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Learning Materials of Atmospheric Pressure Plasma Process: Application in Wrinkle-Resistant Finishing of Cotton Fabric

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***Abstract*—**Cotton fibre is a commonly-used natural fibre because of its good fibre strength, high moisture absorption behaviour and minimal static problems. However, one of the main drawbacks of cotton fibre is wrinkling after washing, which is recently overcome by wrinkle-resistant treatment. 1,2,3,4-butanetetracarboxylic acid (BTCA) could improve the wrinkle-resistant properties of cotton fibre. Although the BTCA process is an effective method for wrinkle resistant application of cotton fabrics, reduced fabric strength was observed after treatment. Therefore, this paper would explore the use of atmospheric pressure plasma treatment under different discharge powers as a pretreatment process to enhance the application of BTCA process on cotton fabric without generating adverse effect. The aim of this study is to provide learning information to the users to know how the atmospheric pressure plasma treatment can be incorporated in textile finishing process with positive impact.

***Keywords*—**Learning materials, atmospheric pressure plasma treatment, cotton, wrinkle-resistant, BTCA.

I. Introduction

COTTON is an important natural fibre due to its good tensile strength, high absorption of moisture and few static problems [1]. However, cotton fibre tends to have a wrinkling effect after washing, a problem which is recently solved by wrinkle-resistant finish treatment [2]. The success of the wrinkle-resistant treatment is critical in order to maintain the image in high performance apparel textiles [3]. Among different wrinkle-resistant agents, BTCA is a non-formaldehyde release substance which is a desirable reactant when catalysed with sodium hypophosphite (SHP) to provide good wrinkle-resistant performance. However, the application of BTCA may lead to a reduction of fabric strength. Therefore, this paper will investigate the effect of the pre-treatment of cotton fabric by atmospheric pressure plasma, prior to applying BTCA to the wrinkle-resistant treatment, in order to compensate for the lost fabric tensile strength. With the understanding of the operation process of the atmospheric pressure plasma treatment (with the use of discharge power as an example), this paper can provide learning information on how the atmospheric pressure plasma treatment could be worked together with common textile finishing processes. This paper is also serving as reference materials for those who are interested in learning the application of atmospheric pressure plasma treatment in textile processing.

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II. Experimental

A. Materials Used

For the experiment, 100% scoured and bleached plain weave cotton fabric (300 mm x 300 mm) was used. The fabric was washed with 1 g/L non-ionic detergent at 50 ºC for 30 minutes to remove any impurities. After washing, the fabric was dried at 90 ºC, and the completely dried fabric was conditioned at 20±2 ºC and 65±2% relative humidity for 24 hours prior to any treatment.

B. Atmospheric Pressure Plasma Treatment

Plasma pre-treatment of cotton fabric was conducted by an atmospheric pressure plasma jet (APPJ), which can produce a stable discharge at atmospheric pressure with a radio frequency of 13.56 MHz. The plasma pre-treatment parameters of the cotton fabric were: (i) discharge power = 100 W and 130 W, 150 W; (ii) substrate speed = 10 mm/s; helium flow rate = 30 L/min.; oxygen flow rate = 0.3 L/min. and jet-to-substrate distance = 3 mm. Helium and oxygen were used as carrier and reactive gases, respectively. Figs. 1 and 2 show the diagram of the atmospheric pressure plasma system and the schematic diagram of atmospheric pressure plasma system used in this process, respectively.

Fig. 1 Diagram of atmospheric pressure plasma system [4]

C. Wrinkle-Resistant Treatment

The BTCA (5% w/v) and SHP (10% w/v) was applied to the cotton fabric through the pad-dry-cure method, in which the chemicals were padded onto the cotton fabric with 80% wet pick up and the fabric was dried completely at 100 ºC. Then, the fabric was cured at 170 ºC for two minutes. Finally, the fabric was conditioned at 20±2 °C and 65±2% relative humidity for 24 hours prior to evaluation.

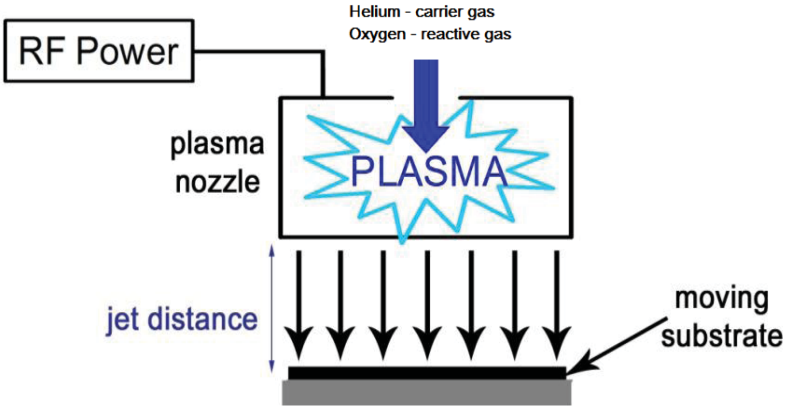

Fig. 2 Schematic diagram of atmospheric pressure plasma system [4]

D. Determination of Wrinkle-Resistant Property

Wrinkle-resistance was evaluated by wrinkle recovery angle (WRA) which was tested according to the AATCC Test Method 66-2003 (Option 2) (Wrinkle Recovery of Woven Fabrics: Recovery Angle). In this test, the face and back of the fabric sample should be identified first and the sample should be free from creases wrinkles, or distorted sections. Twelve specimens of 40 mm x 15 mm were cut, in which six specimens were in their long dimension parallel to warp direction of the fabric, and six specimens were in their long dimension parallel to the weft direction. A wrinkle recovery tester (Fig. 3) was used for measuring the WRA. The specimens were folded end to end and held by tweezers which was gripping no more than 5 mm from the ends. Then, the specimen was placed on the marked area of the lower plate of the loading device and a load (500 g) was applied gently for five minutes. After five minutes, the load was removed, by means of tweezers, and the specimen was transferred directly to the specimen holder of the wrinkle recovery tester. The WRA was then measured after five minutes of the removal of the load. The average WRA was then calculated.

E. Cotton Fabric Strength – Tensile and Tearing Strength

The tensile strength and tearing strength of the fabrics were measured in accordance with the ASTM D5034 – 09 (Standard test Method for Breaking Strength and Elongation of Textile Fabric (Grab Test)) (using Instron 4411) (Fig. 4) and ASTM D1424 – 09 (Standard Test Method for Tearing Strength of Fabric by Falling-Pendulum (Elmendorf-Type) Apparatus) (using Elmendorf Tearing Tester) (Fig. 5) respectively.

In the tensile strength test (ASTM D5034 – 09), a 100 mm wide specimen was mounted centrally in clamps of the tensile testing machine (Instron 4411) and a force was applied until the specimen broke. Values for breaking force were obtained from the computer connected.

Fig. 3 Wrinkle recovery angle tester

Fig. 4 Instron 4411

Fig. 5 Elmendorf tearing tester

In the tearing strength test (ASTM D1424 – 09), a slit was centrally precut in a test specimen held between two clamps and the specimen was torn through a fixed distance. The resistance to tearing was in part factored into the scale reading of the Elmendorf tearing tester.

III. Results and Discussion

A. Cotton Fabric Wrinkle-Resistant Property

Atmospheric pressure plasma pre-treatment alters the surface characteristics of fabrics and forms a large variety of chemically active functional groups [5]-[8].Atmospheric pressure plasma also alters the surface of the materials and increases the surface area for reaction between the finishing agent and the fibre [5]-[7], [9], [10]. In recent years, surface modification of cotton fabrics with atmospheric pressure plasma treatment has been studied widely because it is a continuous and environmentally friendly process that offers the reduction of wet chemicals and energy consumption [5], [11].

The wrinkle-resistant property of the cotton fabrics with atmospheric pressure plasma pre-treatment and with or without wrinkle-resistant post-treatment is summarised in Table I. The wrinkle-resistant property of the cotton fabric was measured by the wrinkle-recovery angle (WRA). The greater the WRA value, the better the wrinkle-resistant of the cotton fabric will be. According to Table I, the WRA of the treated specimens increased significantly and it is noted that the WRA of cotton fabrics increased obviously after atmospheric pressure plasma pre-treatment with increasing discharge power which could be further enhanced by the subsequent BTCA treatment. This phenomenon could be explained by the etching effect of the fabric surface after plasma pre-treatment [12]. This provided a new pathway for the finishing agent to enter into the fibre resulting in an increase in WRA. Generally speaking, at a higher discharge power, the etching of the surface layer could occur more rapidly than at a lower discharge power [13], [14]. In addition, the increase in the wettability of the cotton fibres might also facilitate the BTCA treatment [12].

TABLE I
THE WRA (°) OF DIFFERENT SPECIMENS

Specimen	Untreated	Wrinkle-resistant treatment
No atmospheric pressure plasma treatment	71.0	108.2
100W	79.4	111.0
130W	89.0	114.6
150W	96.2	116.0

B. Tensile and Tearing Strength

The tensile strength and tearing strength of fabric specimens treated under different condition are shown in Table II. Table II clearly shows that the tensile and tearing strength of the cotton fabrics treated with wrinkle-resistant treatment reduced to a great extent. Since the pH value of the BTCA solution was pH 1-2 and the acidity of the crosslinking treatment had a severe effect on the reduction of the tensile and tearing strength of the treated cotton fabrics due to the tendering effects of the fibres. The tendering effect of the fibre results in damage to the cotton and thus increases the brittleness of the cotton fibres. Therefore, the application of BTCA on the cotton fibre will reduce the tensile and tearing strength of the fabric. However, when the fabrics were pre-treated by atmospheric pressure plasma, the tensile and tearing strength of the BTCA treated cotton fabrics increased respectively to the increase of the discharge power, as shown in Table II. It is obvious that the plasma treatment could roughen the fabric surface resulting in the enhancement of inter-yarn and inter-fibre friction. This would lead to the development of a larger cohesive force during the application of the breaking force, and hence, a larger amount of energy was required to tear the fabrics [9].

TABLE II
THE TENSILE AND TEARING STRENGTH OF DIFFERENT SPECIMENS

Sample	Atmospheric pressure plasma condition	Tensile strength (N)	Tearing strength (gf)
Untreated	No	330.8	960.5
	100W	333.6	961.3
	130W	339.4	963.4
	150W	342.2	965.3
Wrinkle-resistant treatment	No	203.5	476.8
	100W	208.0	488.6
	130W	213.6	498.3
	150W	217.2	507.3

IV. Conclusion

In this paper, the BTCA was proved to be a desirable reactant when catalysed with SHP to provide a good performance in terms of the wrinkle recovery of cotton fabric; however, the fabric tensile and tearing strength were reduced significantly. When cotton fabrics were pre-treated by atmospheric pressure plasma with different discharge power, the fabric tensile and tearing strength were increased. Therefore, wrinkle-resistant finishing formulation with BTCA on cotton fabrics with plasma pre-treatment could minimise the side effect, i.e. reduced fabric strength.

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