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Atmospheric plasma treatment of wool fabrics for rapid wicking and drying

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Abstract: Wool fabrics were treated under glow discharge atmospheric plasma for between 1 to 10 minutes with helium or mixture of helium and acetylene. The influence of gas type, treatment time, and post-treatment dyeing on the wicking and drying properties of the treated fabrics were studied. The wicking and drying effects were assessed by wicking height, wetting time, drying time and contact angle. Topographical changes in the fabric surface were observed by scanning electron microscopy (SEM). Both helium and mixture of helium and acetylene plasma treatments impart rapid wicking and quick drying properties to wool fabrics. The effect of rapid wicking and quick drying is quite obvious after a short treatment time. The hydrophilicity of treated wool fabrics is remarkably decreased after six weeks ageing. By means of dyeing, the plasma treated wool fabrics with a reactive dyestuff, hydrophilicity of plasma treated fabrics is improved and less affected by ageing.

Key words: wool fabric; atmospheric plasma; wicking; drying; contact angle; ageing

0 Introduction

Wool fibre consists of cuticle and cuticle cells linked to one another by the cell membrane complex. The cuticle is formed by epicuticle, exocuticle and endocuticle layers. The epicuticle, which surrounds each cuticle cell of the wool fibre, consists of an outermost fatty acid monolayer and a protein matrix. Fatty acid chains are oriented away from the fibre to produce a "polyethylene-like" layer at the fibre surface, thus making the epicuticle hydrophobic and resistant to the attack of different agents [1-2]. Therefore, wool has a hydrophobic water-repellent surface even after removal of wool grease by aqueous scouring or solvent extraction.

By means of different treatments the nature of the fibre surface can be modified to enhance some important textile properties, such as handle, felting resistance, dye-ability, wettablity, adhesion and diffusion properties. A recent alternative to the conventional wool hydrophilicity treatments includes the application of hydrogen peroxide (H₂O₂) as an oxidative pre-treatment [3]. The purpose of hydrogen peroxide pre-treatment was to promote the formation of cystic acid and consequently to reinforce the anionic character of the fibre surface. Hydrogen peroxide pre-treatment probably induces a partial removal of the fatty acid barriers from the epicuticle, which confers hydrophilicity to wool [4-5]. Combined with the enzyme treatment, the hydrogen peroxide treatment achieves maximum efficiency and minimum degradation of wool fibre [6-7].

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Increased environmental awareness has driven the investigation into more sustainable physical or chemical means of fibre surface modification. These will eventually replace the common "wet" chemical treatment. One of the most promising treatments for wool surface modification has been low-temperature plasma (LTP), which is considered environmentally acceptable and results in considerable energy saving compared with conventional wet methods. It is well known that LTP treatments can modify selectively the nature of the wool surface by reducing its degree of felting shrinkage and improving its wettability, fibre cohesion and subsequent polymer adhesion to the fibre surface. 

Although there have been numerous publications about plasma treatments of wool, most of the publications focus on felting shrinkage, only limited results were reported on wicking, hydrophilicity and the drying properties of wool fibre. The focus of this investigation was to study the wicking and drying properties of the wool fabric due to atmospheric plasma treatment with either helium or a mixture of helium and acetylene and the change in these properties after the fabric is dyed. The effect of ageing is also examined in this study.

1 Experimental

1.1 Material

Unbleached and undyed 100% pure 2/1 twill wool fabrics, 228g/m², end: 16tex x 2, pick: 28tex, 38 ends/cm and 32 picks/cm. Fabrics were cut to dimension of 40cm x 40cm for relative properties testing. All samples were oven dried at 40°C for 24 hours to minimise the water content.

1.2 Low temperature plasma treatment

An APC 2000 atmospheric plasma machine (SigmaTech.) was used to treat the wool fabrics, using either helium or a mixture of helium and acetylene. Wool fabric samples were stuck to the machines discharge roller for plasma treatment. Two types of gas with a controlled flow rate were used, namely (1) helium (14,000s/min) and (2) mixture of helium (14,000s/min) and acetylene (280s/min). During all treatments, the surface speed of the discharge roller and the generator output power were kept constant at 25.4 m/min and 970W at 90kHz respectively.

1.3 Dyeing

Untreated wool fabric and plasma treated wool fabric were dyed with a wool reactive dyestuff. The dyes and chemicals used were 1.5% w/w Lanasol Red CE (Ciba Specialty Chem), 1.0% w/w Albegal B (Ciba Specialty Chem), 1.0 g/L Albegal FFA, (Ciba Specialty Chem); 1.0g/L sodium acetate (Aldrich); and acetic acid (Aldrich) to adjust the pH to 4.5 ~5. The liquid ratio used was 30:1 and the dye bath was heated to 100°C at 1.0°C/min and held there for 60min.

1.4 Wicking height and wetting time measurement

According to FZ/T01071, vertical wicking tests were carried out. The result of the test is expressed as wicking height (in cm) in a vertically positioned sample as a function of wicking time (up to 30 min). Both weft and warp wicking heights of the samples were taken. A contact angle meter (KSV CAM101) was used to measure the wetting time. The image of each drop was captured by the camera connected to a computer based image capture system. The captured images were viewed on the monitor. The images were captured as quickly as possible after liquid droplets were placed onto the test specimen. Therefore, the wetting time between the liquid droplet contacting the specimen surface and the liquid absorbed into the specimen was measured.

1.5 Drying time measurement

Drying time was measure according to of the standard test method Adidas-Salomon 6.04. The fabric moisture content was recorded at 2 minute intervals until the weight had returned to the original fabric sample weight.

1.6 Contact angle

The contact angle meter (KSV CAM101) was used. After a drop of liquid was dropped onto the fabric surface, the camera connected to a computer recorded the image, which was then used to calculate the contact angle.
The dynamic contact angle was measured during liquid absorption into the specimen.

1.7 SEM morphological investigation

SEM observations were made with a scanning electron microscope (LEICA S440W). The working distance was 10mm and the EHT was set at 10kV. All samples were mounted and gold sputtered under vacuum prior to observation.

2 Results and discussion

2.1 Wicking property

The wicking height of a fabric gives a good indication of its hydrophilicity. The higher the liquid wicks into the fabric the better its hydrophilicity. The averaged wicking curves after 2 weeks ageing are presented in Figure 1. Untreated wool fabric was hardly wetted and its wicking height was almost zero after 30 minutes. Compared with untreated wool fabric, a short atmospheric plasma treatment is sufficient to significantly improve the wicking height of wool fabrics. With the increase of treatment time, the wicking height increases slightly. The mixture of helium and acetylene gas was as effective as the helium gas alone. With a treatment time greater than 4 minutes, fabrics treated with the helium and acetylene gas mix reach a wicking height greater than 15 cm within 30 minutes, which is higher than the wicking height of fabrics treated with helium alone. Generally, when wicking height exceeds 15 cm, the fabric can be regarded as having rapid wicking.

![Graphs showing wicking height versus wicking time for plasma-treated wool fabrics.](image)

**Figure 1** Wicking height versus wicking time curve of plasma treated wool fabrics

2.2 Wetting performance

The wetting time of treated wool fabrics is shown in Figure 2. Because of the fatty acid layer of wool fibre, untreated wool fabric took a long time to wet and its wetting time was over 3 hours. After a short plasma treatment time, the wetting time of wool fabrics significantly decreased to 0.3~4 seconds. Extending the treatment time tends to reduce the wetting time. In addition, plasma treatment with a mixture of helium and acetylene has more effect on the wetting time than treatment with helium alone. There is also a noticeable difference in wetting time for the back and face of the treated wool fabrics. Because the plasma treatment was on the fabric face, the wetting time of the fabric face was shorter than that of the back.

![Graphs showing wetting time for plasma-treated wool fabrics.](image)
2.3 Drying property

The drying curves of untreated and treated wool fabrics are illustrated in Figure 3. The water evaporation from treated wool fabrics was faster than that of untreated wool fabrics. No significant influence of gas type on drying time was noticed.

Because of the improvement of wicking in the treated wool fabrics, water in the fabric wicked so that a larger surface area was covered. The larger surface area enabled a quicker evaporation of the moisture present. According to the Adidas-Salomon standard fabrics with a drying time of less than 30 minutes can be regarded as quick dry. The current study suggests that this "quick dry" can be achieved with wool fabrics when the treatment time is greater than 4 minutes.

2.4 Contact angle

Hydrophilicity of the plasma-treated fabrics was estimated by contact angle measurements. Because of the improvement of hydrophilicity in the plasma-treated fabrics, the water was quickly absorbed into the treated fabric. In order to comprehensively assess hydrophilicity of treated fabrics, the dynamic contact angle was observed in evaluating the hydrophilicity. The average curves of contact angle over time are shown in Figure 4. The water contact angle on plasma-treated fabrics significantly decreased compared with untreated fabric. The rate of contact angle reduction depends largely upon the treatment time. The influence of plasma gas type was noticed. Generally, the decrease rate of fabric contact angle with helium and acetylene plasma was larger than that with helium alone.

2.5 Ageing effect

After ageing for two weeks, the hydrophilicity of treated wool fabrics remained almost unchanged, with little decrease in their rapid wicking and quick drying properties. However, after six weeks of ageing, the hydrophilicity significantly decreased. The change of wicking height is shown in Figure 5. The wicking height of the treated wool
fabrics with helium plasma gas decreased more than that with mixture of helium and acetylene plasma gas. The change of drying time is shown in Figure 6. The drying time of treated fabrics with both helium and mixture of helium and acetylene slightly increased after six weeks ageing. Figure 7 illustrates the change of contact angle over time. The contact angle for water absorption into the fabric, had changed from large to small. The greater the angle change, the better the hydrophilicity. After six weeks ageing, the rate of contact angle change on the treated wool fabrics with both helium and a mixture of helium and acetylene plasma had dropped. The results indicate a significant decrease in the rate of contact angle change.
2.6 Influence of dyeing

Three wool fabrics were dyed in the same bath, namely (1) untreated fabric; (2) treated fabric with helium over 8 minutes; (3) treated fabric with mixture of helium and acetylene over 8 minutes. After six weeks ageing, their water contact angles were measured. Their dynamic contact angle curves are shown in Figure 8. A good hydrophilicity and anti-ageing performance of plasma treated and dyed fabrics were observed. The mechanism for this warrants further examination.

2.7 SEM observation

The effect of plasma treatment on the morphology of untreated and treated wool is illustrated in Figure 9. Most of the research into the plasma treatment of wool fibres is investigating the plasma degradation of the scale structure as an alternative to chlorination. It was expected that atmospheric plasma treatment for long periods of time would have an effect on the scale structure of the fibre used in this experiment.

Figure 8 Contact angle of wool fabric

Figure 9 The SEM images for untreated (A), treated with helium (B) and treated with mixture of helium and acetylene (C).

Significant scale structure damage or modification was not seen after plasma treatment. There was a low level of surface etching that is difficult to distinguish from these SEM images.

3 Conclusions

Helium and a mixture of helium and acetylene plasma treatments significantly improve the wicking and drying property of wool fabrics. A wicking height of more than 15cm and a drying time of less than 30min can be obtained by controlling the treatment time. The effect of plasma treatment with a mixture of helium and acetylene on wicking and wetting is better than that with helium alone. The dynamic water contact angle was used to assess hydrophilicity of the treated wool fabrics. The results show that the hydrophilicity depends largely upon the treatment time. After a long period of ageing, the wicking height and water contact angle decrease significantly, while the drying time increases slightly. The hydrophilicity of treated wool fabrics treated with helium reduces more rapidly than that treated with a mixture of helium and acetylene. After dyeing of treated wool fabrics with wool reactive dyes, the wool fabrics exhibit improved hydrophilicity and anti-ageing effects. The scale structure of the wool fibre is not significantly eroded by plasma treatment.

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References:


常压等离子体对羊毛织物的吸湿快干处理

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摘要: 采用氦气及氮气与乙炔的混合气体, 对羊毛织物进行了1~10min的常压发光等离子体处理。对气体种类、处理时间及后处理染色对羊毛织物吸湿快干性能产生影响进行了研究。通过芯吸高度、润湿时间、干燥时间和接触角对吸湿快干效果的评价。用扫描电子显微镜观看了织物表面的形态变化。氦及氮与乙炔的混合气体等离子体处理赋予了羊毛织物吸湿快干性能, 经过短时间的处理获得了十分明显的吸湿快干效果。但经过6周的老化, 羊毛织物的亲水性明显降低。通过对接离子处理的羊毛织物经活性染料染色, 等离子体处理的羊毛织物的亲水性得到改善并有较小的老化影响。

关键词: 羊毛织物; 常压发光等离子体; 芯吸; 干燥; 接触角; 老化