Application of atmospheric pressure low temperature plasma in cotton fabric desizing

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Abstract. In order to solve the problem of high energy consumption and high pollution in traditional alkali desizing process of cotton fabric, atmospheric pressure low temperature plasma was used to treat pure cotton fabric containing sizing. Through single factor variable experiment, the optimum desizing process was determined. The optimum process conditions were as follows: the optimum treatment power of plasma is 400 W, the optimum treatment time is 15 min, the distance between discharge electrode and grey cloth is 1 mm, the optimum alkali boiling concentration is 8 g/L. Compared to traditional desizing process, the usage of caustic soda was saved by 60%.

1. Introduction
Cotton fabric has worldwide popularity for its good moisture-absorption behavior, good permeability, excellent dyeing properties [1-4]. In order to increase the wearing performance of the cotton fabric, the warp yarns should be sized before weaving [5]. At present, starch or polyvinyl alcohol (PVA) was mainly used as seriflux in industrial production [6]. Because the performance of the un-desizing fabric was very poor, it cannot be directly applied to the dyeing and finishing process. So pre-treatment desizing played a significant role for the successful dyeing and finishing of cotton fabric [7-8]. The desizing method generally was divided into enzyme, alkali, acid and oxidative desizing. The most common method was alkaline desizing, which the wastewater discharged during the desizing process causing serious environmental pollution. So environmental friendly desizing methods have been received widespread attentions. Atmospheric pressure plasma treatment has been proved to be an effective technique for modifying the surface of textile materials with an etching process [9]. Unlike the processing methods mentioned above, the low temperature plasma technology was a new type of green cleaning process without water [10-12].

Bozduman et al. used corona plasma discharge technology to treat the cotton fabrics. The results showed that plasma has a positive effect on the desizing rate and hydrophilic property of fabrics with PVA and starch as slurry [13]. Sun et al. demonstrated that plasma pre-treatment can be used to improve the adhesion of starch slurries on cotton fabrics [14]. Suzanne et al. studied the atmospheric pressure plasma desizing of PVA film by Helium plasma (He), Oxygen-Helium plasma (He/O2) and Helium/Carbon Tetrafluoride (He/CF4) plasma, and the chain was broken by the plasma treatment [15].
Effective and comparable pretreatment efficiency of gray cotton fabrics was obtained by the proposed method of oxygen and argon plasma assisted respectively[16]. Therefore, the purpose of this work was to improve the desizing process of cotton fabrics by atmospheric pressure low temperature plasma, and optimize the experimental conditions in combination with the wear performance parameters to provide an environmentally friendly process for cotton fabric desizing. The change of the fabric before and after desizing was characterized by Scanning Electron Microscopy (SEM). The whiteness, capillarity, moisture permeability, air permeability, stiffness and thickness of the fabric before and after desizing were tested.

2. Materials and Methods

2.1. Materials

Cotton gray fabric containing PVA size (yarn count 35.8 tex × 35.8 tex, fabric density 267/10 cm × 267/10 cm) was commercially available. NaOH (analytical purity, 96 %) was supplied by Tianjin Tianli Chemical Reagent Co., Ltd.; K₂Cr₂O₇ (analytical purity, 99.8 %) was supplied by Shenzhen Xunye Chemical Reagent Co., Ltd.; CaCl₂ (analytical purity, 96 %) was supplied by Tianjin Damao Chemical Reagent Factory; the deionized water was self-made in the laboratory.

2.2. Desizing Process

2.2.1. Traditional Alkali Treatment The fabric was basted for 1 h at the temperature of 95℃. And then the samples were washed in the hot water (95℃) for 10 min with three times. After that, the samples were washed in the cold water for 10 min. Finally the samples were vacuum dried at 75℃.The concentration of NaOH was 20 g/L, 25 g/L, and its bath ratio was 1:30.

2.2.2. Atmospheric Pressure Low Temperature Treatment A CTP-2000A type low temperature plasma apparatus (Nanjing Suman Plasma Technology Co., Ltd, China) was employed in the treatment experiments. Experimental parameters: the discharge treatment height was 1 mm, the processing time was 5 min, 10 min, 15 min, 20 min, 25 min and 30 min, the discharge voltage was 0~220 V, and the processing power was 200 W, 300 W, 400 W, 500 W and 600 W.

2.2.3. Plasma + Alkali Treatment The grey fabric was first subjected to plasma treatment in the same way, and then alkali-boiled at a temperature of 95℃ for 1 h, and the alkali concentration was changed during the alkali boiling process. Then, the grey fabric was washed in hot water, then fully washed in cold water, and finally dried.

2.3. Desizing Rate

The moisture regain of the sample was calculated according to the equation (1). The results were calculated as an average.

\[ A = \frac{W_1 - W_2}{W_2} \times 100\% \]  

Where: \( W_1 \) is the weight (g) before the grey fabric is dried, and \( W_2 \) is the weight after drying the grey fabric (g).

The desizing rate (%) of the sample was calculated according to the following equation (2):

\[ \text{Desizing Rate} = \frac{G(1 - A) - G'}{G(1 - A)} \times 100\% \]  

Where: \( G \) is the weight (g) before the grey fabric is untreated, \( G' \) is the weight (g) after drying of the grey fabric, and \( A \) is the moisture regain.

2.4. Tensile Properties, Whiteness, Capillary Effect
The fabric was cut into strips (25 cm × 5 cm), and the breaking strength and breaking strength retention rate were measured on an electronic fabric compactor. The whiteness of five different parts of the sample was tested using a smart digital whiteness meter (WSB-3A) and the average value was calculated. The sample was cut into strips (20 cm × 5 cm), and then a straight line was drawn with the pencil in the latitudinal direction at the bottom, and aligned the straight line with the liquid surface; K$_2$Cr$_2$O$_7$ solution was used as the test solution, and the rise height of the test solution was recorded at room temperature for 30 min.

2.5. Structure Characterization

The fiber to be tested was vacuum-sprayed, and the morphology of the fiber sample was observed and analyzed by scanning electron microscopy (SEM, magnification: 8 to 300,000 times, JSM-7800F, JEOL, Tokyo, Japan).

3. Results and Discussion

3.1. Effect of Plasma Treatment Power

![Figure 1](image)

Figure 1. Effect of different plasma treatment power on whiteness, breaking strength, capillary, weightlessness rate and desizing rate of samples. Note: The distance between the discharge electrode and the fabric was 1 mm.

Figure 1 showed the effect on whiteness, breaking strength, capillary, desizing rate and weight loss rate when the processing power was changed. With the increase of the processing power, the whiteness and breaking strength of the samples showed a decreasing trend, which the capillary, weight loss rate and desizing rate were showed an increasing trend. Because the electric field and current between the plates were increased as the processing power increased. The energy of the excited particles reaching the surface of the sample was increased, and the optimization to the sample was enhanced. The whiteness and breaking strength of the sample were lead to decreased, but at the same time the voids of the sample was increased and the capillary was enhanced. The rate of desizing and weight loss rate also increased. Therefore, it was suitable that the processing power of the pure cotton sample was 400 W.
3.2. Effect of Plasma Treatment Time

Figure 2. Effect of different plasma treatment time on whiteness, breaking strength, capillary, weightlessness rate and desizing rate of samples. Note: The plasma treated cotton fabric has a power of 400 W.

Figure 2 was showed the effect on whiteness, breaking strength, capillary, desizing rate and weight loss rate when the processing time was changed. With the increase of the processing time, breaking strength of the samples were showed a decreasing trend, weight loss rate and desizing rate were showed an increasing trend. But there was almost no change in the whiteness and capillary effect of the sample. Increasing the time, the breaking strength, desizing rate and weight loss rate were reduced gradually. Because the ion continues to bombard the sample, the slurry on the surface of the sample and some of the wax coat and the pectin in the fiber were degraded or volatilized. The capillary, the desizing rate and the weight loss rate of the sample were gradually increased, and the breaking strength was decreased. However, as the processing time was continued to increase, the damage to the sample became more and more serious, which causing the capillary, the desizing rate and the weight loss rate of the sample to decrease gradually. And the breaking strength was suddenly decreased. Therefore, it was suitable to treat the cotton sample for 15 minutes.

3.3. Effect of Plasma + Alkali Treatment

It could be seen from Figure 3 that the whiteness, the capillary and the desizing rate of the samples exceeded the conventional alkali process after the combined treatment. The same effect can be achieved by alkaline treatment with plasma and 8 g/L caustic soda solution and treatment with only 20 g/L or 25 g/L caustic soda. That is because the hydrophilic hydroxyl group on the surface of the fiber was increased and the content of the hydrophobic group was decreased after the low temperature plasma treatment. Further, the slurry of the surface was decomposed and removed as a gas by the low temperature plasma treatment. Therefore, the surface of the sample was etched to become rough, and the pores on the surface of the fiber were increased. It was promoted the entry of caustic soda into the interior of the sample during the alkaline boiling process to make desizing easier and greatly reduced
the amount of caustic soda used. Therefore, it was suitable to treat the cotton sample for the caustic concentration of 8 g/L.

Figure 3. Effect of plasma treatment and concentration of alkali liquor on whiteness, breaking strength, capillary, weightlessness rate and desizing rate of samples. Note: The plasma treated cotton fabric has a power of 400 W and a processing time of 15 min.

3.4. Structure Characterization

Figure 4. SEM images of plasma treated cotton fabric a), alkali treated cotton fabric b) and cotton fabric treated with plasma and alkali c).
4. Conclusions
In this experiment, the plasma and alkali desizing method were used to treat the sample, the
mechanism of the combined desizing method was studied, and the desizing process conditions were
optimized. The optimum process conditions were as follows: The plasma treatment power was 400 W.
The plasma treatment time was 15 min. The alkali concentration was 8 g/L. The plasma changed the
morphological structure of the sample surface, weakened the cohesion between the fibers, and the new
hydrophilic group was introduced between the fiber macromolecules.

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