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Effect of Oxygen Plasma Treatment on Wicking behavior of Bamboo Nonwoven Fabric

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ABSTRACT

In this paper, the effect of glow discharge oxygen plasma on the hydrophilic properties of pure bamboo spunlaced nonwoven fabric has been investigated. The influence of various plasma process parameters such as discharge power, exposure duration and inter-electrode spacing on the hydrophilic properties of pure bamboo nonwoven was investigated by conducting vertical wicking test. Oxygen plasma being a highly reactive etchant, better plasma penetration has been achieved due to the open porous structure of bamboo spunlaced nonwoven resulting in improved hydrophilic properties.

Keywords : Bamboo nonwoven, Glow discharge, Oxygen plasma, Plasma process parameters, Wicking

I. INTRODUCTION

Surface modifications using plasma treatment have been studied widely for textile and polymers as it is a dry environment friendly and worker friendly method to achieve surface alteration without modifying the bulk properties of materials[1,2]. Thermodynamic non-equilibrium physical processes such as gas plasma presents more ecologically acceptable alternative to chemical processes[3]. Plasma contains the mixture of reactive species like free radicals, electrons and heavy particles which makes it an ideal media for surface modification. It is often termed as the fourth state of matter. Gas plasma (Glow discharge) is a partially ionized gas which is generated by an electrical discharge. The type of gas (etchant) is the most important discharge parameter. Oxygen plasmas are known to be very reactive etchants[4].

Glow discharge plasma is created when an increased voltage is applied to two electrodes which are specially separated in a container with reduced pressure. The electrons created in the glow discharge penetrate the fibre surface well and alters it more intensively[5]. Glow discharge plasma assures the highest possible uniformity and flexibility of all plasma treatments[6]. As a general rule, the fabric becomes more hydrophilic with oxygen plasma treatment due to surface functionalization with polar functional groups. The wettability of fabric surface is enhanced by oxidation and etching[7]. Introducing oxygen elements onto the fibre surface in the form of –OH, C=O and –COOH increases hydrophilicity[8]. Surface modification of plasma treated textiles is dependent on various process parameters like discharge power, inter-electrode spacing, exposure time, nature of gas used and nature of the substrate[9].

Bamboo, a natural cellulosic material being soft, comfortable and eco friendly has a wide range of medical textile applications[10]. Textile materials being porous with high specific area, open and porous structure of nonwoven fabric enables better plasma penetration. Nonwoven sample consists of a great number of fibres arranged together in a disordered manner forming spacing between the fibres. The looser structured nonwoven material aids in improved hydrophilicity of plasma treated sample[11]. Therefore pure bamboo spunlaced nonwoven fabric has been chosen for the study.

Plasma treatments enhance wickabilty and therefore it is important to quantify the changes in the wickability of plasma treated materials. It is difficult to measure contact angle, especially when a textile material is absorbent and have irregular structure with high porosity. In such cases, wicking behavior of textiles provide information about the wetting properties of textiles. In the case of fibrous material such as nonwoven structure, the fibre surface properties and pore structure of the material are the main determinants of wicking properties. Vertical wicking test has been used as a principle method to study the wicking behavior of textiles[4]. Experimental methods based on capillary rise are widely used for characterization of porous materials[12].

The study reported in this paper has been carried out to improve the hydrophilic properties of pure bamboo spunlaced nonwoven fabric by using glow discharge oxygen plasma. The influence of process parameters in plasma treatment viz. discharge power, duration of treatment and inter-electrode spacing on the hydrophilic properties has been studied. Wettability of treated samples is compared by wicking height measurements.

II. METHODS AND MATERIAL

A. Materials

Pure bamboo spunlaced nonwoven fabric purchased from South Indian Textile Research Association (SITRA), Coimbatore was used for the study. The surface mass of the fabric was 111.6 g/sq.m (ISO 9073-1) and thickness was 0.6 mm (ASTM D 1777).

B. Plasma Treatment

The bamboo spunlaced nonwoven fabric was subject to glow discharge oxygen plasma using High Voltage Pulse Transformer (HVPT) vaccum plasma system. It consists of two stainless steel plates each 20cmx20cm, the lower plate being covered by a plate of 1mm thickness. The sample was placed in a regular pyrex enclosure into which the working gas was introduced to pass through the gap between the electrodes. The exhaust gas was carried via plastic tubing to the fuming cupboard. The electrodes were connected to the power supply. The chamber is evacuated by a diffusion stack pump Model – OD114D and backed by a 250 LPM double storage rotary vaccum pump. For the study, the fabric sample of size 20x20 cm was placed between the electrodes and oxygen gas was admitted into the plasma chamber and Radio Frequency glow discharge was generated at 3.5 mbar pressure. The fabric samples were passed through the plasma zone at different discharge conditions.

The process parameters considered for the study namely the RF discharge power (450W to 650W), duration of exposure (40 seconds to 80 seconds) and inter-electrode spacing (4.5 cm to 5.5cm) are listed in the Table 1.

Table 1: Process parameters used for plasma treatment of bamboo nonwoven fabric

Parameter	Levels		
Inter-electrode spacing (cm)	4.5	5.0	5.5
Discharge power (Watt)	450	550	650
Duration of exposure (sec)	40	60	80

C. Study of wicking behavior by capillary rise method

The wicking ability of the treated and untreated samples were tested as per the standard (ISO 9073-6) in both machine direction and cross direction of the fabric. The plasma treated samples were conditioned at 65% RH and 27^0C temperature prior to testing. The height of capillary rise of liquid in mm was measured for 60 seconds with a time interval of 10 seconds due to the highly porous and absorptive nature of the spunlaced bamboo nonwoven. To study the effect of an individual plasma process parameter, the remaining parameters were kept constant.

III. RESULTS AND DISCUSSION

A. Effect of inter-electrode spacing on wicking

The samples were exposed to oxygen plasma treatment by varying the inter-electrode spacing inside the plasma chamber. The effect of variations in inter-electrode spacing was brought about by varying three different settings 4.5cm, 5.0 cm, 5.5 cm during which the plasma discharge power and plasma exposure duration was kept constant at three different levels. The effect of inter-electrode spacing on wicking behavior was analyzed for all the 27 samples in both machine direction and cross direction.

In Figure 1a & 1b, the effect of variations in inter-electrode spacing was observed in both machine direction and cross direction by keeping the discharge power at 650W and plasma exposure duration at 80 seconds. The wicking height of the untreated sample after 60 seconds was recorded as 61 mm in machine direction and 57 mm in cross direction. In the plasma treated sample, the values of capillary height after 60 seconds in machine direction obtained for inter-electrode spacing at 4.5cm, 5.0 cm, 5.5 cm were recorded as 87mm, 83mm, 79mm respectively and in cross direction it was found to be 82mm, 77mm, 73mm respectively. It is evident from the above observation that, the height of capillary rise increased with decrease in inter-electrode spacing [9,13].

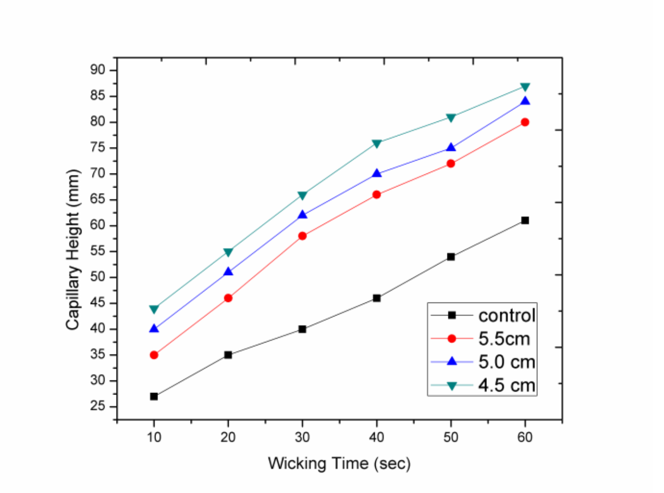

Fig.1a: Effect of inter-electrode spacing on capillary height in machine direction

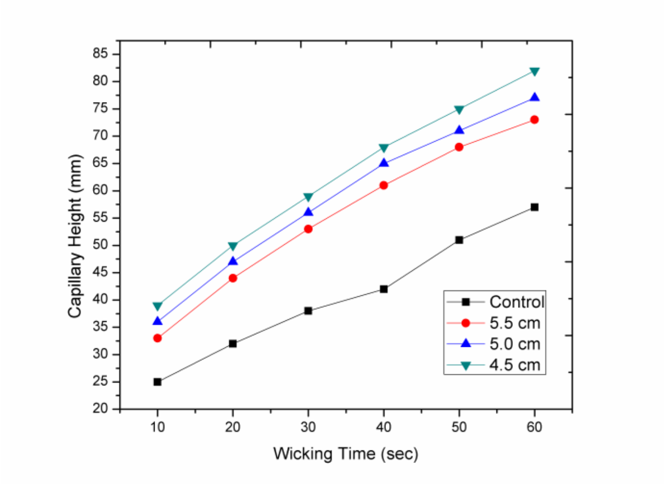

Fig. 1b: Effect of inter-electrode spacing on capillary height in cross direction

B. Effect of plasma discharge power on wicking

Experiments were conducted by varying the discharge power (450W, 550W, 650W) during which for each experiment, the plasma exposure duration was fixed at three levels (40sec,60sec,80sec) and inter-electrode spacing was fixed at three levels (4.5cm,5.0cm, 5.5cm) and the wicking behavior was observed for all the 27 samples in both machine direction and in cross direction. The height of the capillary rise was observed up to 60 seconds with a time interval of 10 seconds due to the highly absorptive nature of porous nonwoven fabric. The value of the capillary height recorded for predetermined time was plotted against the wicking time.

Figure 2a and 2b represents the changes in wicking height of samples treated with oxygen plasma under different discharge powers at duration exposure of 80 seconds and at inter-electrode spacing of 4.5 cm in machine direction and cross direction respectively. It was seen that all the plasma treated samples showed higher wicking heights when compared to the untreated sample. The wicking height of the untreated sample after 60 seconds was recorded as 61 mm in machine direction and 57 mm in cross direction. After the plasma treatment, the values of capillary height obtained for discharge powers 450W, 550W and 650W were recorded as 79mm, 83mm and 87mm in machine direction and 76mm, 80mm and 83mm in cross direction respectively. It is observed that, at any point of wicking time, when the discharge power was increased from 450W to 650W, the wicking height increased gradually. This indicates that the increase in discharge power has a profound impact on the wicking behavior of the fabrics thereby improving the hydrophilic property of the fabric[14].

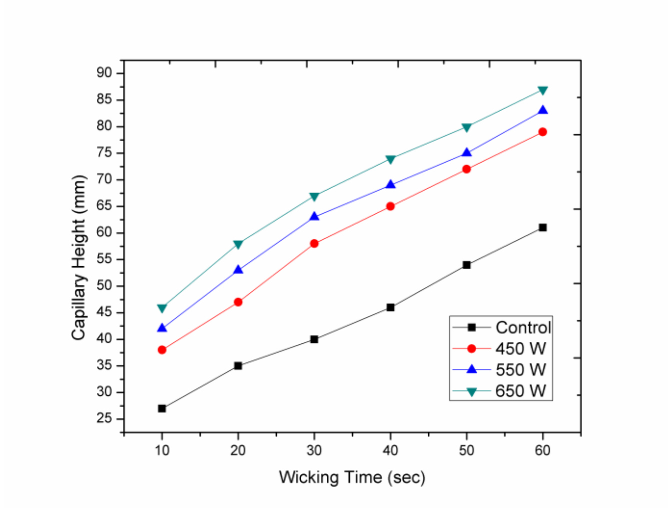

Fig. 2a: Effect of discharge power on capillary height in machine direction

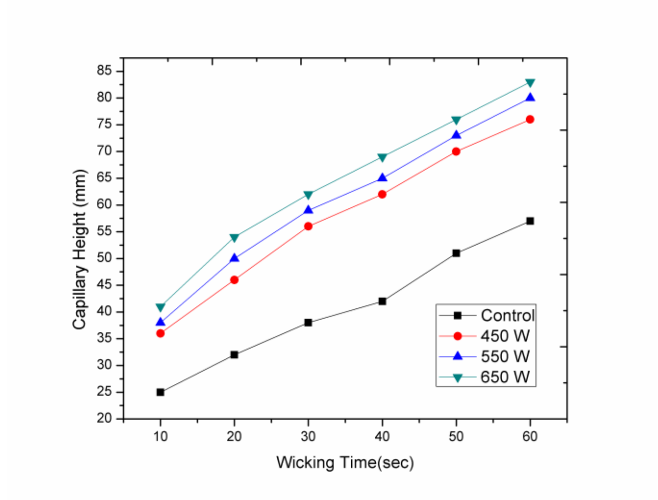

Fig. 2b: Effect of discharge power on capillary height in cross direction

C. Effect of duration of exposure of plasma treatment on wicking

The effect of different exposure durations at 40 seconds, 60 seconds and 80 seconds were observed by keeping the discharge power and inter-electrode spacing constant at three different levels. The wicking behavior of all the 27 samples was analysed both in machine direction and cross direction. The Figure 3a & 3b shows the effect of variations in plasma exposure duration in machine direction and cross direction in which the discharge power was kept constant at 650W and the inter-electrode spacing was kept constant at 4.5 cm.

The wicking height of the untreated sample after 60 seconds was observed as 61 mm in machine direction and 57 mm in cross direction. After subjecting to oxygen plasma treatment, the values of capillary rise at 40 seconds, 60 seconds and 80 seconds were recorded as 81mm, 86mm and 89mm in machine direction and 74mm,80mm and 85mm in cross direction respectively. Similar trend was observed in all other samples. It is observed that, the increase in exposure of plasma duration resulted in improved wicking behavior of the samples. The increase in the efficiency of plasma treatment with increase in exposure time is already reported by many other researchers[15,16].

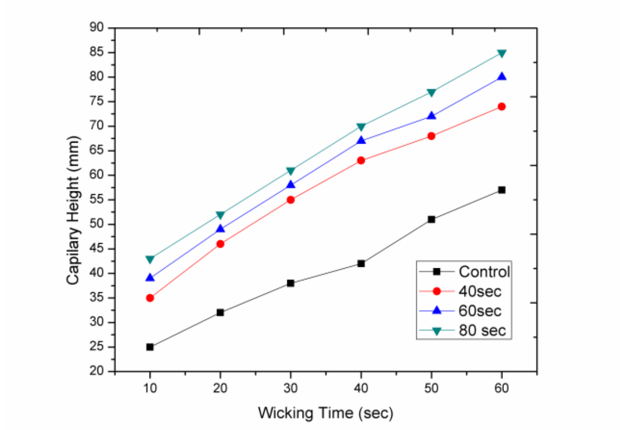

Fig. 3a: Effect of exposure duration on capillary height in machine direction

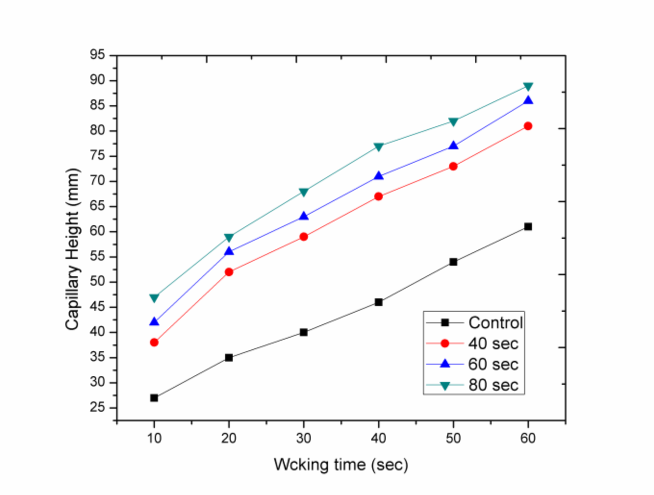

Fig. 3b: Effect of exposure duration on capillary height in cross direction

IV. CONCLUSION

Glow discharge plasma using oxygen gas has enhanced the hydrophilic properties of pure bamboo spunlaced nonwoven fabric. Improved hydrophilicity has been obtained for samples treated at higher discharge power, longer treatment duration and at minimum inter-electrode spacing which was revealed through wicking behavior study. With respect to the above study, maximum wickability was achieved at a discharge power of 650W, exposure duration of 80 seconds and at inter-electrode spacing of 4.5 cm. Bamboo spunlaced nonwoven fabric treated with glow discharge oxygen plasma presents promising future in the area of medical textile applications.

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