Continuous Modification Treatment of Polyester Fabric by Dielectric Barrier Discharge

Ren Zhongfu[1], Qiu Gao[2], Ren Xiandong[1], Wang Zhonghua[1]

(1. Jining Medical College, Jining, 272000 ; 2. College of Basic Science, Donghua University, Shanghai, 200051)

Abstract: Continuous modification of polyester fabric was carried out by dielectric barrier discharge (DBD) of Ar-O_2 (10:1) at atmospheric pressure. The results revealed that the dyeability of polyester fabric was dramatically improved, and its reflectivity of light was considerably decreased. The spectral value (K/S) was found to be increased by about 50％. The dye up-take was found to be increased by about 18％. However, the dyeing fastness was the highest degree, that is to say, despite the large increase of the up-take, the dyeing fastness was not be affected by the modification treatment of the DBD. SEM studies showed that the smooth and glossy surface of polyester fibre became rough and deep in colour after treatment by the reason of etching action of the discharge. XPS studies showed that Ar-O_2 discharge could help to form a few carboxyl groups on the polyester fibre surface.

Keywords: dielectric barrier discharge, continuous modification treatment, dyeability, reflectivity, polyester fabric

1. Introduction

The requirement of vacuum systems for low pressure plasma has been a burden for the textile industry, hence there is now an enthusiasm for plasma generated at atmospheric pressure. Dielectric barrier discharge (DBD) is effective in generating uniform plasma at atmospheric press. In addition to its freedom from the reliance on vacuum systems and adaptability to continuous industrial production, DBD at atmospheric pressure costs much less than low pressure plasma, consequently, DBD will play an active part in future textile industry[1-7].

Polyester is one of the most popular principal synthetic textile materials nowadays, which many people are very fond of at present. Yet it has some defects in practice. Because of its high molecule crystallization and deficiency of reactive group on fibre surface, polyester fabric is rather reflective and dye-resistant to some extent, especially not suitable to be dyed in deep colour, and all these affect its common application and appearance.

To meet the requirements in technical textiles, modification of polyester fabric is important to achieve improvements in surface properties, such as the promotion of dyeability and the reduction of reflectivity. DBD technology can effectively achieve modification of near-surface region without affecting the desirable bulk properties of material. In the experiment, polyester fabric was continuously treated by DBD of Ar-O_2(10:1) using a simple system at atmospheric pressure. This paper, firstly describes the experimental system, then presents detailed results of the continuous modification effects of DBD on polyester fibre surface, this is to say, the spectral value (K/S), the relative dye up-take, the dyeing fastness, the scanning electron microscope (SEM) and also the X-ray photoelectron spectroscopy (XPS) of polyester fabric, finally, this paper analyzes and studies the likely mechanisms of the modification processes.

2. Experimental set-up

The set-up of continuous modification treatment is shown in Figure 1. Two plane-parallel copper electrodes covered with dielectric material (usually mylar or glass) are separated by a uniform gap. An A.C. power supply is connected to the two electrodes to enable discharge. The gas passes a flow meter that shows its flow rate, and then is distributed to the discharge gap. Cooling liquid goes through the hollow electrodes, so that the heat produced during discharge can be emitted promptly, and the temperature in the gap would not rise too high for synthetic material. Discharge voltage, discharge power, and charge current can be measured with measurement system. The material is fed by a conveying system into the gap continuously, and the treatment time can be controlled by adjusting the conveyer's moving speed. The whole set-up is fixed in a transparent chamber.

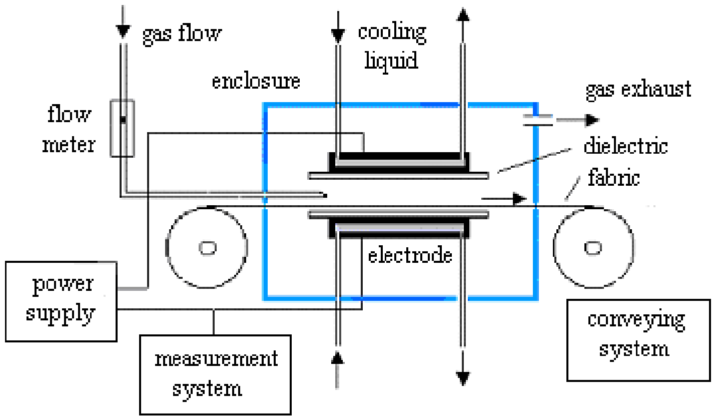


Figure 1. The continuous modification treatment system of dielectric barrier discharge

In the experiment pure Argon was not chosen as discharge gas on account of its inertia, instead it was mixed with a little oxygen. The addition of a little oxygen was to introduce oxygen groups into polyester fibre surface via chemical reaction for the reason of oxygen activity. In the discharge gas the ratio of argon to oxygen is 10 to 1 in volume, so that the discharge gas is formulated into Ar-O_2(10:1) in this thesis.

3. Results and discussions

Polyester fabric samples treated for various time by discharge were dyed with blue disperse dye under high temperature and high pressure. The change of K/S value is shown in Figure 2. It can be seen that the process of continuous modification treatment resulted in a large increase of K/S value. In the initial time of treatment the K/S value rised sharply, then slowly, and after about 1 minute it reached the maximum. The maximum of K/S value was dramatically increased by about 50％ in comparison with that of untreated sample. The increase of K/S value indicates the improvement of dyeability and also the reduction of reflectivity.

The plot of the relative dye up-take is depicted in Figure 3, which is somewhat parallel to the increase of K/S value. The relative dye up-take reached saturation after about 1minute too. The maximum of dye up-take was increased by about 18%.

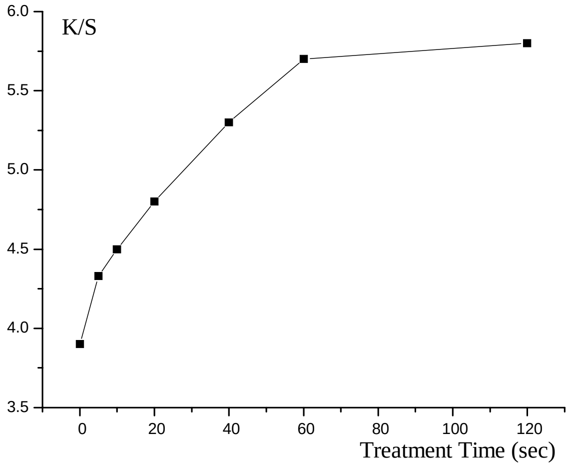


Figure 2. K/S value versus treatment time

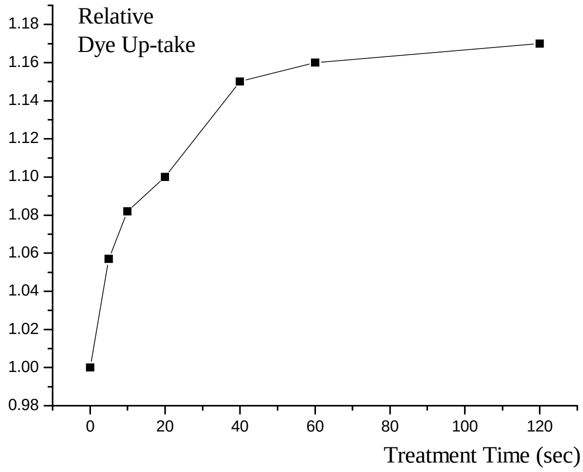


Figure 3. Relative dye up-take versus treatment time

The increases of the K/S value and the dye up-take both illustrate that the discharge of $Ar\text{-}O_2$ can satisfactorily improve the dyeability of polyester fabric. To test the dyeing fastness of polyester fabric treated with discharge, the rubbing dye fastness was tested, as is shown in the table 1. The treatment time was 1minute. Reaching the 5degree (the highest degree), the two kinds of rubbing dyeing fastness of polyester fabric treated by discharge remained the same as that untreated, which is very significant. By the way, the rubbing dyeing fastness of the untreated polyester fabric is usually the highest degree. So it can be concluded that even though the dye up-take was increased, the dyeing fastness wasn't be affected by discharge modification treatment.

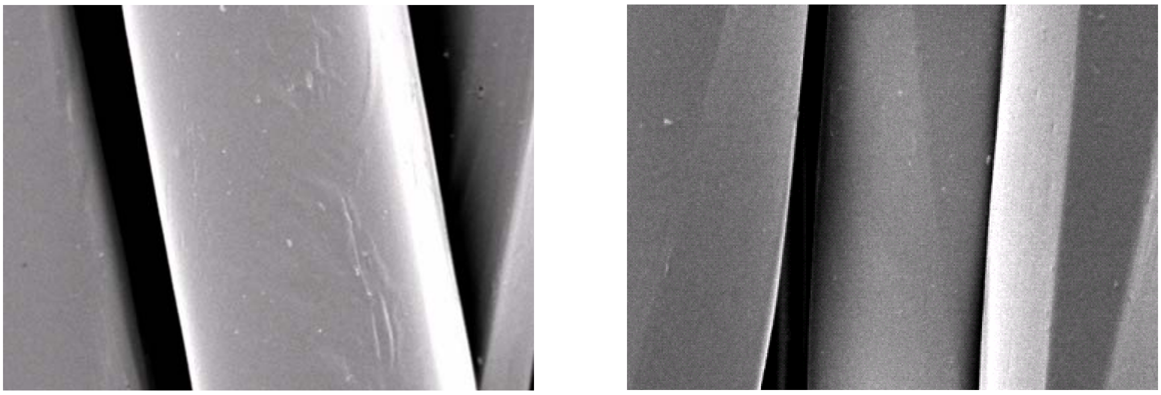
Table 1. Dyeing fastness of polyester fabric treated and untreated

Polyester fabric	Untreated	Treated
Rubbing dyeing fastness (dry)	5	5
Rubbing dyeing fastness (wet)	5	5

In preceding part of the paper it is illustrated that discharge of $Ar\text{-}O_2$ can satisfactorily improve the dyeability of polyester fabric under the condition of keeping dyeing fastness. In order to study further the likely mechanism of the discharge modification to polyester fabric surface, and also to analyze the surface state change during treatment, the samples before and after treatment were analyzed with scanning electron microscope (SEM) and X-ray photoelectron spectroscopy (XPS). As is shown in Figure 4 (a) the polyester fibre surface before treatment looks smooth and glossy. And the fibre surface treated for 1minute is shown in Figure 4 (b). It was rougher and deeper than before treatment. The roughness and deepness was due to etching process, which helped to the increase of the K/S value, and the decrease of reflectivity as well.

Figure 5. shows C(1s) XPS spectra of polyester fibre surfaces before and after treatment by

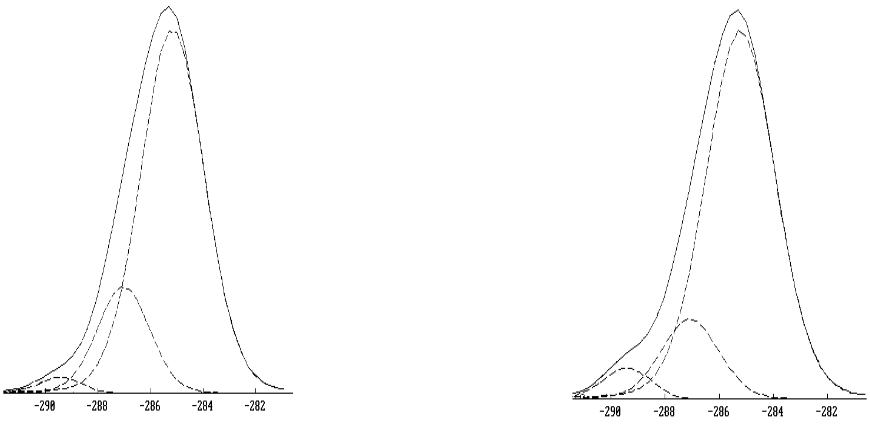
Ar-O_2 discharge, the treatment time was 1minute too. Binding energies characteristic of different levels of oxidized carbon are assigned as follows: saturated carbon (C-C/C-H) at 285.0eV, carbon bonded to hydroxyl group or doubly bonded to one oxygen atom (C-OH/C=O) at 287.2eV, and carbon bonded to carboxyl group (C-COOH) at 289.3eV[8]. The Figure 5. (b) has one a little



(a) (b)

Figure 4. SEM image of untreated polyester fibre. (a) untreated (b) treated

bigger shoulder at higher binding energy than Figure (a), which indicates a little more carboxyl groups on fibre surface after treatment. The XPS datas show that Ar-O_2 discharge can help to form a few carboxyl groups on polyester fibre surface. Carboxyl group is hydrophilic, and its formation on surface is advantageous to the improvement of polyester fabric dyeability to a certain extent.



(a) (b)

Figure 5. C1s XPS spectra of polyester. (a) untreated (b) treated

4. Conclusion

The continuous modification of Ar-O_2(10:1) discharge can improve polyester fabric dyeability and reduce its reflectivity dramatically. The K/S value and dye up-take was enormously increased. In spite of the large increase of dye up-take of the treated fabric, the rubbing dyeing fastness still reached 5 degree (the highest degree) as well as that untreated, so it can be concluded that modification treatment of Ar-O_2 discharge does not affect the dyeing fastness of polyester fabric. The discharge has two kinds of modification action on polyester fabric surface, i.e. etching and chemical reaction. Due to etching the smooth and glossy surface of polyester fibre became rough and deep in colour, in other words, its reflectivity was decreased, which corresponded with the large increase of K/S value. On the other hand, chemical reaction can introduce a few -COOH groups， which is hydrophilic, into the polyester fabric surface, and the formation of -COOH group is another positive factor to improve polyester fabric dyeability.

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