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Effect of atmospheric pressure air plasma treatment on desizing and wettability of cotton fabrics

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Atmospheric pressure air plasma has been used to treat grey cotton fabrics and the effect of treatment on their desizing and wettability properties is studied using the dielectric barrier discharge plasma with air and helium gas mixture. The weight loss due to etching has been determined by gravimetric method, the surface structure observed by SEM, the wettability studied by wicking action and the angle of contact test using water. It is observed that the rate of desizing increases when the fabric is pre-treated with plasma. This phenomenon of surface etching and chemical modifications can be used advantageously for industrial processing.

Keywords: Air plasma, Cotton fabrics, Desizing, Plasma treatment, Wettability

1 Introduction

Recent development in the plasma treatment of textile materials has revealed that it has an enormous potential as an alternate technology for the textile processing in terms of cost saving, water saving and ecofriendliness [1,2]. Although wet processing is a well-established method in textile industries to carry out desizing, bleaching, dyeing/printing and finishing, it must be remembered that it needs water as the processing medium. As pure water is becoming scarce and expensive, electrical/fuel energy is unavailable at times, and environmental pollution and global warming becoming the major issues, it is necessary to look out for "green processes". Plasma technology offers such advantages as it is a dry process, is energy efficient, needs minimum chemicals and causes no down-stream pollution.

The main aspect of plasma is that it is a partially ionized gas, containing ions, electrons, neutral species and UV radiations. It thus has a capability to modify the surface by ion etching, activating charged species and polymerizing the gas which can deposit or graft with fabrics. There exists a capability to modify surface, using different approaches, in terms of appearance, texture, aesthetic appearance and functional performance.

It has been shown that plasma treatment can cause both chemical and physical changes on the fibre surface to improve the properties such as wettability, water repellency, soiling, printing, dyeing and finishing without affecting the bulk properties[3-7].

The effect of plasma treatment on fabric dyeing is very significant for wool fabrics [8] and to some extent for cotton and polyester [9,10]. The earlier studies were mostly carried out by using low pressure plasmas and were batch processes. Recently, it has been realized that atmospheric pressure plasma can be of use when we need to have a continuous process so that it becomes fast and economical. Recent review articles [11,12] have made it very clear that plasma power should be recognized as the technology of future.

Sizing and desizing are important processes in textile manufacturing. Size materials have to be removed before the dyeing and finishing operations. Desizing studies using atmospheric plasma process have been reported[13,14].

The present paper reports the findings of the study on the surface modifications of cotton fabrics using atmospheric air plasma. It is observed that the sizing material can be easily removed with plasma pre-treatment. The changes observed in wetting phenomenon and wicking action are also discussed.

2 Materials and Methods

2.1 Materials

Cotton fabric (mill sized) supplied by Alok Industries, Mumbai, of the specifications warp count 50 Ne and weft count 60 Ne, was used. It was sized

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by the standard sizing recipe containing starch. The mill sized sample (as obtained) was used as grey sample (control)

2.2 Plasma Processing

The plasma treatment was carried out on an atmospheric pressure plasma equipment of GRINP make, Italy. A schematic diagram of the plasma machine is shown in Fig.1. It is based on dielectric barrier discharge principle.

The air plasma zone was created by applying 8 kV supply operating at 50 hertz. The assembly consists of four stainless steel rods of length 50 cm mounted in the upper part. These rods were suitably coated with dielectric material, and separated from each other, in the horizontal direction, by about 3 cm so that the total width of the plasma zone was about 12 cm. Similar four electrodes were mounted in the lower part , facing the upper electrodes, so that the discharge could be produced in these pairs of electrodes. The distance between the electrodes could be varied from 1 mm to 8 mm. In the present study, it was kept constant at 2 mm. The residence time in the plasma zone could be varied by changing the speed of the take-up rollers. In the present work the residence time was adjusted at 2 s. The amount of desizing caused during the plasma processing was determined by gravimetric method.

2.3 Wicking Measurement

Wicking action was measured by standard test method BS 3432. At least three pieces of control and plasma treated fabrics of size 15 cm × 2 cm were tested and the average value was taken. The fabric was mounted with length in the vertical direction and the time to rise the liquid up to a specific height was measured at different times.

2.4 Contact Angle

The angle of contact was determined by the sessile drop method. A drop of distilled water of size one microlitre was placed on the fabric using a micro-syringe from the distance of 2 mm. In the present study, the photographs were also obtained with digital camera within 3 s after placing the drop. A typical image captured by the camera is shown in Fig.2. The angle of contact was then determined by drawing a tangent at the point of contact with the fabric surface. In addition, the height h and radius r of the spherical segment were measured and the angle was calculated by the following equation:

$$\text{Contact angle } (\theta) = \text{Sin}^{-1}(2rh/ r^2 + h^2)$$

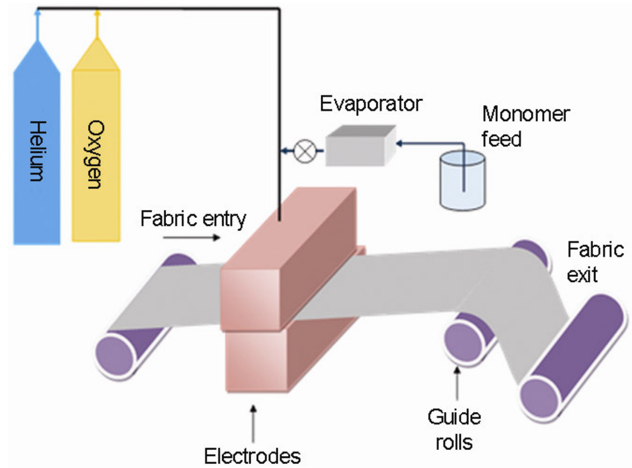

Fig.1—A schematic view of atmospheric pressure plasma machine

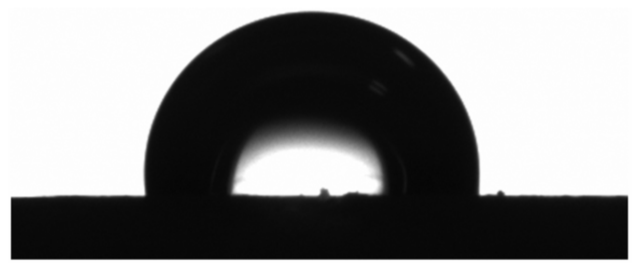

Fig.2—A photograph of a typical water drop on the surface of fabric

An average of five readings was taken to reduce the error of measurement. The experimental error was found to be ± 1°. A schematic diagram explaining the principle of sessile drop method and the related calculations is given in Fig.3.

2.5 SEM Studies

The surface morphology of treated fabrics was established by using scanning electron microscope (JEOL, SEM-5400) . The fabric samples were coated with gold to dissipate the static charges occurring due to electron bombardment. Photographs were obtained at different magnifications (×500 – 5000).

2.6 Desizing

The following recipes were used for carrying out the conventional desizing and scouring of the fabrics:

Enzymatic desizing

Alpha-amylase	: 5 gpL
Sodium chloride	: 10 gpL
Temperature	: 70 °C ± 2 °C
Time	: 5 - 60 min

Scouring

Sodium hydroxide	: 4 gpL
Non-ionic wetting agent	: 1 gpL

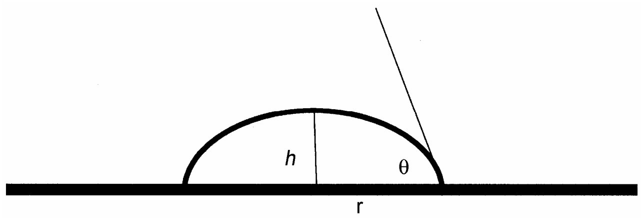

Fig. 3—Sessile drop method for the calculation of contact angle

3 Results and Discussion

3.1 Weight Loss due to Etching

One of the important aspects of plasma processing is that the electron and ion bombardment on the sample gives rise to etching phenomenon. It occurs by direct removal of a very thin layer as well as by the indirect method of interaction of ions with the molecules of the material. Polymers and fabrics being the soft materials, direct removal of material is important. The sizing material applied on the surface of the yarn consists of low molecular weight compounds having starch or polyvinyl alcohol. Our earlier studies[15,16] of the etching phenomenon has revealed that in case of films of polyethylene, polyester and cellophane the weight loss due to etching is in the range of 1 – 3%, depending on the conditions of treatment. The studies[17] on polyester fabric also gave similar results with the indication that it could rise upto 5% in some cases.

However, the results of present study show that the weight loss is 1.12% which is rather low. This is probably due to the fact that the residence time is very short as compared to our earlier work. Secondly, the tight weave of the fabric is not allowing the inner surface of the fabric to be exposed evenly to the plasma.

3.2 Surface Morphology

The above results of etching can further be supported by the surface observation using SEM. It can be seen from Fig.4 that the surface morphology changes due to plasma treatment. Now, it looks as damaged or abraded. This is due to the removal of some material by etching.

However, hitting of ions can give rise to loosening of the surface, which may not result in the direct removal. It can lead to easy removal of the loosened material in the subsequent process of washing. In order to check the possibilities of loosened structures and how it may aid in the subsequent process of desizing, the phenomenon was studied systematically.

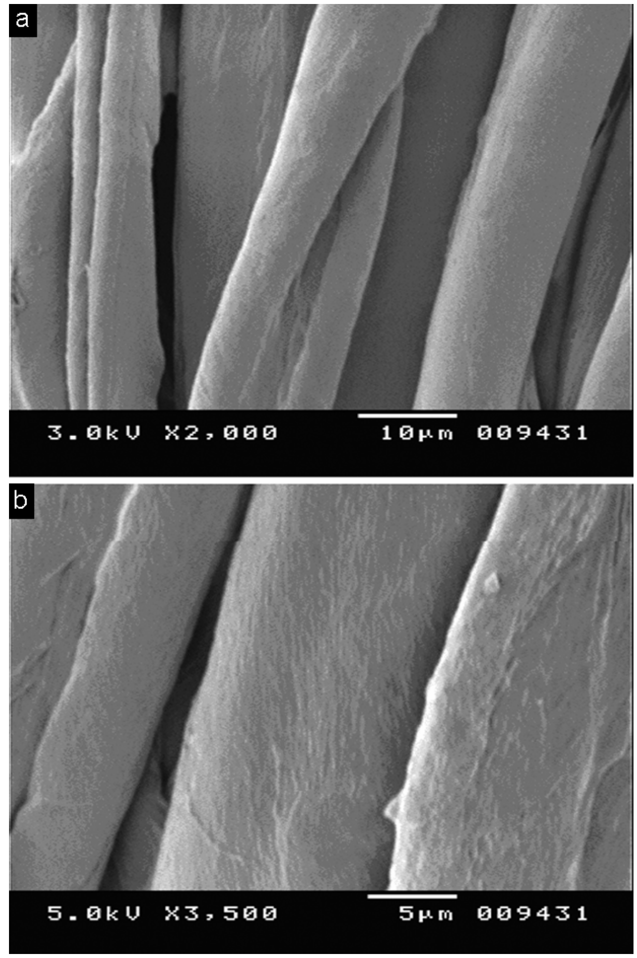

Fig.4—Surface morphology of cotton fabric [(a) control, and (b) treated with plasma]

3.3 Contact Angle

When fabric is exposed to plasma, various chemical interactions are also possible. These interactions break the bonds of the molecules and secondary reactions occur. In the present study, air was used as the gas to sustain the plasma. Thus, oxygen and nitrogen from air can interact with the starch and cellulose. This can lead to the formation of -C = O, -OH or C – N bonds which causes the newer reactions to occur in the subsequent treatment of washing and scouring. The hydrophilic groups thus created can help in the subsequent treatments. The amount of hydrophilicity developed was tested by the methods of contact angle and wicking action.

The results for the contact angle measurements of the plasma-treated and untreated cotton samples reveal some interesting features. The angles were measured with the pure distilled water as well as with desizing bath solution. It has been found that the contact angle decreases considerably with plasma treatment for pure water from 64° to 21°. The angles are found to decrease further when the desizing solution is used, the values being 60° for untreated and 19° for the plasma-treated fabrics. Thus, it shows that functional groups created on the surface of cotton fibres are responsible for the enhanced hydrophilic properties.

3.4 Wickability

The wickability of cotton fabrics treated with plasma increases dramatically in both pure water as well as in scouring solution. Figure 5 shows the relative time to achieve a certain height for the water to rise. Even while using pure water, it reaches a height of 100 mm in 10 min for plasma-treated fabric, whereas it reaches a height of only 50 mm in 10 min for control sample. Similarly, in the scouring solution also it reaches a height of 10 mm in 5 min for the control fabric, whereas it reaches a height of more than 120 mm for the plasma-treated fabric.

Thus, the increased wettability and wickability of fabrics is due to the enhancement in the surface roughness properties and introduction of polar groups due to the air plasma.

3.5 Desizing Studies

Weight loss observed immediately after the plasma treatment is rather low, indicating that the direct desized amount is small. However, it is of interest to observe how it helps in the subsequent processes. Usually, desizing by conventional wet process is an important first step. Therefore, the control as well as the plasma-treated fabrics were subjected to desizing process using the recipe given in the experimental section. Conventionally, the complete removal of the size material needs about 6 - 10 h at room temperature depending on temperature, type of enzyme, concentration, *p*H and the thermal deactivation rate of the enzyme. When it has been carried out for both the samples at 70 °C, the weight loss is found to be more or less the same (12.5%). Thus, it seems that this is the maximum or the equilibrium loss. In order to assess the effectiveness of plasma, desizing was carried out for the short duration. Figure 6 shows the loss of weight versus time of desizing treatment for both the fabrics. It can be seen that the loss of weight in the desizing process is always more for the plasma pre-treated fabric. Further the rate of loss is quite high for the plasma- treated samples in the initial period of 15 min of the desizing treatment. Thus, it is concluded

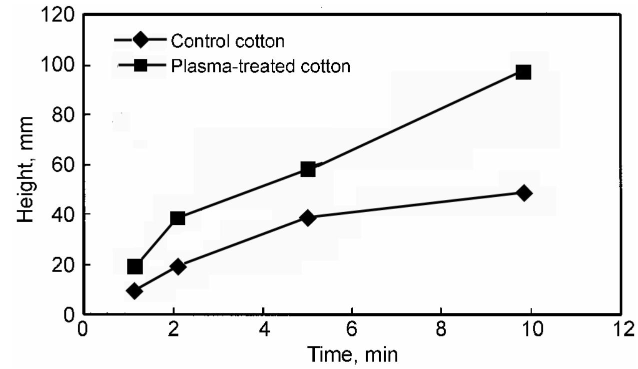

Fig. 5—Wicking action of control and plasma-treated fabrics in pure water

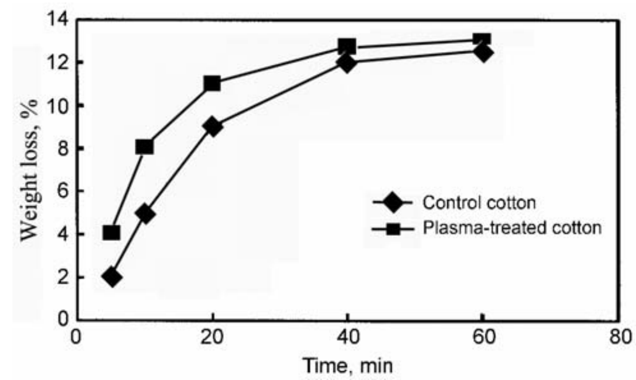

Fig. 6—Weight loss during desizing of control and plasma-treated cotton fabrics

that plasma treatment helps considerably in the desizing process.

4 Conclusion

It is found that the plasma modification alters the surface morphology, gives rise to desizing effect and enhances the wettability and wicking action. The higher rates of desizing for the plasma pre-treated fabrics can save the time, energy and water. The plasma process being dry is ecofriendly, has instant on/off operation and can be easily amalgamated with the present industrial set-up.

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