



Effect of hydrogen peroxide treatment on the properties of wool fabric

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ARTICLE INFO

Article history:

Received 14 April 2012

Received in revised form 11 June 2012

Accepted 18 June 2012

Available online 25 June 2012

Keywords:

Wool

Hydrogen peroxide

Surface wettability

Clothing

ABSTRACT

In this study, hydrogen peroxide treatment was applied to improve the surface wettability, moisture transfer properties and other related properties of wool fabric. SEM images showed the tip of wool scale was smoothened and parts of the scale were peeled off after hydrogen peroxide treatment. The time for a water droplet to sink into the fabric could decrease to less than 1 s and the wicking properties of wool fabrics were dramatically improved after hydrogen peroxide treatment. Shrinkage and whiteness of the fabric were improved due to the modification of scale and the bleaching effect of hydrogen peroxide, respectively. The fabrics became weaker and ductile with less than 4% weight loss. This study would benefit further application of wool fiber in summer clothing in which the surface wettability and moisture transfer properties are essential and determinative.

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1. Introduction

Wool fiber can be manufactured into different textile products such as carpets, rugs, blankets, socks and apparel. When used as clothing materials, wool fibers are usually used to produce outerwear in cold weather. Wool fibers can also be applied in underwear, but very fine fibers must be selected to diminish the itchiness of the product. The proteins in wool contain $-\text{CONH}-$ and other groups that attract moisture [1], which suggests that wool fabric could transfer sweat to keep the body warm and comfort. Wool fiber holds potentials in underwear even though very limited amount of wool fibers are applied in today's underwear market. Except for the itchy effect of wool fiber, poor water absorbing properties, normally refers to the wicking properties, of wool fabric confine its further application in underwear or sportswear. Wool fiber holds a moisture regain of 14–18%, which shows a very good moisture absorbing properties. Unfortunately, the resistant membrane in the epicuticle of wool fiber makes the fiber resistant to liquid water [2]. Even though the endocuticle of wool fiber could be served as the diffusion pathway for water, it takes time for the water to be absorbed into the fiber. Previous study suggests that the time for a water droplet to sink into the surface of wool fabric is higher than 1800 s [3] obviously the fabric is unable to keep the body comfort if sweat can not be absorbed and transferred swiftly.

Wool fabric made from fibers with cuticle scale layer removed shows good water absorbing properties [4]. However, to obtain water absorbing properties by the removal of the scales of wool

fiber is not worthwhile as further finishing of the product is very expensive and the conventional properties of wool, such as physical properties, dyeing and finishing properties may be greatly affected due to the treatment. Pure wool fabric with good water-absorbent properties is still of great challenge in textile field.

Hydrogen peroxide has been widely applied in the finishing process of textile, especially for bleaching of wool fabrics [5,6]. Even though improvement on wicking properties of wool due to hydrogen peroxide treatment has been noticed [3], little attention has been paid on this as wool is normally served as winter clothing in which hydrophilic properties are not the dominant factors that affect the comfort of the clothing itself.

Previous study has proven that hydrogen peroxide treatment can be applied as a pre-treating method for further improving the properties of wool fabric using corona discharge treatment [3]. Hydrogen peroxide treatment itself, as shown in this study, could grant the treated wool fabric with excellent hydrophilic properties. This study would benefit the further application of wool fiber in summer clothing in which the hydrophilicity is an essential property of fabric.

2. Experimental

2.1. Materials

Wool twill fabrics (serge, 270 g/m² and 200 g/m²) were provided by the Third Wool Factory of Lanzhou, China. Samples for treatment were prepared in the size of 35 cm × 15 cm. All the samples were washed in deionized water, then dried and conditioned at conventional conditions (temperature 20 °C and relative humidity 60%).

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Hydrogen peroxide (30%), sodium carbonate and sodium silicate were chemical grade, purchased from Shanghai Chemical Reagents Co. Ltd. Shanghai, China.

2.2. Hydrogen peroxide treatment

Wool fabrics were treated in an aqueous bath with a liquid to fabric ratio of 25:1. Hydrogen peroxide concentration was set as 5% and the solution contained 0.2% (w/w) sodium carbonate and 0.7% (w/w) sodium silicate. The bath temperature was controlled as 50 °C and the treating time was 1 h. Hydrogen peroxide concentration was changed while other parameters were kept the same to investigate its effect on properties of the treated wool fabric.

2.3. Measurements and characterizations

Scanning electron microscopy (SEM) analysis was carried out on a field emission SEM (SIRION TMP, FEI Company, OR, USA) at an acceleration voltage of 15 kV. Wool fibers were picked out from the yarn of treated and untreated fabrics and stuck on the SEM sample holder; all the samples were sputter-coated with a 10–15 nm layer of gold before testing.

The treated and untreated wool fabrics were both analyzed on a FTIR tester (Nicolet Avatar 360, Waltham, MA) with attenuated total reflectance and a scanning range from 600 to 4000 cm⁻¹.

Fabrics were placed on a table to test the surface wettability, 0.7 ml water was dropped using a syringe from 2 cm above the sample. The time for the droplet to sink into the fabric was then recorded by a stop watch when there was no obvious mirror reflection on the wet mark. Every fabric was tested for 5 times and the results were averaged.

The wicking height of the samples was tested by suspending the fabric vertically above a reservoir of distilled water with its lower edge immersed in, the height from the water level to the top of the wet mark on the fabric was recorded as wicking height at every minute for 15 min [7].

The shrinkage of the samples was measured by calculating area shrinkage of the samples according to the following equation:

$$\text{Shrinkage} = \frac{S_0 - S_1}{S_0} \times 100\% \quad (1)$$

where S_0 and S_1 refer to the area of fabric without and after a certain cycles of washing, respectively.

Whiteness of all the samples was tested on a whiteness meter (WSB-II, provided by Wenzhou Instruments and Apparatus Co. Ltd., China). In the test, the property of sample to reflect light at all wavelengths was characterized and compared with the standard, whiteness index value was reported to reflect the whiteness of the tested sample. The higher the whiteness index value, the greater the whiteness of the measured sample.

The dry weight of the fabric before and after hydrogen peroxide treatment was tested, and the weight loss percentage was calculated follow the equation:

$$\text{Weight loss percentage} = \frac{W_0 - W_1}{W_0} \times 100\% \quad (2)$$

where W_0 and W_1 refer to the weight of fabric before and after treatment.

Mechanical properties were tested on an Instron5566 Universal Testing Machine, at a gauge length of 30 mm and strain rate of 50 mm/min. Samples were obtained from warp direction of each fabric with a width of 20 mm. Each sample was tested for 5 times and the results were averaged.

3. Results and discussion

3.1. SEM images

Fig. 1 shows the SEM images of untreated wool fiber (a) and wool fibers treated by hydrogen peroxide (b–f). Scale shape can be observed clearly from untreated wool fiber with the tip of scales extruded out from the surface, as shown in Fig. 1(a). From Fig. 1(b–d), the tip of scale is smoother than the untreated wool fiber, some parts of scale were peeled off and other parts were severely damaged when lower concentration of hydrogen peroxide was used. Under higher concentrations, the treated fibers show an uneven surface with debris of the scales left on the stem, as seen from Fig. 1(e–f). The profile of the scale could hardly be seen as the tips of the scale were almost disappeared. Obviously hydrogen peroxide treatment has evident modification on the surface of wool fiber with parts of the scale peeled off or seriously damaged.

3.2. FTIR analysis

FTIR spectra of wool fabric before and after hydrogen peroxide treatment are shown in Fig. 2. The two curves exhibit similar absorption bands around 3290 cm⁻¹ (N–H and O–H), 2927 cm⁻¹ (–CH₂), 1643 cm⁻¹ (Amide I), 1535 cm⁻¹ (Amide II) and 1234 cm⁻¹ (Amide III). These are the typical absorption peaks of wool according to previous studies [8,9].

The peaks of treated fabric around 1643 cm⁻¹, 1535 cm⁻¹ and 1234 cm⁻¹ are sharper than that of the untreated fabric, this is probably due to the changes in some amic groups during the hydrogen peroxide treatment. Usually in the range from 1000 cm⁻¹ to 1300 cm⁻¹, the spectra are characterized by the presence of medium-to-high intensity bands attributed to the different sulfur-containing chemical groups of keratin [10], the sharper peak at 1234 cm⁻¹ indicates some changes in sulfur-containing groups during the treating process.

It has been established that the resistant membrane in the epicuticle of wool fiber makes the fiber resistant to liquid water [2]. The resistant membrane is sulfur-rich and characterized by a high degree of crosslinking via disulfide and isodipeptide bonds. According to SEM observation, the epicuticle of wool fiber is severely damaged after the treatment, which indicates the damage of sulfur-rich membrane. The damage caused by hydrogen peroxide is due to the attacking of perhydroxy formed from hydrogen peroxide. The disulfide bond is attacked and the disulfide oxidation products from ruptured –S–S– bonds are cysteic acid and intermediate sulfoxides [11,12]. Combined with the FTIR results, it could be estimated that the resistant membrane of the epicuticle of wool fiber was damaged through hydrogen peroxide treatment, which would facilitate the diffusion of water through the pathway in the endocuticle of wool fiber.

3.3. Surface wettability

The surface wettability of the treated fabrics under different concentrations of hydrogen peroxide was tested to validate the discussion above, as shown in Table 1. It is obviously that the treated fabric absorbs water much quicker than the untreated fabric. The time for treated fabrics to absorb 0.7 ml water droplet was less than 5 s, while that for the untreated fabric was more than 1800 s. A thin wool fabric was also used to do the same test and it was found that the time for the same droplet to sink into the fabric was less than 1 s when the concentration of hydrogen peroxide was higher than 1%. This suggests that the water absorbing properties could be improved to as higher level as that of cotton fabric.

Hydrogen peroxide had oxidative effect on the surface of wool scale. During the oxidation, the disulfide linkage of cystine and

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