Effect of Plasma Treatment on the Moisture Management Properties of Regenerated Bamboo Fabric

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Abstract- Moisture management is the ability of a fabric to transport moisture away from the skin to the garment's outer surface in multi-dimensions and it is one of key performance criteria in today's textiles for garments for various end uses. This property has a significant effect on the human perception of moisture sensations as well as the growth of microorganisms. Plasma treatment on textiles is a novel dry processing technique used to enhance comfort, functional and aesthetic properties of regenerated cellulosic fabrics and at the same time reduce the pollution load on the environment. In this study air, argon and oxygen gas plasma treated pure regenerated bamboo fabric in single jersey construction were tested for their moisture management capacity using "SDL-ATLAS moisture management tester". Dynamic liquid transport properties of textiles such as wetting time, maximum absorption rate, maximum wetted radius and spreading speed were measured. The result revealed that the type of plasma treatment and the duration of air, argon and oxygen gas plasma treatment have significant effect on all the parameters of the moisture management capacity. In case of all the plasma treated samples the wetting time and the absorption rate (%/sec) increased, both for the top and bottom surface with the highest duration of 8.2 seconds and highest absorption rate of 64.99 (%/sec) respectively, in case of 10 minutes argon plasma treated sample. The spreading speed (mm/sec) decreased in case of all the plasma treated samples. Slow spreading of 2.1(mm/sec) was recorded in case of 5 minutes air plasma treated sample as compared to 3.21 (mm/sec) in case of the untreated sample. In case of argon and oxygen gas plasma the value of accumulative one way transport index and overall moisture management capacity increased, with the highest value of 265 and 2.04 recorded in case of 10 minutes oxygen gas plasma treated sample. The relationship between the duration of treatment and the absorption rate of the bottom surface in the case of bamboo fabrics was linearly related. The results revealed that the effect of air, argon and oxygen gas plasma treatment on the bamboo knitted sample are significant in altering the parameters of the moisture management properties. Ten minutes oxygen gas plasma has led to significant improvement in the overall moisture management. Special needs for a health care and hygiene products, sportswear and infant garments can be met by plasma treated moisture management fabrics.

Index Terms- Knitted structure; Low pressure glow discharge plasma treatment; Moisture Management Property.

I. Introduction

Moisture management property is a buzz word today as it refers to transportation of moisture to the fabric through the skin. In some of the sportswear and uniforms, moisture management plays an important role as the moisture is moved away from the skin. In view of its usefulness, many have published papers in particular by Hu et al (1), Wardiningsih and Mazloumpour (2, 3). The effect of cover factor on moisture management was examined by the latter, while the former dealt with the development of a tester. In addition Olga Troynikov and Wiah Wardiningsih have looked into the moisture management property of wool/polyester and wool/bamboo blends suitable as the base layer for sportswear (4). In none of the above studies the effect of plasma treatment on the moisture management of bamboo knitted fabrics has been studied and this paper reports the findings.

Moisture transmission through textiles has a great influence on the thermo-physiological comfort of the human body which is maintained by perspiring both in vapour and liquid form. Most recently, major upsurge on research related to absorption properties of fabrics used for apparel, health care, hygiene products and sportswear has taken place, since this plays an important role in moisture management and its performance.

The base layer of garments is commonly made from knitted fabric due to their high stretch and recovery, ability to provide greater freedom of movement, drapability and tailored fit. Knitted fabrics also have relatively uneven surfaces; this makes them feel more comfortable as compared to the smooth surface of the woven fabrics with similar fibre compositions. This effect results from the fact that fabric that has uneven surfaces has less direct contact with the skin (4, 5). Plasma treatment is a dry textile processing technique and is a surface-sensitive method that allows selective modification for imparting product specific functionality in textiles and apparel. The plasma reaction involves the interaction of atoms, free radicals and metastable particles, electrons and ions. The effect and efficiency of the plasma treatment depends on the pressure, power, duration of treatment and the choice of working gas. Plasma treatment improves wettability, hydrophobic finishing, adhesion functionality and product quality in cellulosic fabric. The use of oxygen plasma can modify the wettability of cotton and other cellulosic materials. Argon gas is used to increase surface roughness and modify the texture. It also alters the tensile properties and functional behavior of the fabric. It improves air permeability and drape properties (6, 7). Optimization of surface properties of textile materials without altering the inherent properties of the textile materials can be achieved by air, argon and oxygen gas plasma treatments. Plasma treatment can be a viable substitute to conventional processes and very often it can provide the advantageous effect that cannot be obtained by wet processing of textile material. Considering these facts, this research addresses the moisture management properties of pure bamboo knitted fabrics.

In the present study, the simultaneous liquid moisture transport performances on the top and bottom surfaces of knitted fabrics made from pure bamboo were tested using "SDL-ATLAS Moisture Management Tester" (8). The effect of 5, 10 and 20 minutes duration of air, argon and oxygen gas plasma treatments was assessed on the pure bamboo knitted fabrics.

II. MATERIALS AND METHODS

a. Materials

In the present study, hundred percent bleached Bamboo knitted fabric was produced using a yarn of linear density of 19.68 tex and having 8.89 twists per cm. The single knitted fabric was produced on a circular knitting machine. The number of courses and wales per cm was 21 and 16 respectively. The mass per unit area (g/ m^2) was 160 with a loop length of 2.5mm.The thickness of fabric was 0.56 mm. The other dimensional properties of the sample used for this research are given in TABLE I.

Table 1: Properties of Bamboo Knitted fabric

Stitch Density (Stitches/ cm^2)	336.00
Loop length (mm)	2.50
Mass per unit area (g/ $m^{2)}$	160.00
Tightness factor(tex $^{0.5}$ cm^{-1})	17.89
Loop shape factor	1.37
Thickness(mm)	0.56
Bulk Density (g/ m^3)	3.14

b. Method

(i) Plasma treatment

The regenerated cellulosic pure bamboo knitted fabric was treated using low pressure glow discharge plasma. The glow discharge was generated using an apparatus made by Bangalore Plasmatek, Bangalore, India. The DC glow discharge was operated at 0.5 mbar. Different gases like air, argon and oxygen were admitted into the plasma chamber using needle valve to control the pressure. Cathode was located in the centre of the chamber and the chamber walls acted as anode. Samples were placed hanging at a distance of about 18 cm from the cathode. It was operated at radio frequency of 150 to 192 MHz. The process parameters that were varied during the air, argon and oxygen gas plasma was the duration of treatment. The fabrics were treated for 5, 10 and 20 minutes duration.

(ii) Testing of liquid moisture management properties.

The AATCC 195-2009 standard test method was used for the measurement, evaluation and classification of liquid moisture management properties of the untreated and air, argon and oxygen gas plasma treated pure bamboo samples using "SDL-ATLAS Moisture Management Tester" .Before testing the untreated and all the plasma treated samples were conditioned at 25 ± 2^0C and 65± 2% RH according to ASTM D1776 standard practice for conditioning and testing textiles. The test solution was prepared by dissolving 9 g sodium chloride (USP Grade) in 1 litre of distilled water and the electrical conductivity was adjusted to 16+0.2 milli Siemens(ms) at 25 ^{o}C by adding sodium chloride or distilled water as necessary. The" Pump- on Time was set at 20 s to assure the predetermined amount of 0.22 cc of test solution is dispensed. The "Measuring time" for each of the untreated and all the air, argon and oxygen gas plasma treated samples was set for 120 s. The objective measurement of liquid moisture management properties was evaluated by placing the 8x8 cm cut fabric specimen between the two horizontal (upper and lower) electrical sensors of the "SDL-ATLAS Moisture Management Tester". The sample was placed on the lower sensor with the specimen's top surface up. The upper sensor was released until it freely rested on the test specimen. The test solution moved freely in three directions: radial spreading on the top surface, movement through the specimen from top surface to bottom surface, and radial spreading on the bottom surface of the specimen. The SDL-ATLAS Moisture Management Tester recorded the following parameters of the liquid moisture management properties .The wetting time (WT_T) (top surface) and (WT_B) (bottom surface) in seconds when the top and bottom surfaces of the specimen started to wet. The absorption rate (AR_T) (top surface) and (AR_B) (bottom surface) was recorded to measure the average speed of liquid moisture absorption for the top and bottom surfaces of the specimen during the initial change of water content during testing. The maximum wetted radius (MWR_T) and (MWR_B) was recorded to measure the greatest ring radius of the solution on the top and bottom surfaces. The accumulated rate of surface wetting from the center of the specimen where the test solution was dropped to the maximum wetted radius was measured both for top and bottom surface as spreading speed (mm/sec) (SS_T and SS_B).The accumulative one way transport capability (R) was recorded to establish the difference between the area of the liquid moisture content curves of the top and bottom surfaces. An index of the overall capability of the untreated and plasma treated fabrics to transport liquid moisture was calculated by the inbuilt software by combining the three measured attributes of performance i.e. the liquid moisture absorption rate on the bottom surface (AR_B), the one way liquid transport capability (R), and the maximum liquid moisture spreading speed of the bottom surface (SS_B). For each sample five trials were recorded and the average values plotted in form of histograms.

III. RESULTS AND DISCUSSION

The results obtained from this test method are based on the water resistance, water repellency and water absorption characteristics of the fabric structure, including the fabrics geometric and internal structure and the wicking characteristics of its fibres and yarns. The moisture management properties of the untreated and the plasma treated samples are depicted by graphical representations. The top surface parameter means, the side of the fabric that would come in contact with the skin when the garment is worn or when a product has been used. The bottom surface is the side of the fabric that would be the outer exposed surface of a garment when worn or product when it is used.

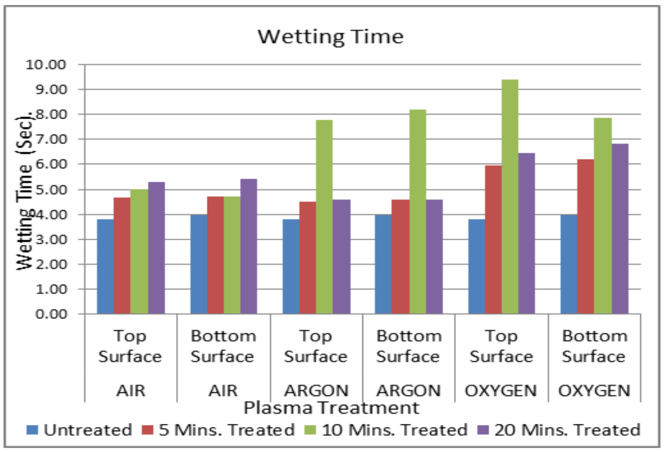

Figure 1: Wetting time (sec) values for the Bamboo fabrics-Top and Bottom Surface

Figure 1 reveals the wetting time per second of pure bamboo fabric on the top surface and bottom surfaces. The samples treated with air plasma treatment showed a slower wetting as compared to the untreated sample. In case of the untreated Bamboo sample the wetting time recorded was 3.79 seconds whereas the maximum wetting time was 5.31 seconds in case of Bamboo sample treated for 20 minutes duration. There is gradual increase in wetting time as the duration increases from 5 to 20 minutes in case of air plasma treated samples. Slower wetting was evident as compared to untreated Bamboo sample, in samples treated for 10 minutes duration both in case of argon and oxygen gas plasma treated samples. The longest time of 9.41 seconds was recorded in case of 10 minutes oxygen gas plasma treated sample. In case of argon gas plasma treatment the samples treated for both 5 and 20 minutes duration was 4.5 seconds. The longest wetting time (8.2 seconds) was recorded in case of 10 minutes argon gas treatment.

The wetting time of the untreated bamboo sample both on the top and bottom surface was 3.9 seconds A higher wetting time of 5.8 seconds in case of the bottom surface was recorded in case of air plasma treated sample treated for 20 minutes. The impact of duration of treatment i.e. 5 and 10 minutes on the samples in case of air plasma and argon gas plasma was not significant, while, the 10 minutes treatment time both in the case of argon and oxygen gas plasma showed a significant delay in the wetting time. The faster wetting is due to the high attraction between the liquid and the fabric surface, known as the fibre surface energy. Untreated Bamboo can be classified as cellulose with high surface energy. The plasma treatment must be lowering the fibre surface energy.

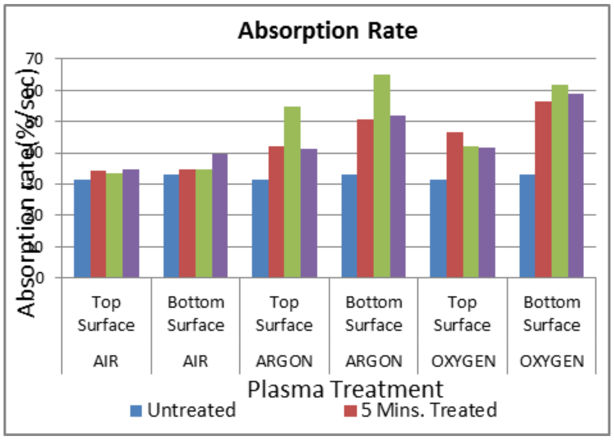

Figure 2: Absorption rate (sec) of Bamboo Fabric-Top and Bottom Surface

Figure 2 indicates the absorption rate of bamboo fabric on the top and bottom surface. The absorption rate is the average moisture ability (%/sec) of the top and bottom surfaces of the fabrics. The results indicate that although there is an increase in the rate of absorption as the duration of treatment increases from 5, 10, 20 minutes, the difference is not very significant. There is a significant change in the absorption rate in case of argon and oxygen gas plasma treated samples. Highest absorption rate of 54.65 (%/ sec) was recorded in case of 10 minutes argon gas plasma treated sample, while the sample treated for 5 minutes using oxygen gas plasma recorded 46.73 (%/ sec) .This is in agreement with the finding of Wong et al (9) who have studied the effect of oxygen plasma treatment on cotton .Formation of voids and cracks on fibre surface are the reasons for this phenomenon. Comparing the absorption rate of top and bottom surfaces of the plasma treated knitted fabric, there is higher absorption by bottom surface as compared to the top surface in all the treatments and time variations. The highest of 64.99 (% sec) was in case of 10 minutes argon plasma treated sample as compared to 33.20 (% sec) in case of the untreated sample. Similarly the highest value of 61.62(%/sec) is recorded in case of 10 minutes oxygen plasma treated sample and 59.09 in case of 20 minutes plasma treatment. The absorption rate of bottom surface indicates that the argon and oxygen plasma treatment and the duration of treatment have had significant effect. Maximum absorption rate values generally decrease due to more compact structure of yarns. The argon and oxygen plasma treatments may be altering the cover factor and making the fabric more open there by indicating an increase in absorption rate. These plasma treatments are altering only the surfaces and the impact is evident both on the top and bottom surfaces.

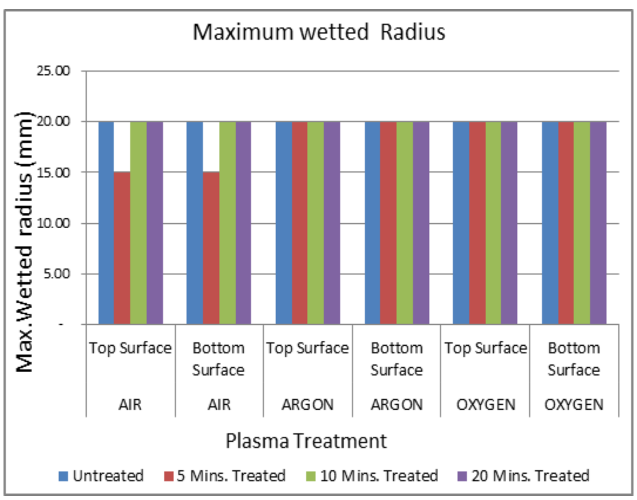

Figure 3: Maximum wetted radius (mm) values of the fabric-Top and bottom surface.

Figure 3 indicates that the maximum wetted radius did not reach the limit of 20 mm even after 120 seconds, possibly the water flow was restricted because possibly the water flow was restricted because of the atmospheric plasma treatment. This was observed both in case of the top and bottom surfaces of the 5 minutes plasma treated samples. This may be due to the surface distortion that could be hindering the spreading. Nevertheless, the spreading symmetry in form of a well-defined circle indicates that the knitted structure and the Plasma treatments is supporting uniform spreading of liquid. The main contributing factors to fabric being slow drying or quick drying are their water spreading area and the spreading speed on the outer surface. A slow drying fabric has a small spreading area and fast spreading speed on the outer fabric surface. It is clear that with the same amount of liquid being dropped onto the fabric's inner surface during testing time, if the liquid is spreading in a large area on the inner fabric surface with high spreading speed and then quickly transported to the outer surface, the liquid content on the inner fabric surface will be small and the liquid moisture will move more easily from the outer fabric surface into the environment thus, the fabric will dry faster.

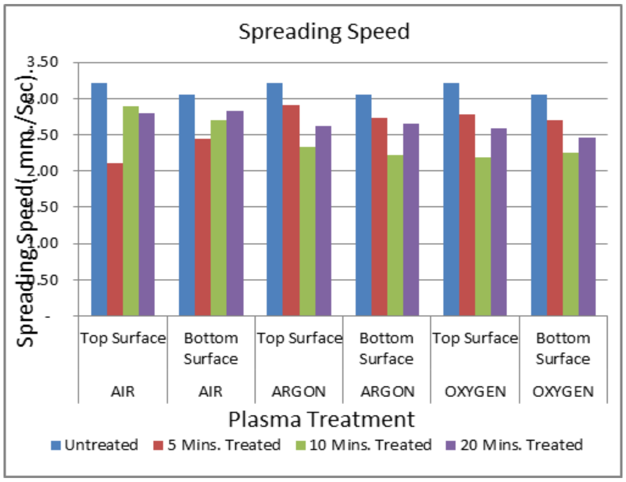

Figure 4**:** Spreading speed (mm/min) values of fabrics-Top and Bottom surface.

Spreading speed (mm/sec.) test results are given in figure 4. It is associated with the moisture transport, which occurs parallel to the fabric surface. As the spreading speed values are compared it can be seen that, all the three types of plasma treatment have reduced the spreading speed. The values of the spreading speed (mm/sec.) for the top and bottom surface for argon gas plasma treated sample were 2.91(mm/sec.) and 2.72 (mm/sec.) respectively. In case of oxygen gas plasma treated sample the spreading speed (mm/sec.) for the top and bottom surface was 2.78 (mm/sec.) and 2.69 (mm/sec.) respectively. These spreading speed values were recorded for 5 minutes duration in case of both argon and oxygen gas plasma treated samples.
Figures 1 and 4 show the wetting time and spreading speed of the untreated and plasma treated samples. Analyzing the combined effect of wetting time and spreading speed it can be stated that in the case of all the plasma treated samples the wetting time has increased and consequently spreading speed for the wetting of the fabric extended in case of the both the top and bottom surfaces . The advantage of this occurrence for the inner surface will be that the fabric will not feel clammy during excessive sweating as in case of athletic wear and that for the outer layer, it will act like a quick drying fabric since the perspiration would not have penetrated into the interstices of the fabric structure.

Figure 3 and 4 indicate the spreading area and the spreading speed. The main contributing factors to fabric being slow drying or quick drying are their water spreading area and the spreading speed on the outer surface. A slow drying fabric has a small spreading area and slow spreading speed on the outer fabric surface as in case of the 5 minutes air plasma treated samples. The spreading area in case of untreated and 5 minutes air plasma treated sample were 20 mm and 15 mm, while the spreading speed was 3.04 mm/sec and 2.44 mm/sec for the top and bottom surface respectively.

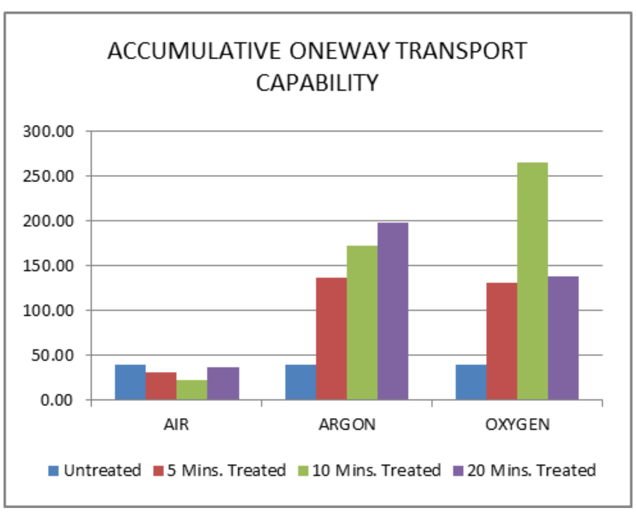

Figure 5: Accumulative one way transport capability

The accumulative one way transport capability index (AOWTI) that 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 is represented in figure 5. The results in case of all the argon and oxygen plasma treated samples indicate an improvement, while in case of the 5,10 and the 20 minutes air plasma treated sample recorded a decline in the accumulative one away transport capability index, as compared to the untreated pure bamboo sample(38.7). Within the 5, 10 and 20 minutes argon plasma treated sample the highest accumulative one way transport capability index (199) was in case of sample treated for 20 minutes duration, while the highest accumulative one way transport capability index (265), among all the plasma treated samples was recorded in case of 10 minutes oxygen gas plasma treated sample.

This is probably due to the difference in accumulative moisture content between the two surfaces of the fabric during the 120 second of testing time. This indicated that before the completion of the 120 second, at certain interval the moisture content of the top fabric surface is more that of the bottom surface and at other time interval the opposite is true. The significant difference AOWTI of the untreated and 5, 10 and minutes argon and oxygen gas plasma treated samples indicated that the top and the bottom surfaces in these cases have undergone uneven pattern of physical modification.

The AOWTI of the untreated pure bamboo was recorded as 38.7 while the 5, 10 and 20 minutes argon and oxygen gas plasma treated samples indicate significantly higher values (>120).The heterogeneity in the fabric surface characteristics due to the argon gas plasma treatments has facilitated the penetration of liquid intermittently. In case of argon gas plasma treated sample the duration of treatment has influenced the AOWTI value since the Pearson correlation of AOWTI and duration of treatment are linearly related (0.90). This indicates that the AOWTI is not influenced by the duration of treatment in case of the air and oxygen gas plasma treated samples.

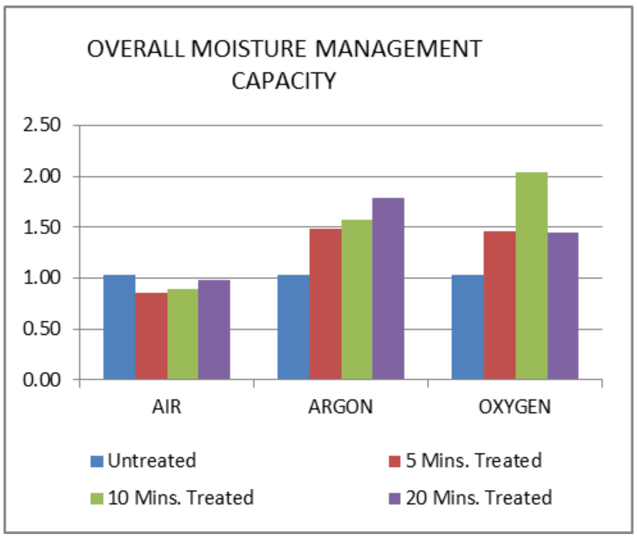

Figure 6: Overall moisture management capacity

The overall moisture management capacity (OMMC) of untreated and plasma treated samples is given in figure 6. The OMMC of the air plasma treated samples decreased in case of air plasma treated samples, while there was a remarkable difference between the untreated pure bamboo sample (1.03) and in case of argon as well as oxygen gas plasma treated samples. In case of argon gas plasma treated samples the OMMC increased as the duration increased. Among the argon gas plasma treated samples the highest OMMC (1.78) was in the case of 20 minutes duration. The highest OMMC (2.04) among all the plasma treated samples was recorded in the case of 10 minutes oxygen gas plasma treated sample. The higher OMMC indicated that when liquid sweat increases and accumulates in the fabric the OMMC value becomes more important and plays a very important role in making the wearer feel dry. This feature is essential in case of athletic wear since the sweat generation is gradual but excessive due to physical movement and exertion.

Pearson correlation between the duration of treatment and the moisture management properties are given in TABLE II. It can be seen that the duration of treatment and the absorption rate of the bottom surface are linearly related since the Pearson correlation are close to +1.The statistical analysis result revealed that the parameters of moisture management properties are significantly affected by the plasma generated by the feeder gas namely air, argon and oxygen gas plasma treatments and the duration of the treatments i.e. 5, 10 and 20 minutes. As the duration of treatment increases in case of air, argon and oxygen gas plasma the wetting time of the top surface and bottom surface increased. The maximum wetted radius of the top and bottom surface of 5 minutes atmospheric plasma decreased as compared to the untreated sample. The accumulative one way transport index and overall moisture management capacity decreased in case of air plasma treated samples as compared to the untreated pure bamboo sample. In case of argon and oxygen gas plasma the value of one way transport index and overall moisture management capacity increased , with the highest value recorded in case of 10 minutes oxygen gas plasma treated sample.

The type of plasma used and the duration of each of the treatments have played a vital role in the transmission of water through the knitted fabric. The characteristics that define the properties that have a bearing on surface characteristics viz. wetting time spreading speed etc. has altered by the various plasma treatments whereas the bulk properties involving both the top and bottom surfaces of the fabric namely accumulative one way transport index and overall moisture management capacity have improved by the argon and oxygen gas plasma treatments. The statistical analysis results indicate that there is a good correlation between the duration of treatment and the moisture management parameters such as wetting time of bottom surface of air plasma and oxygen gas plasma treated sample, absorption rate of bottom surface of oxygen gas plasma treated sample plasma treated sample. A very good correlation exists in the case of wetting time of top surface and absorption rate of bottom surface of air plasma treated bamboo fabric.

Based on the results obtained, it was found that 10 minutes oxygen gas plasma treatment is enough for the effective modification of pure bamboo fabric for improving the moisture management properties. The changes in morphology and formation of polar groups on the substrates surface, caused by plasma treatment are responsible for the improved property. The changes and improvement differs based on the type of plasma treatment given and the duration of treatment given to the hundred percent pure bamboo knitted fabric. Of all the types of plasma treatment applied to bamboo fabric, oxygen plasma treatment offered the best result, due to the formation of void and reduction in fibre diameter as compared with other types of plasma treatments.

Table 2: Cumulative coefficient of the time of treatment

TEST PARAMETERS:	AIR		ARGON		OXYGEN	
Dependent-independent variable	Pearson correlation coefficient (r)	p-value	Pearson correlation coefficient (r)	p-value	Pearson correlation coefficient (r)	p-value
Duration of Treatment-wetting time_ top surface	0.843	0.009	0.243	0.562	0.48	0.228
Duration of Treatment- wetting time_ Bottom Surface	0.805	0.016	0.205	0.626	0.678	0.065
Duration of Treatment- Absorption rate_ top Surface	0.726	0.042	0.411	0.312	0.43	0.288
Duration of Treatment-Absorption rate_ Bottom Surface	0.950	0.000	0.565	0.144	0.713	0.047
Duration of Treatment- Spreading speed_ top Surface	0.131	0.758	0.581	0.131	0.522	0.185
Duration of Treatment-Spreading speed_ Bottom Surface	0.069	0.871	0.082	0.847	0.678	0.065
Duration of Treatment-Accumulative one way transport capability	0.129	0.760	0.891	0.003	0.439	0.277
Duration of Treatment-Overall moisture management capacity	0.031	0.942	0.911	0.002	0.403	0.322

IV. CONCLUSION

The moisture management tester has provided a comprehensive summary of all the water absorption and spreading ability simultaneously for the surface towards the skin and the outer surface of the garment. In case of the argon gas plasma treated fabrics the AOWTI increases linearly as the duration of treatment increases from five to twenty minutes. The plasma treated bamboo fabrics can be effectively used for sport wear and infant layettes to prevent these garments getting clammy and exhibit quick drying properties. Oxygen plasma treatment offered the best result, due to the formation of void and reduction in fibre diameter as compared with other types of plasma treatments. It is found that the argon and oxygen gas plasma modification alters the surface morphology, give rise to moisture management fabrics. Air, argon and oxygen gas plasma treatment on pure regenerated bamboo knitted fabrics can provide a solution to producing product specific fabrics. Further, the plasma process can be easily amalgamated with the present day industrial set up.

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