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Plasma utilization for treating wool/polyester blended fabric to improve its printability

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A wool /polyester blended fabric (45/55) has been printed using two different dye mixtures. The substrate is exposed to low temperature plasma treatment prior to printing and then the prints are steamed and washed off. The changes induced in wettability, tensile strength and colour strength of treated samples are studied. The surface morphology of treated fabric is investigated using scanning electron microscopy. The experimental results indicate that the wettability and colour strength of treated fabrics are enhanced. Moreover, changes in surface morphology of treated samples are also observed.

Keywords: Dielectric barrier discharges, Fastness properties, Low temperature plasma, Printing, Surface modification, Tensile strength, Wool/polyester blend

1 Introduction

Blended fabrics of wool and polyester fibres are usually dyed with dyestuff mixtures having acid or metal complex dyes for the wool and the conventional disperse dyes for the polyester, i.e. considering two classes of dyes which are poorly compatible. To obtain a homogeneous shade on both substrates, it is necessary to use complicated dyestuff mixtures even for simple shades, since a disperse dye alone never has the exact shade of a specific wool dye. In addition, dyestuff mixtures can only be adjusted to a very specific mixture ratio of polyester/wool. If this ratio changes, differences in the depth of shade on both substrates result[1].

Over the past three decades, low temperature plasma (LTP) technology has been the focus of much research for improving the surface properties of polymeric materials without changing the bulk properties[2]. Plasma technology is suitable to modify the chemical structure as well as the topography of the surface of the material. Plasma surface modification does not require the use of water and chemicals, resulting in a more economical and ecological process[3]. The enormous advantage of plasma is the drastic reduction in pollutants and a corresponding cost reduction for effluent treatments, so it can be considered as an environmentally benign technology[4]. In recent years, the utilization of dielectric barrier discharges (DBDs) has received much attention on account of numerous industrial applications. Dielectric barrier discharge has been known for more than a century[5-8]. The DBD device consists of two metal electrodes, at least one of them should be covered with dielectric material, when an AC high voltage is applied on the electrodes. The dielectric is the key for the proper functioning of the discharge. It limits the charge transported in the discharge, i.e. limits the current flow to the system, and distributes the discharge almost uniformly over the entire electrode area. Therefore, the DBD is highly transient, non-thermal discharge form, which exists in broad pressure ranges.

In the present study, wool/polyester blended fabrics are treated with DBD prior to the printing process at different current and exposure time. According to economical and ecological demands, plasma is used as a clean technology and an alternative to wet chemical fabric treatment and pretreatment to modify the fabric. It acquires new surface properties and improves the printability of fabric. The fabrics are printed with two different dye mixtures and only urea is incorporated in the printing paste. Various parameters and measurements involving the evaluation of surface characteristics and printing properties of the prints are investigated in detail.

2 Materials and Methods

2.1 Materials

A wool/polyester 45/55 blended fabric of the weight 154 g/m^2 was used. The following dyestuffs are selected and for the study: Realan Blue B/33 (a reactive vinyl sulphone dye) and Supralan Blue

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GLW (an acid milling dye). They were mixed separately with the Dianix Class Orange S-2R dye (an anthraquinone disperse dye) according to the blending ratio of the substrate. The thickening agent used throughout this work is Monaprint P-MV which is a depolymerised galactomannan (guar).

2.2 Procedure

2.2.1 Plasma Treatment

The wool/polyester blended fabric was exposed to atmospheric air plasma generated using dielectric barrier discharge (DBD) technique of batch type. The experimental arrangement of DBD used in textile treatment is shown in Fig. 1.

The DBD cell consists of two electrodes of stainless steel disc, having a diameter of 25.5 cm and a thickness of 2 mm. The lower electrode is fixed to a Perspex base of 30 cm diameter and 2 cm thickness and connected to earth. The upper electrode is fixed to a Perspex disc of 30 cm diameter and 1 cm thickness and is connected to high voltage (H.V.) AC power supply of 50 Hz frequency and a variable voltage of 0-20 kV via a load resistance (R). A dielectric material of glass having a thickness of 1.7 mm is fasted to the upper electrode. The upper and lower Perspex discs are connected to each other via O-ring. The gap distance (d) between dielectric glass and the lower electrode is 3 mm. DBD treatment occurs completely in the atmospheric pressure of air[6, 7].

2.2.2 Printing Technique

The untreated and treated wool/polyester blended fabrics were printed using conventional silk screen printing technique. After air drying the samples were steamed at 103° C for 20 min, then washed off at 60 °C for 10 min.

2.3 Measurements and Analysis

Colour Strength

The colour strength (***K/S***) of the printed specimens was evaluated by a light reflectance technique at maximum. The

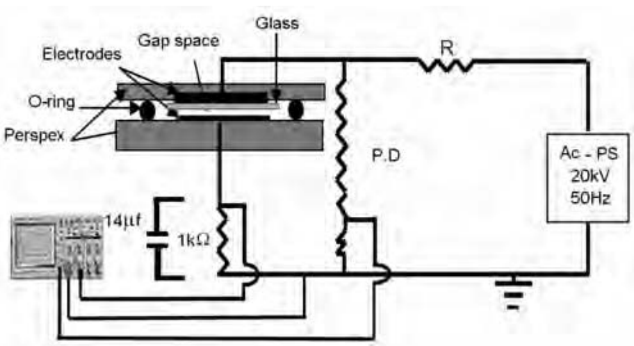

Fig. 1—Schematic setup of DBD technique

spectrophotometer of the model ICS-Texicon Ltd., England was used.

Tensile Mechanical Testing

Tensile strength measurement was carried out using a textile tensile strength tester No. 6202, 1987, type Asano Machine MFG Japan.

Wettability

The wettability was evaluated by measuring the wetting time according to the AATCC standard test method no. 39 (1971). A drop of water was allowed to fall from a fixed height onto the surface of wool/polyester blend. The time taken for the water drop to disappear was measured and expressed as the wetting time.

Morphological Study

The surface morphology of the untreated and plasma-treated samples was investigated by a scanning electron microscope (SEM) Philips XL 30 attached with EDX unit; with accelerating voltage of 30 kV, magnifications range of ×1500-2000 and a resolution of 200 A. Before examinations, the fabric surface was prepared on an appropriate disk and coated randomly by a spray of gold.

Fastness Properties

Fastness properties of wool/polyester printed samples to rubbing, washing, perspiration and light were assessed according to standard methods (Society of Dyers & Colorists 1997).

3 Results and Discussion

3.1 Effect of Printing Paste *p*H on *K/S* Values

The ***p***H control has received a considerable attention in dyeing and printing processes because of its critical role in quality assurance[8]. To print the wool/polyester blended substrate, two dye mixtures are used. It is found that the best ***p***H values for printing reactive dyes on wool is from 5 to 6, while it ranges from 5 to 7 for acid milling dyes also, ***p***H 6 is preferred on printing polyester with disperse dyes. Different printing paste ***p***H values are used to investigate the influence of ***p***H on the colour yield of wool/polyester blended fabric and the ***K/S*** results are plotted in Fig. 2.

It is clearly noticed from the figure that the best ***K/S*** values of the prints may be obtained at ***p***H 5, as it gives relatively the highest ***K/S*** on printing the wool/polyester blended fabric using both Realan /

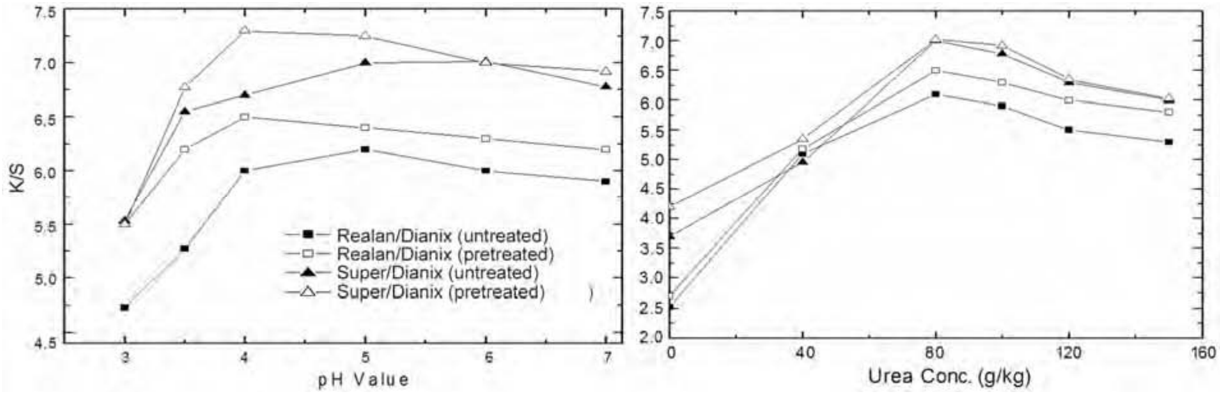

Fig. 2—Effect of printing paste ***p***H and urea concentration on ***K*/*S*** values of the prints using two dye mixtures

Dianix and Supralan / Dianix dye mixtures. Despite that, ***p***H 7 is chosen to be used in rest of the study, although using a stronger acidic medium may have enhanced the ***K*/*S*** results. Application of a neutral medium in printing is preferred to give plasma the opportunity to enhance dye fixation, as will be investigated afterwards.

3.2 Effect of Urea Concentration on *K*/*S* Values

The action of urea in printing wool fabrics may depend on the nature of both the substrate and the dye used. Urea enhances the solubility of dyes in the printing paste due to its salvation and disaggregating action on dye molecules[9]. This action varies from one dye to another according to its ability to dissolve in the printing paste. Therefore, the hydrophobic / hydrophilic balance of the dye molecule will determine its ability to dissolve under the action of urea. Hydrophobic dyes such as disperse dyes are not affected by urea addition, as it is shown by the hydrophilic dyes. Thus, increasing the hydrophobic character of the used acid or disperse dye may diminish the solvolysis effect of urea and reduces its role in the printing paste.

It is well noticed from Fig. 2 that the best ***K*/*S*** results are obtained on adding urea to the printing pastes by a concentration of 80 g/kg for the wool/polyester blend printed with Realan/Dianix and Supralan/Dianix dye mixtures for both the untreated and pretreated samples with air plasma. For the blend printed with Realan/Dianix mixture, adding 80 g/kg urea to the printing paste increases ***K*/*S*** by 142% and 140% for the untreated and plasma-treated fabrics respectively, while ***K*/*S*** increases by 89% and 67% for the untreated and plasma-treated samples respectively printed with the Supralan/Dianix dye mixture, all compared to the samples printed without adding urea to the printing pastes.

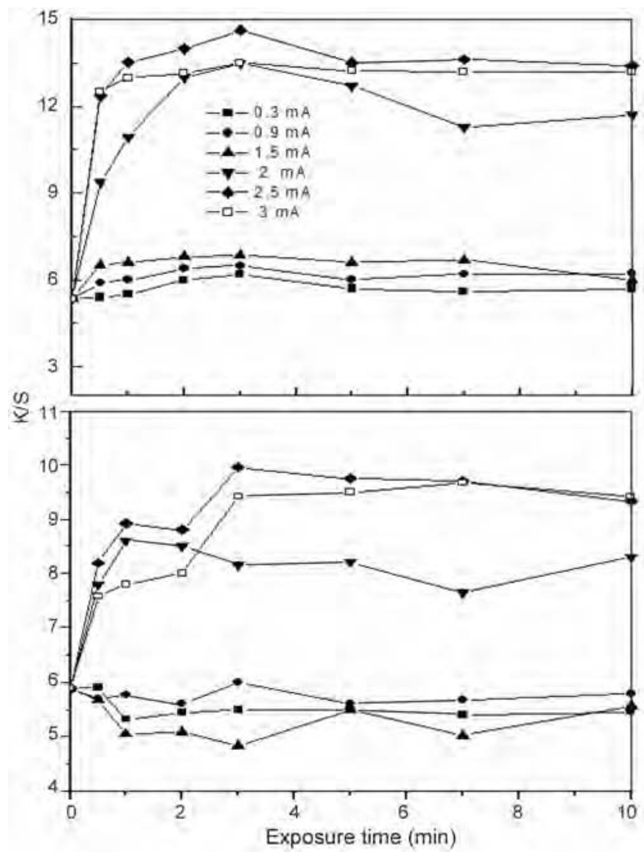

Fig. 3—Colour strength of printed wool/polyester blended fabric with Realan/Dianix and Supralan /Dianix dye mixtures versus plasma exposure time at different discharge currents

3.3 Effect of Current and Exposure Time on *K*/*S* Values

The influence of air plasma discharge current and exposure time on the colour strength of the wool/polyester blended fabric printed using the two different dye mixtures is also studied. The obtained ***K*/*S*** results are depicted in Fig. 3 for both dye mixtures.

It is clearly observed from the data that exposing the blended samples to air plasma at lower discharge currents than 2 mA does not cause any improvement in ***K*/*S*** values. It is noticed that the best pretreatment conditions of the fabrics are observed at a discharge current of 2.5 mA and an plasma exposure time of 3 min. They result in enhancing the ***K*/*S*** values by 173.6% and 68.9% for printing with both dye mixtures Realan/Dianix and Supralan/Dianix respectively when compared with the untreated printed sample.

It can be concluded from the previous data that low temperature plasma ablation attacks the chains on the crystalline surface and amorphous region and causes a significant change in fibre crystallinity[10]. For certain phenomena in which the mobility of molecules in a noncrystalline phase plays a dominate role such as dye absorption, the noncrystalline phase can no longer be treated as amorphous phase. The dyeability[11-13] study have shown that there exists at least dyeable and non-dyeable domains (areas) within the noncrystalline phase. From the view point of fibre dyeability, the non-dyeable amorphous consists of polymer segments that significantly restrict the mobility of molecules. Such a domain might be visualized (imagined) by analogy to a liquid crystalline phase[14].

3.4 Tensile Strength

Low temperature plasma (LTP) can modify the surface of a polymer substrate by physical and chemical changes, e.g. etching, grafting and cross linking[15]. The influence of air plasma pretreatment on the tensile strength of wool/polyester substrates is studied at different discharge currents as well as exposing times and the results are plotted in Fig. 4. It can be noted that air plasma treatment has a negative influence on the tensile strength of the treated substrate. This behaviour can more be observed in prolonged plasma treatments.

In, general, tensile strength of fabrics depends on many factors such as fabric structure, yarn twist and yarn count[16]. However, the LTP treatment could not alter the fabric structure as it is only a surface treatment method causing an etching action, resulting in a roughening effect on the fibre surface[17-19]. Such a roughening effect might impart more contact points within the fibres microscopical and yarns macroscopical scale[20]. Increment at a number of contact points results in the enhancement of inter-yarn and inter-fibre friction, where a larger cohesive force develops during the application of tensile stress. The reduction in the value of tensile strength after LTP treatment can be explained by the increment of the cohesive force between the fibres and between the yarns.

3.5 Wettability

The influence of air plasma pretreatment on the wettability of the wool/polyester blend fabric at different levels of discharge currents and plasma exposing times is investigated. Figure 4 shows that the longer air plasma treatment of fabrics shows significantly shorter wetting time and lead to a higher wettability compared to the untreated samples. This may be explained by the fact that longer plasma exposure time may induce more hydrophilic functional groups on the fabric surface due to longer duratuion of the chemical interaction of plasma and substrate[21] and hence, the cantact angle decreases. This indicates that the surface free energy is increased for air plasma treated fabric as compared with that of

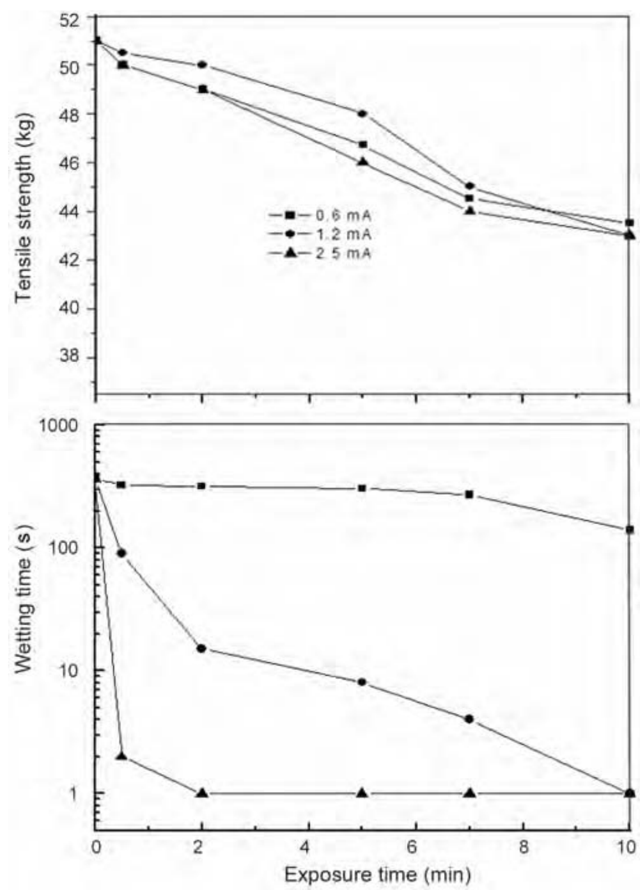

Fig. 4—Tensile strength and wetting time of wool/polyester blended fabric versus plasma exposure time at different discharge cuurents

Table 1—Effect of plasma treatment on the fastness properties of wool/polyester blended fabrics printed with Realan/Dianix and Supralan/Dianix dye mixtures.

Plasma treatment	Wash fastness			Rub fastness		Perspiration fastness						Light fastness
						Acidic			Alkaline			
	Alt.	St.*	St.**	Dry	Wet	Alt.	St.*	St.**	Alt.	St.*	St.**	
Untreated Realan/Dianix prints	4	4	4	3-4	2	4	3-4	4	4	4-5	4	5
Pretreated Realan/Dianix prints	4	4	4	3	2	4	4	4	4	4	3-4	5
Untreated Supralan/Dianix prints	4-5	4-5	4	2	2	3-4	3-4	3-4	4	4	4	5
Pretreated Supralan/Dianix prints	4	4	4	2	2	4	4	4	4	4	4	5

*St. — Staining on cotton. **St. — Staining on wool. Alt. — Change in colour.

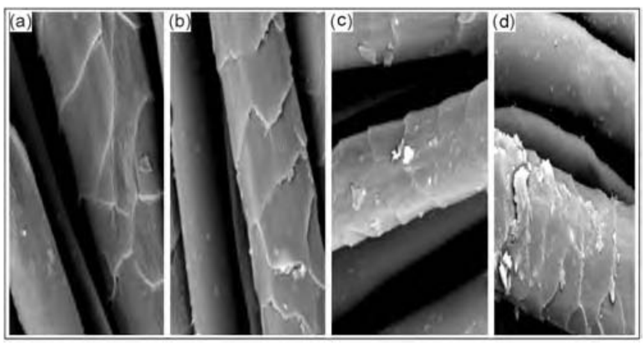

Fig. 5—SEM images of untreated and plasma-treated 45/55 wool/polyester samples (×1500) [(a) untreated, (b) air plasma at 0.6 mA – 2 min, (c) air plasma at 1.2 mA – 30 s and (d) air plasma at. 2.5 mA – 3 min]

the untreated[4]. This is clearly proved as the wetting time decreases sharply from 6 min to 1s for the wool/polyester blended fabric. These results are in good agreement with other studies[22-24].

3.6 Surface Morphology

The effect of air plasma treatment on the morphological changes of the wool/polyester blended fabric is studied using scanning electron microscope (SEM) and the obtained micrographs are illustrated in Fig. 5. It is clearly demonstrated from the figure that the untreated wool/polyester fibres show a relatively smooth surface with some grooves, while plasma-treated fabric exhibits changes in surface morphology. These changes show good correlation with the discharge current and exposure time of plasma treatment. Increased surface roughness can be produced by the etching effect of plasma active species bombardment of the fibre surface. It is well known that the plasma treatment of fabric surface leads to etching, cleaning and activation[25, 26]. Figure 5 clearly shows that an ablation effect occured at long plasma treatment time. It is therefore suggested that a short treatment time is favourable for the surface of wool/polyester fabric.

3.7 Fastness Properties

The durability of printing of the wool/polyester blended fabric with different dye mixtures, pretreated with air plasma at optimum conditions of discharge current (2.5 mA) and time (3 min) is evaluated in terms of fastness towards washing, rubbing, perspiration and light. The results are shown in Table 1. It can be observed that there is no difference between untreated and plasma-treated fabrics.

4 Conclusion

This study clearly demonstrates that the pretreatment of wool/polyester (45/55) blended substrate with air plasma can enhance the ***K*/*S*** values of the printed samples, using two dye mixtures and incorporating only urea in the printing pastes at ***p***H 7, discharge current 2.5 mA and treatment time 3 min. Exposure of materials to suitable plasma treatment can cause both chemical and physical changes on the surface layers so as to provide a more reactive surface without interfering the bulk properties, simply because of the shallow depth of penetration. Hence, a thin surface layer can be formed by means of surface bombardment with ions, electrons and other high energy particles which knock polymer material out of the surface. Air plasma treatment of fabric results in great improvement in fabric wettability without affecting its tensile strength or fastness properties negatively.

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