure times could induce more hydrophilic functional groups on the fabric surface due to the longer duration of the chemical interaction of plasma and the fibres. The change in moisture absorbency will depend on two main factors, viz the changes in surface morphology due to the etching action of the plasma and the formation of polar groups on the surface, which will help moisture penetration and binding on the fabric surface.

3.3 Influence of Plasma Treatment on Vertical wicking

The tri-layer composite fabric sample and all the samples exposed to plasma treatment by varying the process parameters through the Box and Benkhen experimental plan were tested for vertical wicking. The experiment was conducted both course wise and wales wise and also on both lyocell side and Bamboo charcoal side of the tri-layer composite fabric.

Five specimens of 6 × 1 inch cut along the wales-wise and course-wise directions were prepared. The specimen was suspended vertically with its bottom end dipped in a reservoir of distilled water. In order to ensure that the bottom ends of the specimens could be immersed vertically at a depth of 30 mm into the water, the bottom end of each specimen was clamped with a 1.2 g clip. The wicking heights, measured after every minute for 10 min, were recorded for a direct evaluation of the fabric's wicking ability.

Contour plot shown in Fig. 3(a) represents the vertical wicking (course-wise – bamboo charcoal side) of fabric specimen *vs.* distance between electrode, time and current. The effect of process parameters on course-wise vertical wicking of Bamboo charcoal side of the fabric is similar to that of lyocell side. Increasing distance between the electrodes upto 4.8 cm and increasing time above 100 s, increases the wicking length, whereas current has less or no effect.

Contour plot shown in Fig. 3(b) represents the vertical wicking (course-wise –lyocell side) of fabric specimen. The course-wise vertical wicking of lyocell side of the fabric is greatly influenced by distance between the electrodes which is then followed by time and current. Increase in distance between the electrodes increases the wicking length upto 4.8 cm, whereas further increment in distance between the electrodes reduces the wicking. When considering time, higher wicking is noted after 100 s, below which the wicking length is found decreasing. Current has lesser effect on the wicking length of the fabric.

Contour plot shown in Fig. 4(a) represents the vertical wicking (wales-wise – bamboo charcoal side) of fabric specimen. In the case of wales-wise vertical wicking on bamboo charcoal side of the fabric, the effects of process parameters are noted similar as in the case of wales-wise vertical wicking on lyocell side of the fabric.

Contour plot shown in Fig. 4(b) represents the vertical wicking (wales-wise –lyocell side) of fabric specimens. While considering the wales-wise vertical wicking on the lyocell side of the fabric, increased distance between the electrodes at increased time can increase the wickability. At increased time and

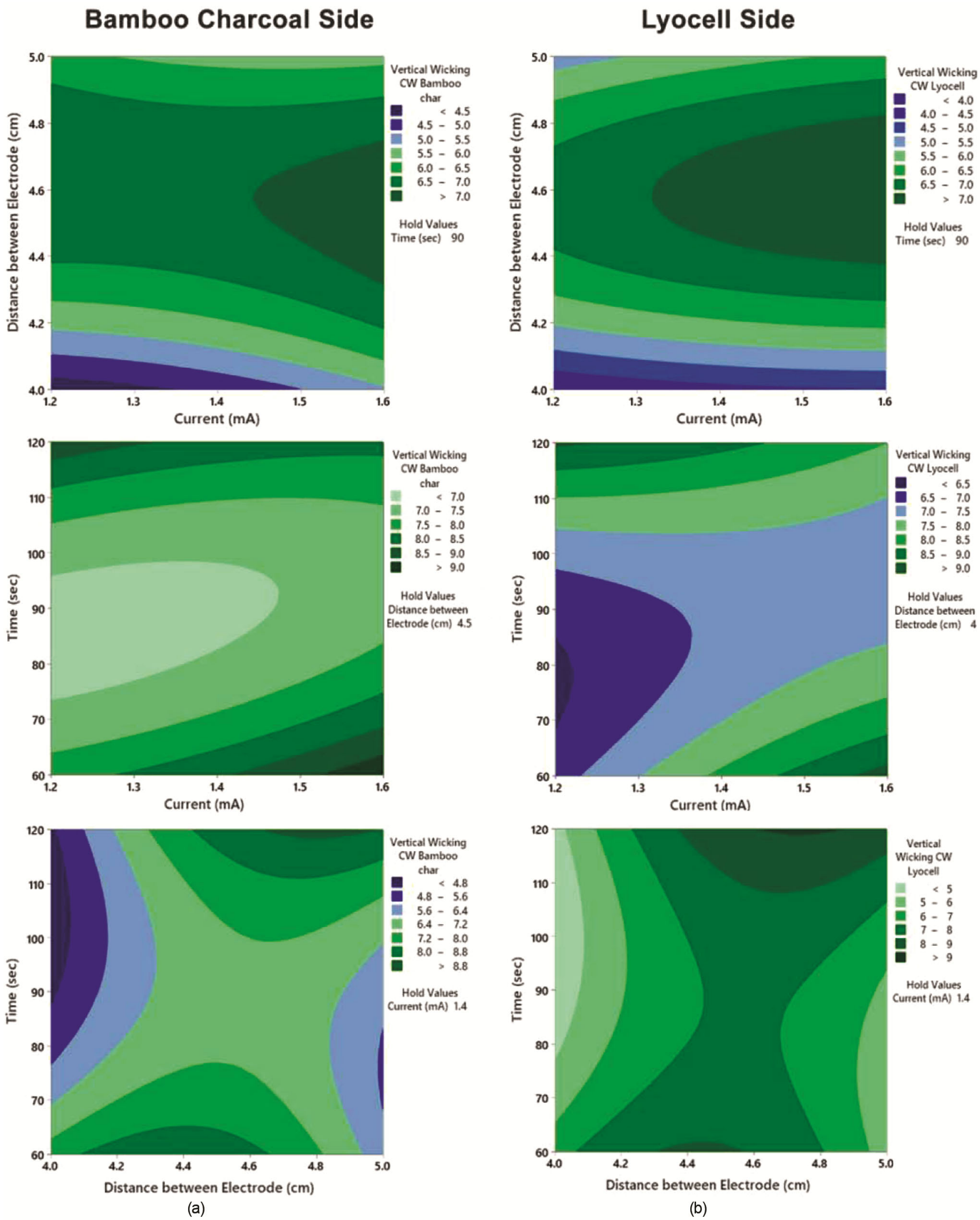

Fig. 3 — Influence of process parameters on vertical wicking (course- wise) (b) bamboo charcoal side and (b) lyocell side

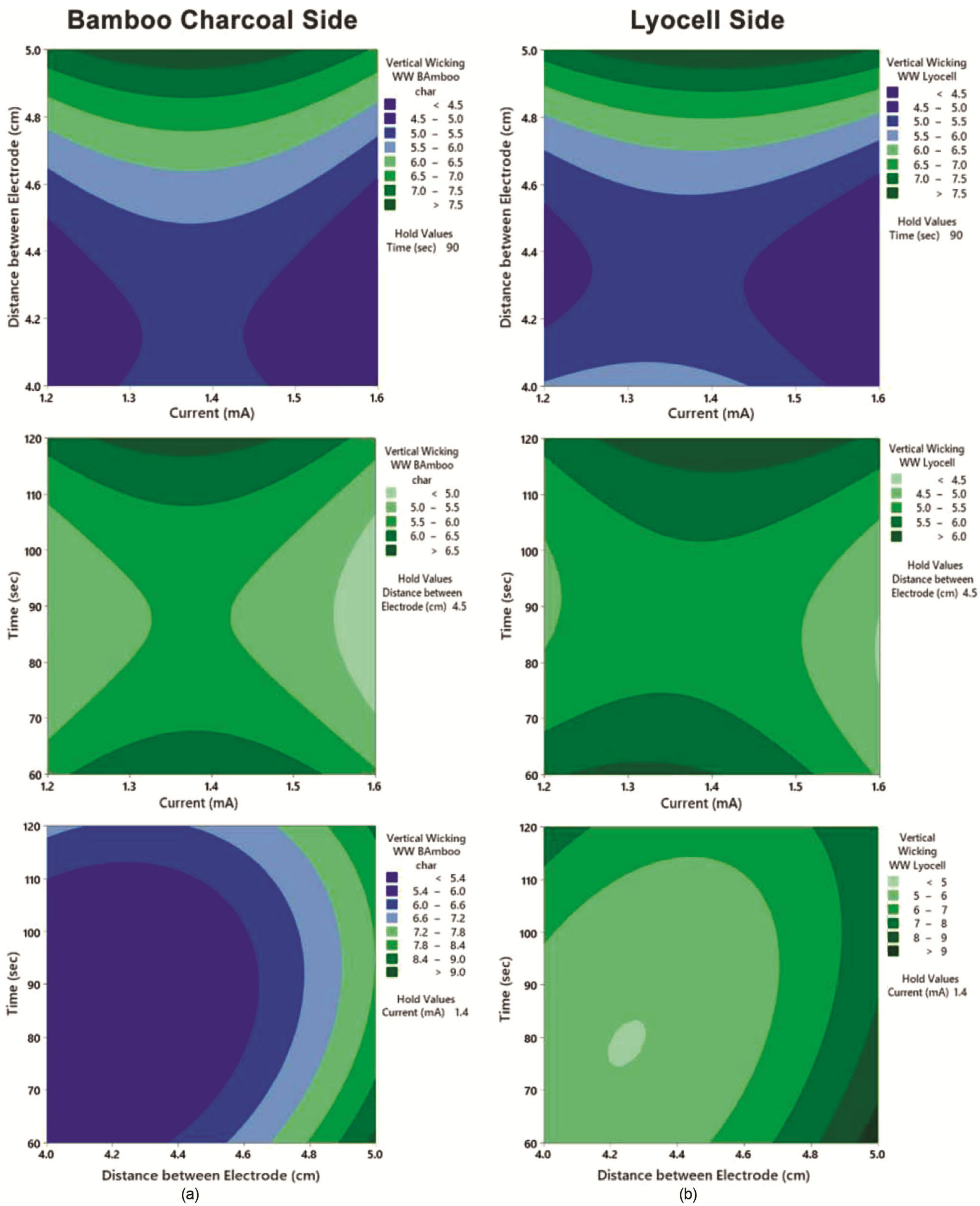

Fig. 4 — Influence of process parameters on vertical wicking (wales-wise) (a) bamboo charcoal side and (b) lyocell side

distance between the electrodes, current has no effect on wickability, whereas at lower levels, increase in current above 1.4 mA reduces the wicking length.

The bamboo charcoal tri-layer composite fabric exhibits higher wicking tendency due to the presence of bamboo charcoal and micro polyester combinations. Compared to single layered fabrics, multi layered structure has almost 3-4 times increase in wicking height. This phenomenon can be attributed to the presence of more number of micro-pores in the bamboo charcoal yarn and more capillaries in the micro polyester yarn due to its finer diameter. Also being hydrophobic in nature bamboo charcoal polyester does not form bonds with water molecules, and also due to its positive contact angle (75^o), drags the liquid surface very smoothly, which offers high wicking in case of bamboo charcoal.

Among the process parameters, electrical power and treatment speed were important. Indeed, various studies show that the increase in electrical power and/or treatment time result in improved wettability and capillarity of textile fabrics. However, treatment time was identified as the second-most relevant parameter for contact angle and the third-most relevant parameter for capillarity height. This fact suggested that electrical power was more significant than treatment time and the other parameters. These results were attributed to the molecular structures and properties of the treated samples[25]. The water vapor permeability and thermal resistance of cotton fabric increased with the plasma exposure time, oxygen plasma, and the frequency of the plasma machine; furthermore, they decreased with the air plasma and the distance reserved between the electrode and the fabric sample[26]. The accumulative one way transport capability index (AOWTI) which represents the difference between the area of the liquid moisture content curves of the top and bottom surfaces of the sample with respect to time increases linearly as the duration of treatment increases from 5 min to 20 min, in case of the argon gas plasma treated fabrics[27]. Our study shows that the maximum wettability and capillarity reached after air-plasma treatment are higher for bamboo charcoal side as compared to lyocell side.

3.4 Influence of Plasma Treatment on Transverse Wicking

The ability of the fabric to absorb water is measured by spreading action as per AATCC 79:2000. This property was evaluated by measuring the time required for a piece of fabric to sink completely from the surface layer of water in a beaker. The transverse wicking of the fabric was measured by cutting a sample of 3 × 3 cm^2 and placing it on the surface layer of water. The time taken by the sample to sink is calculated.

Contour plot shown in Fig. 5(a) represents the transverse wicking (bamboo charcoal side) of fabric specimen *vs.* distance between electrode, time and current. The increase in current increases the absorption time, whereas the effect of distance between the electrodes is significantly lesser. While considering time, increase in time increases the wicking time.

Contour plot shown in Fig. 5(b) represents the transverse wicking (lyocell side) of fabric specimen *vs.* distance between electrode, time and current. The increase in distance between the electrodes after 4.2 cm, the transverse wicking time got increased. The increase in time increases the wicking time, whereas current has no significant effect on the transverse wickability of the fabric.

The transverse wicking characteristics of the plasma treated and untreated tri-layer composite fabrics were compared. The time taken to sink on the bamboo charcoal side of the fabric (9.7 s) is more compared to lyocell side of the fabric (4 s) due to the hydrophobic nature of bamboo charcoal fibre. Due to high surface energy and hydrophilic nature of lyocell fibre, the time taken to sink is very less. The plasma treatment improves the transverse wicking on both the sides of fabric, but still the extent of improvement is very high in the case of bamoo charcoal side (0.5 s) which proves the hydrophilization of the bamboo charcoal fibre. The transverse wicking of plasma treated lyocell side of the fabric was 0.75 s. This higher absorbing tendency of the multi layered structure results in absorption of more amount of sweat from the skin and hence keeps the wearer in comfort zone.

3.5 Influence of Plasma Treatment on Drying Time

Quick drying capability of the fabric was evaluated by its drying rate as per ASTM D 4935-99. The remained water ratio (RWR) was calculated using the following equation to express the change in water weight remained in the specimen over the time for drawing the evaporating curve from 100% to 0%:

$$\text{RWR (\%)} = [w_i\,(g) - w_f\,(g) / w_o\,(g) - w_f\,(g)] * 100\% \qquad \ldots (2)$$

where $w_f(g)$ is the dry weight; $w_o(g)$, the wet weight after adding 30% of the dry weight of water; w_i (g), the change in weight of water.

Contour plot shown in Fig. 6 represents the drying rate of fabric specimen *vs.* distance between electrode, time and current. The drying rate of the fabric is greatly influenced by current and distance between the electrodes which is followed by time. Increase in distance between the electrodes increases the water retention %, whereas increase in current reduces the water retention % at higher time (90 – 120 s).

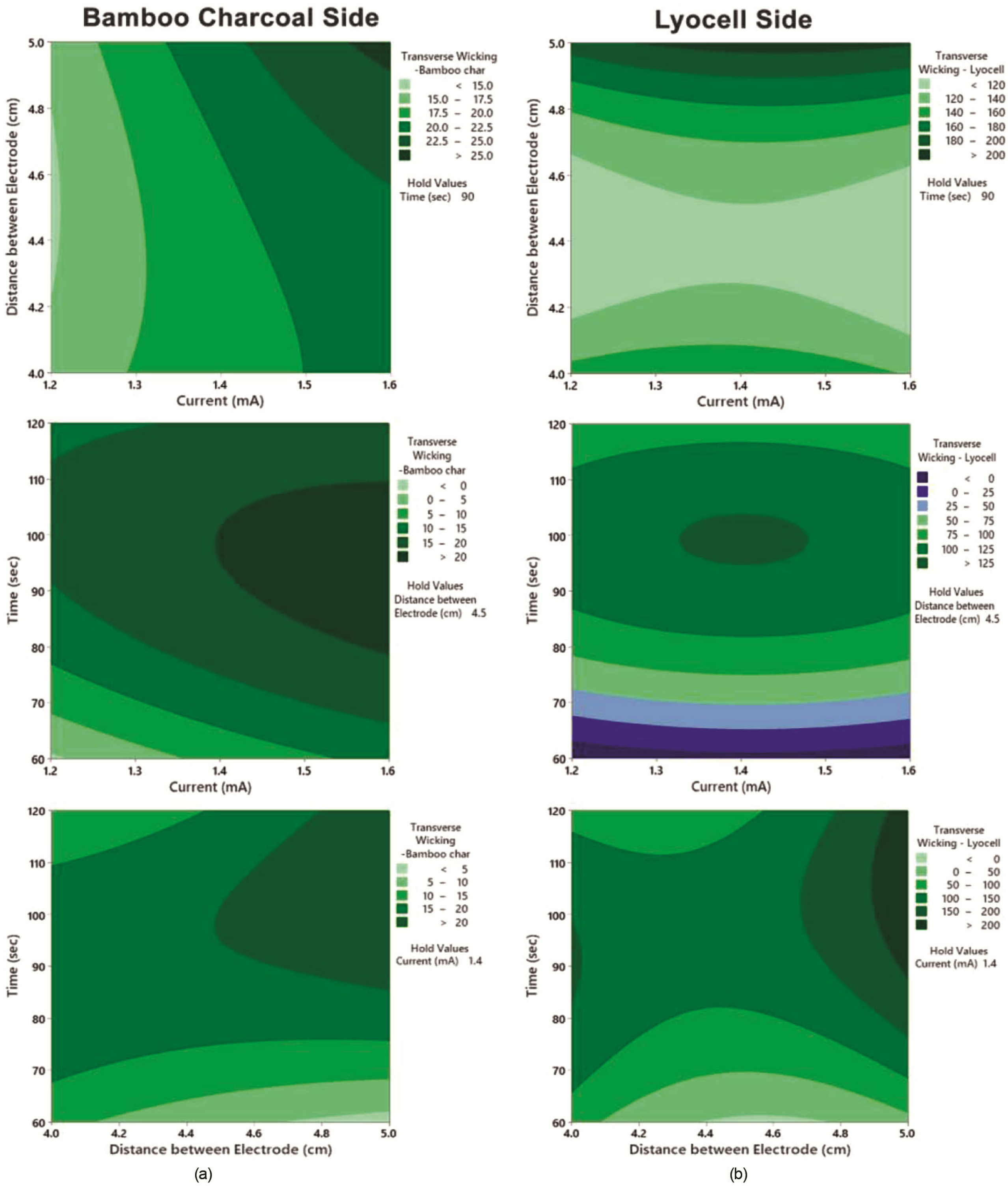

Fig. 5 — Influence of process parameters on transverse wicking (a) bamboo charcoal side and (b) lyocell side

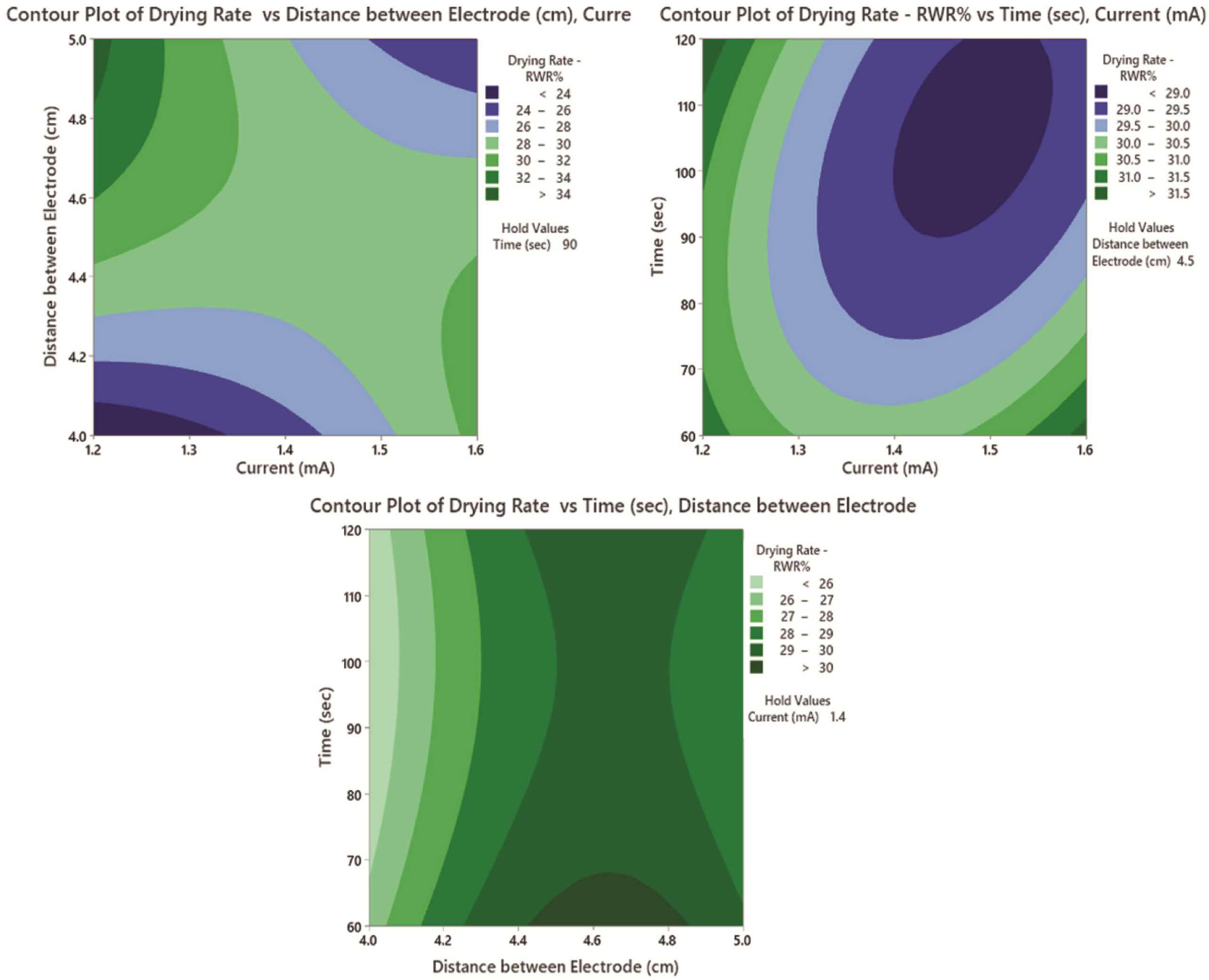

Fig. 6 — Influence of process parameters on drying rate

Liquid transporting and drying rate of fabrics are two vital factors affecting the physiological comfort of garments. The moisture transfer and quick drying behaviors of textiles depend mainly on the capillary capability and moisture absorbency of the fibres. These characteristics are especially important in garments worn next to the skin or in hot climates. In these situations, textiles are able to absorb large amounts of perspiration, draw moisture to the outer surface and keep the body dry. The remained water ratio (RWR%) of untreated fabric is 2.04 and the plasma treated fabric is 1.97. It can be observed that the drying rate of the plasma treated fabric increases considerably. Bamboo charcoal fabrics have faster drying rate due to hydrophobic nature, and addition of lyocell delays the drying time of the fabrics as the moisture content of lyocell fibre is more than the polyester based bamboo charcoal yarns. But still the bamboo charcoal side dries faster and gives a dry feel to the wearer.

3.6 Influence of Plasma Treatment on Water Vapor Permeability

The moisture vapour transfer rate (MVTR) is the measurement used to characterize the breathability of fabrics. Evaporative dish method following the British Standard BS 7209:1990 was used to evaluate the MVTR of untreated and plasma treated tri-layer fabric. The testing was carried out under standard laboratory condition of 65± 2 % Rh and 20±2˚C temperature.

As the cellulosic content in the fabric increases, moisture regain of the material will be increased causing higher diffusivity. A hygroscopic fabric absorbs water vapour from the humid air close to the sweating skin and releases it in dry air. This enhances the flow of water vapour from the skin to the environment comparatively higher than a fabric which does not absorb and reduces the moisture built up in the microclimate. However, less hygroscopicity offers less resistance to the transfer of moisture vapour to air. Moreover, the highly porous nature of bamboo charcoal also leads to higher water vapour permeability.

Atmospheric pressure plasma treatment has resulted in the enhancement of moisture vapor transport property of tri-layer fabric. The untreated fabric has a moisture vapour transfer rate (MVTR) of 1260g/m^2/day and the plasma treated fabric has 1374 g/m^2/day. This finding could be explained by the fact that when plasma treatment is carried out at higher voltage and more time, higher plasma energy results in sufficient surface oxidation leading to higher air permeability and higher water vapour permeability. Plasma treatment increases the pore size and results in larger pores. The increase in the number of large size pores improves the diffusion of vapor between the fibres in the knitted structure.

The optimization parameter, basis or goal for selecting the responses and the values (responses) under optimized conditions are given in Table 4.

3.7 Scanning Electron Microscopy Image

The surface morphology of untreated and treated fabrics was scanned by an electron microscope at 10 kV under a high vacuum at ×5000 magnification. Figures 7(a) and (b) show the SEM micrographs of untreated and treated lyocell side of fabric and Fig. 7(c)

Table 4 — Optimization of process parameters
[Optimised parameters: Current 1.6 mA, distance between electrodes 4.97 cm and time 60s]

Response	Goal	Value
Transverse wicking – Bamboo charcoal side	Minimum	9.54
Transverse wicking – Lyocell side	Minimum	24.01
Absorption rate – Bamboo charcoal side	Minimum	10.75
Absorption rate – Lyocell side	Minimum	0.91
Vertical wicking (wales-wise) – Bamboo charcoal side	Maximum	8.11
Vertical wicking (wales-wise) – Lyocell side	Maximum	8.52
Vertical wicking (course-wise) – Bamboo charcoal side	Maximum	6.77
Vertical wicking (course-wise) – Lyocell side	Maximum	7.02
Drying rate - RWR%	Minimum	26.36

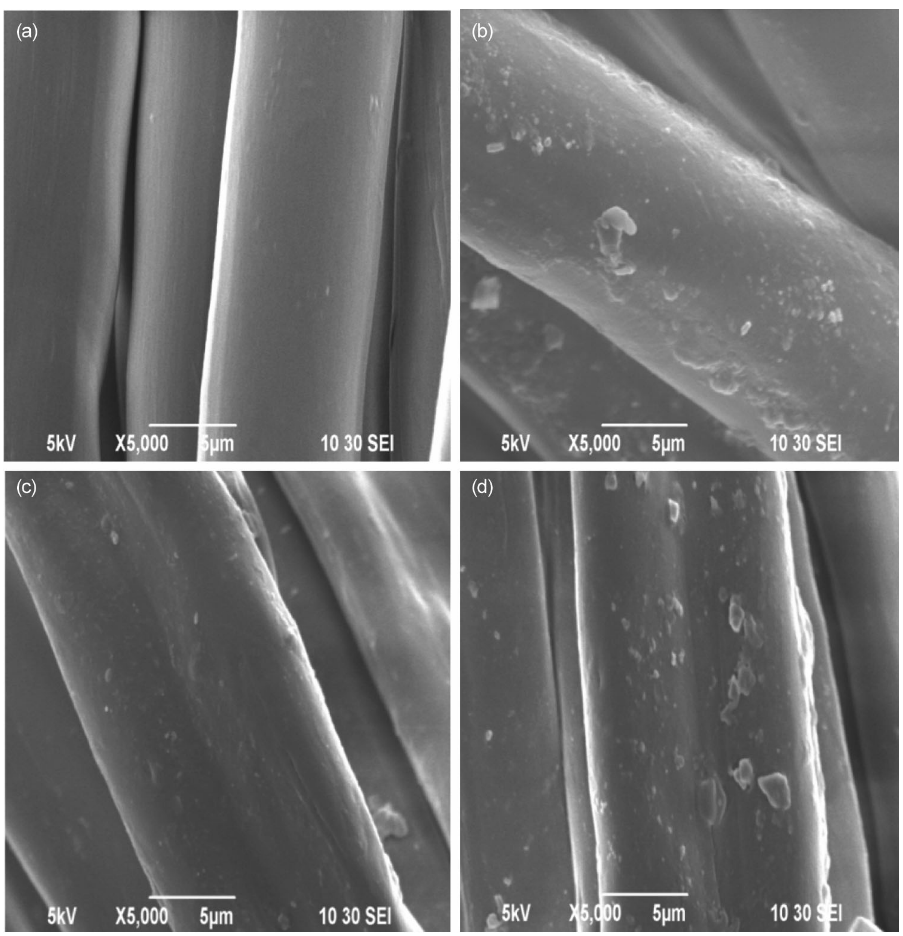

Fig. 7 — SEM images of tri-layer composite fabric (a) lyocell side (untreated), (b) lyocell side (plasma treated) , (c) bamboo charcoal side (untreated) and (d) bamboo charcoal side (plasma treated)

Table 5 — Regression equations for various properties of tri-layer fabric

Property	Regression equation	R^2 Value	p- Value
Vertical wicking–coarse-wise (Bamboo charcoal side)	$Y=6.20+0.38A+0.075B+0.23C+1.10AB-1.15AC+0.40BC+1.80A^2+0.35B^2-1.10C^2$	0.8236	0.0515
Vertical wicking–coarse-wise (Lyocell side)	$Y=6.48+0.6A-A0.012B-0.037C+1.30AB-1.20AC+0.23BC+1.62A^2+0.15B^2-1.70C^2$	0.9336	0.0023
Vertical wicking–wales-wise (Bamboo charcoal side)	$Y=3.92-0.84A-.043B-0.31C+0.075AB+0.45AC+0.78BC+1.04A^2+0.61B^2-1.000E-002C^2$	0.7219	0.1833
Vertical wicking–wales-wise (Lyocell side)	$Y=4.79-0.76A-0.35B-0.24C$	0.3354	0.1385
Transverse wicking–Bamboo charcoal side	$Y=20.49+4.02A-4.23B+2.08C+3.25AB+6.96AC-0.74BC-3.97A^2-6.32B^2+0.18C^2$	0.8063	0.0678
Transverse wicking–Lyocell side	$Y=117.34-18.33A-44.19B-12.85C+54.43AB+86.79AC-32.53BC$	0.7086	0.0254
Absorbency rate–Bamboo charcoal side	$Y=24.72+10.97A+4.21B-7.8C+1.65AB-15.08AC+1.85BC+2.14A^2-17.18B^2+7.05C^2$	0.7486	0.1405
Absorbency rate–Lyocell side	$Y=1.12-0.058A-0.25B-0.087C-0.24AB-0.15AC+0.20BC+0.39A^2+0.18B^2-0.45C^2$	0.8082	0.0658
Drying rate	$Y=68.76+0.90A-2.79B+3.26C-4.27AB+0.18AC+4.75BC+12.02A^2+5.59B^2+7C^2$	0.7899	0.0856

and (d) the untreated and treated bamboo charcoal side of the fabric. After the plasma treatment, the surface become rougher and abrasion can be clearly seen on the surface of the fibre. This result can be attributed to the etching effect caused by the bombardment of plasma species on the polymer surface.

It can be seen from figure that the surface morphology of the fibre is changed after the plasma treatment. The treated surfaces look damaged or abraded. This is due to the removal of some material by etching. In bamboo charcoal fibre, the nano particles of bamboo charcoal are seen as small specs on the surface of fibre and after plasma treatment, fibre surface seems to be etched and the particles are exposed.

3.8 Regression Equations

The regression equations (R & R^2 values) for various properties are given in the Table 5. A check point analysis was performed to confirm the role of derived polynomial equation and contour plots in predicting the responses. Values of independent variables were taken at 3 points, one from each contour plot, and the theoretical values in the polynomial equation.

After developing the polynomial equations for the responses with the independent variables, the formulation was optimized. Optimization was performed to find out the level of independent variables that would yield a maximum value of water management properties efficacy with constraints on distance, time and current.

Comparison between the moisture management properties of plasma-treated tri-layer composite (optimized condition) fabric and untreated fabrics is made. The plasma-treated fabric registers an improvement in moisture management properties compared to untreated tri-layer composite fabric. The improvement in performance (percentage) is as follows: vertical wicking 16.11, transverse wicking 74.88, absorbency rate 72.32, drying rate 14.15, and water vapor permeability 9.05.

4 Conclusion

A tri-layer weft knitted composite fabric has been developed using bamboo charcoal- micro polyester-lyocell fibre combination. The tri-layer composite fabric is soft, with good wickability, which appeals to the comfort properties of the user. This fabric possesses certain exceptionally good functional characteristics, such as moisture absorbency, where the moisture from the body is absorbed by the base layer, passed through the connecting layer and gets evaporated from the top layer. To further enhance the functional properties, the tri-layer composite fabric has been subjected to plasma treatment using atmospheric pressure plasma. The process parameters like distance between the electrode, time and current have been varied and the results are being optimized. The results have been examined for water management properties and the optimum conditions for plasma treatment for the fabric are found to be 4.97 cm, 60 s and 1.6 mA. From the study, it is observed that the plasma process proves to be more efficient and it shall be used for improving the moisture management properties of the tri-layer composite fabric.

Generally, multi layered structures have better moisture management properties when compared to single layered fabrics. The plasma-treated knitted multilayer fabric is a more suitable choice for hospital textile application because of its enhanced comfort and moisture management properties.

References

1 Carla Hertleer, Anneleen Tronquo, Hendrik Rogier & Lieva Van Langenhove, The use of textile materials to design wearable micro-strip patch antennas, *Text Res J*, 78(8) (2008) 651-658,.

2 Behera B K, Mani M P, Amit K, Mondal & Nithin Sharma, Comfort behavior of cotton polypropylene based bi-layered knitted fabrics, *Asian Text J*, 5(1) (2002) 61-67.

3 Guldemet Basal & Sevcan Ilgaz, Functional fabric for pressure ulcer prevention, *Text Res J*, 79 (16) (2009) 1415–1426.

4 Sharabaty T, Biquenet F, Dupuis D & Viallier P, Investigation on moisture transport through polyester/cotton fabrics, *Indian J Fibre Text Res*, 33 (2008) 419-425.

5 Xiaohua Ye, Hong Hu & Xunwei Feng, Development of the warp knitted spacer fabrics for cushion applications, *J Ind Text*, 37(3) (2008) 213-223.

6 Yonenaga A, Engineered fabrics for active and comfort sportswear, *Int Text Bull*, 44(4) (1998) 22-26.

7 Prabhakar Bhat & Bhonde, H U, Comfortable clothing for defence personnel, *Asian Text J*, (2006) 73-77.

8 Hwang Y J, Sang An J & McCord M G, The effect of etching on low stress mechanical properties of polypropylene fabrics under helium/oxygen atmospheric pressure plasma, *Fiber Polym*, (2003) 144-150.

9 Grill A, *Cold Plasma in Materials Fabrication, from Fundamentals to Applications* (IEEE Press, New York, USA), 1993.

10 Shenton M J & Stevens G C, Surface modification of polymer surfaces: atmospheric plasma versus vacuum plasma treatments, *J Phys [D] Appl Phys*, 34 (20012761–2768).

11 Senthilkumar P, Janarthanan M & Krishna Prasad G , Atmospheric pressure plasma systems for textile applications, *IE (I) J-Tex*, 88 (2008) 9–12.

12 McConrd M G, Hwang Y J, Hauser P J, Qiu Y, Cuomo JJ, Hankins OE, Bourhan MA & Canup LK, Modifying nylon and polypropylene fabrics with atmospheric pressure plasmas, *Text Res J*, 72 (6) (2002) 491-498.

13 Masaeli E, Morshed M & Tavanai H, Study of the wettability properties of polypropylene nonwoven mats by low- pressure oxygen plasma treatment, *Surf interface Anal*, 39 (9) (2007) 770-774.

14 Tsai P, Wadsworth L & Roth R, Surface modification of fabrics using a one atmospheric glow discharge plasma to improve fabric wettability, *Text Res J*, 67 (5) (1997) 359-366.

15 Wolf R A, Sparavigna & Montrucchio, *Enhancing RFID label production with atmospheric plasma treatment*, paper presented at the 10th WSEAS International Conference on SYSTEMS, . Vouliagmeni, Athens, Greece, 10 July 2016

16 Abidi N & Hequet E, Cotton fabric graft copolymerization using microwave plasma, *J Appl Polym Sci*, 93 (1)(2004)145

17 Keiko Gotoh & Akemi Yasukawa, Atmospheric pressure plasma modification of polyester fabric for improvement of textile-specific properties, *Text Res J*, 81(4) (2010)368-372.

18 Zdenka Pers, Alenka Vesel, Karin Stana Kleinschek & Miran Mozetic, Characterization of surface properties of chemical and plasma treated regenerated cellulose fabric, *Text Res J*, 82(20) (2012) 2078.

19 Vrabic U, Jesih A & Svetec D G, Physical and absorptive changes in plasma treated viscose fibres, *Fibres Text East Eur*, 15 (5) (2007) 124–126.

20 Vesel A, Mozetic M & Strnad S, Plasma modification of viscose textiles, *Vacuum*, 84(1) (2010) 79–82.

21 Wakida T, Takeda K & Tanaka I, Free radicals in cellulose fibres treated with low temperature plasma, *Text Res J*, 59(1) (1989) 49–53.

22 Zemljic L F, Persin Z & Stenius P, Improvement of chitosan absorption onto cellulose fabrics by plasma-treatment, *Bio-macromol*, 10 (5) (2009) 1181–1187.

23 Jeong-Sook Cho & Gilsoo Cho, Effect of dual functional finish containing an antibiotic and a flouro chemical on the antimicrobial properties and blood repellency of surgical gown materials, *Text Res J*, 67(12) (1997) 875- 880.

24 Thenmozhi R, Sivakumar P, Senthilkumar P, Thilagavathi G & Parthiban M, Development of Odor Free Anti-microbial Hospital Linens, *IE (I) J–Tex,* 91(1) (2010) 3-10.

25 Radhia Abd Jelil, Xianyi Zeng, Ludovic Koehl & Anne Perwnelz, *Applications of atmospheric air plasma treatments on polyester and viscose woven fabrics,* paper presented at the Autex World Textile Conference, Izmir, Turkey, 01st May 2009.

26 Ebastin Rajwin A & Prakash C, A study on the effect of plasma treatment on thermal comfort properties of cotton fabric, *J Test Eval,* 46(5) (2018). https://doi.org/ 10.1520/ JTE20170156.

27 Jayashree Venkatesh & Ninge Gowda K N, Effect of plasma treatment on the moisture management properties of regenerated bamboo fabric, *Int J Sci Res Pub*, 3(10) (2013) 1-8.