Improvement in dyeability of wool fabric by microwave treatment

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Received 16 March 2010, revised received and accepted 2 June 2010

Wool fabric has been treated with microwave irradiation at different conditions and then studied for its physical and chemical properties using a variety of techniques, such as Fourier transform infrared spectroscopy, X-ray diffraction, and scanning electron. It is found that the treated wool fabric significantly improves its dyeability. This may be due to the change in wool surface morphological structure under microwave irradiation which implies that the barrier effect in wool dyeing is diminished. The breaking strength of the treated wool fabrics also improves with microwave irradiation. The chemical structure and crystallinity do not show any significant change.

Keywords: Dyeing, Microwave treatment, Wool fabric

1 Introduction

The difficulty in dyeing of wool fibre is due to its scale like surface structure. This complex structure makes it difficult for the dye molecules to permeate into the fibre, resulting in low levels of dye exhaustion. A number of studies aimed at improving the dyeability of wool by modifying the wool fibre have been reported

1-6. The use of high efficient modification methods to improve the dyeability of wool fibres has been the subject of considerable importance.

In recent years, modifications and dyeing of some materials have been conducted under microwave irradiation condition

7-9. Microwave irradiation is one of the powerful techniques of non-contact heating, and has been used for reacting, heating and drying wool materials. In the conventional processing of fabric, a large amount of energy is consumed. Some new techniques and methods for saving energy have also been studied

10-15. Microwave heating, as an alternative to conventional heating technique, has been proved to be more rapid, uniform and efficient. The microwave can easily penetrate the particle inside and all particles can be heated simultaneously, thus reducing heat transfer problems. It has been assumed that the microwave irradiation modification could affect dyeability of wool fibres. However, the report on the effect of microwave irradiation on dyeability of wool is scanty.

The present study is therefore aimed at developing a new modification technique using microwave irradiation for the improvement in dyeability of the wool fibres. The influence of the time and power of microwave treatment on the colour yield of dyeing, exhaustion, fixation, breaking strength, chemical structure, surface morphological structure and fine structure of wool fibres has been investigated.

2 Materials and Methods

2.1 Materials

100% wool woven fabric (from Qingfeng Textile Company, Beijing, China), having the specifications 15S/2×15S/2 74×64/inch, was used for the study.

Lanasol Red 6G was supplied by Huntsman Co. Ltd, Shanghai, China; Palatin Red GRE by Dystar Co. Ltd, Shanghai, China; ammonium sulphate by Lingfeng NO.4 Reagent & H.V Chemical Co. Ltd, Shanghai, China; acetic acid by Boer Chemical Reagent Co. Ltd, Shanghai, China; sodium sulfate and sulphuric acid by Guoyao Chemical Reagent Co. Ltd,

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Shanghai, China; Peregal O by Saintyear Co. Ltd, Hangzhou, China; and ammonia by Zhenxing Chemical Reagent Co. Ltd, Shanghai, China.

2.2 Microwave Irradiation Treatment of Wool Fabric

A microwave oven (Yk-01) having the continuous adjustable power of 250-1000W was used in this study. The microwave frequency of 2450MHz was chosen as it is widely used as ISM band (industrial, scientific and medical use).

Wool fabric was kept under the conditions 25-30°C, 60-70% RH to achieve an equilibrium moisture content. Wool fabric (enclosed in polythene film) was placed in the microwave oven and then treated with microwave irradiation at various power settings (300, 400, 500, 600 and 700W) for various durations (0.5, 1.0, 1.5, 2.0, 2.5 and 3.0 min) respectively. After irradiation, the fabric was removed from microwave oven and slowly cooled under vacuum for 24 h.

2.3 Dyeing Process

Two different wool fabric samples (untreated and microwave-treated) were dyed at 100°C and 1:50 liquor ratio, using two different dyes with different chemical constitution. Dyeing was carried out using reactive dye (Lanasol Red 6G) and 1:1 metal-complex dye (Palatin Red GRE). The dyeing process was started at 50°C for 10 min and the temperature of bath was then raised to the boiling point over 50 min. The bath was kept at this temperature for a further 60 min. The initial reactive dye-bath contained 2% Lanasol Red 6G, 4.0% ammonium sulphate, 5.0% sodium sulfate and acetic acid (80%), maintaining the pH at 4-4.5. Sodium sulphate was used to promote the dyeing of Lanasol reactive dye. The 1:1 metal-complex dye-bath contained 2% Palatin Red GRE, 2.0% Peregal O and sulphuric acid (98%). Sulphuric acid (98%) was used to adjust the pH of dyeing solution at 3-3.5. The pH of the dyeing solution was evaluated using a PHSJ-4A pH meter (Sartorius Group, GER).

The dyed fabrics were first rinsed with water at 40°C to remove dye portions not fixed to the substrate. Non-reactive dye portions formed by hydrolysis from the dye were washed off at 80°C by treatment with ammonia in an alkaline medium at pH 8.5 for 15 min. The dyed fabric was given one final rinse with water and then neutralized with acetic acid.

2.4 Fabric Performance Evaluation

The breaking strength of the fabric was measured according to ASTM test method (ASTMD 5034). Colour yield (K/S values) was calculated using a Datacolor SF650 color measuring and matching instrument (Datacolor, USA) and was used to determine the depth of shade of dyed wool fabrics. Exhaustion (E%) was determined using a U-3310 UV-vis spectrophotometer (Hitachi Ltd, JPN) and can be expressed as the percentage of the decrease in the dye-bath concentration, as shown below:

\[ E\% = (1 - A/A_0) \times 100 \]  \hspace{1cm} ...(1)

where \( A_0 \) is the optical density (initial dye concentration) of the dye bath at the very beginning of dyeing; and \( A \), the optical density (dye concentration) of the dye bath at the end of dyeing. Fixation (F%) was determined using a Datacolor SF650 color measuring and matching instrument by measuring K/S ratio for wool fabrics, which were rinsed, washed, neutralized and then dried, along with those which were dried after fixation without washing. The surface morphological structures of untreated and microwave-treated wool fibres were measured by a JSM-5600LV scanning electron microscopy (JEOL Ltd, JPN). Crystallinity of untreated and treated wool fibres was measured by a D/Max-2550 PC X-ray Diffractometer (Rigaku Ltd, JPN), using Cu-K target at 40 kV, 300 mA and k = 1.54056. The chemical structures of untreated and treated wool fibres were measured by a 510P infrared spectrum (Nicolet Ltd, USA).

3 Results and Discussion

3.1 Effect on Colour Yield

The colour yield of the wool fabrics treated under various conditions, i.e. the time of microwave treatment and the power of microwave, is given in Table 1.

It is observed that the colour yield of wool fabric improves after microwave treatment. The treatment time and irradiation power have a greater impact on the colour yield of the dyed fabric. The colour yield of dyed fabric increases with increasing treatment time, but decreases with increasing power from 400W to 700W. The longer the treatment time, the greater is the colour yields of dyed fabric, as a result of the greater dyeability of the treated fabric. Higher treating power results in the serious damage of the scale structure. Some hydrophilic groups are lost and hence
the dyeability of the treated wool fabrics decreases with the increase in irradiation power. The optimum values of treatment time and irradiation power are found to be 3.0 min and 400 W respectively.

3.2 Effect on Exhaustion and Fixation

The results of the dyeing exhaustion and fixation of the untreated and the treated wool fabrics are given in Table 2. It is observed that microwave-treated fabrics have improved exhaustion and fixation compared to the untreated fabric. This may be due to the change in wool surface morphological structure under microwave irradiation which implies that the barrier effect in wool dyeing is diminished.

3.3 Effect on Surface Morphological Structure

In order to investigate the influence of the microwave treatment on the wool fibre surface morphological structure, wool fabric was subjected to microwave irradiation with 400 W power for 3.0 min. The SEM photographs of surface morphological structure of untreated and treated wool fibres are shown in Fig. 1.

Microwave pretreatment has a slightly damaging effect on the surface scale-like structure of wool as compared to the untreated wool fibre; the scale edges are slightly eroded. It is considered that the destruction of the surface improved the absorption of dye molecules by the wool fibres during dipping and the diffusion of dye molecules into the wool fibres. As a result, the probability of the reaction between the dye and the wool fibres is increased, resulting in improved colour yield of the dyed wool fabric.

Table 1—Influence of power of microwave and the length of treatment on colour yield of wool fabrics

<table>
<thead>
<tr>
<th>Dye</th>
<th>Microwave power, W</th>
<th>0.5&quot;</th>
<th>1.0&quot;</th>
<th>1.5&quot;</th>
<th>2.0&quot;</th>
<th>2.5&quot;</th>
<th>3.0&quot;</th>
</tr>
</thead>
</table>

Un-treated: 32.632, 32.752, 32.847, 32.541, 33.753, 33.803

Palatin Red GRE

<table>
<thead>
<tr>
<th>Dye</th>
<th>Microwave power, W</th>
<th>0.5&quot;</th>
<th>1.0&quot;</th>
<th>1.5&quot;</th>
<th>2.0&quot;</th>
<th>2.5&quot;</th>
<th>3.0&quot;</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanasol Red 6G</td>
<td>300</td>
<td>32.633</td>
<td>32.751</td>
<td>32.847</td>
<td>33.541</td>
<td>33.753</td>
<td>33.803</td>
</tr>
<tr>
<td></td>
<td>400</td>
<td>32.858</td>
<td>32.893</td>
<td>33.018</td>
<td>33.612</td>
<td>33.861</td>
<td>33.918</td>
</tr>
<tr>
<td></td>
<td>500</td>
<td>32.536</td>
<td>32.704</td>
<td>32.836</td>
<td>33.187</td>
<td>33.311</td>
<td>33.323</td>
</tr>
<tr>
<td></td>
<td>600</td>
<td>32.448</td>
<td>32.648</td>
<td>32.791</td>
<td>32.477</td>
<td>32.522</td>
<td>32.830</td>
</tr>
<tr>
<td></td>
<td>700</td>
<td>32.681</td>
<td>32.844</td>
<td>32.937</td>
<td>33.056</td>
<td>32.454</td>
<td>32.452</td>
</tr>
</tbody>
</table>

Un-treated: 32.447, 32.447

Table 2—Exhaustion and fixation of untreated and microwave-treated wool fabrics

<table>
<thead>
<tr>
<th>Dye</th>
<th>Wool sample</th>
<th>E, %</th>
<th>F, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lanasol Red 6G</td>
<td>Untreated</td>
<td>73.6</td>
<td>94.8</td>
</tr>
<tr>
<td></td>
<td>Microwave-treated</td>
<td>75.0</td>
<td>96.7</td>
</tr>
<tr>
<td>Palatin Red GRE</td>
<td>Untreated</td>
<td>90.7</td>
<td>93.7</td>
</tr>
<tr>
<td></td>
<td>Microwave-treated</td>
<td>92.6</td>
<td>95.8</td>
</tr>
</tbody>
</table>

3.4 Effect on Crystallinity

In order to investigate the influence of the treatment with microwave on the wool fibre fine structure, the wool fabric was subjected to microwave irradiation with 400 W power for 3.0 min. The X-ray diffraction analysis of the crystallinity of untreated and treated wool fibres is shown in Fig. 2.

The crystallinity of the modified wool fibre is found to be very similar to those of the untreated wool fibre. In other words, the microwave treatment does not significantly alter the crystallinity of the wool fibre.

3.5 Effect on Chemical Structure

In order to investigate the influence of treatment with microwave on the wool fibre chemical structure, wool fabric was subjected to microwave irradiation with 400 W power for 3.0 min. Figure 3 shows the FTIR curve of the untreated and treated wool fibres.

It can be seen from Fig. 3 that the FTIR curve of treated wool fibre is almost similar to that of untreated wool fibre. Hence, microwave irradiation does not significantly influence the chemical structure of wool fibres.

3.6 Effect on Breaking Strength

Microwave power and treatment time under microwave irradiation condition also affect the
breaking strength of wool fabric. The breaking strength values of the wool fabric untreated and treated with microwave at various power settings (300, 400, 500W, 600 and 700W) for various treatment time (0.5, 1.0, 1.5, 2.0, 2.5 and 3min) respectively are presented in Fig. 4.

It is observed that the breaking strength of the modified wool fabric increases with increasing the treating time and power. As compared to the untreated wool fabric, the breaking strength of treated fabric slightly increases after modification. This may be due to the existence of bound water molecules in wool.
4 Conclusion

Microwave modification improves the dyeability of wool fabrics. The longer the treatment time the greater is the colour yield of dyed fabric. The dyeability of the treated wool fibres decreases with increasing irradiation power. The exhaustion and fixation of the treated wool fabrics improve with microwave irradiation. The microwave treatment also causes a slight damaging effect on the surface scale-like structure of the wool fibre, promoting the adsorption and permeation of the dye molecules into the wool fibres. This improves the extent of reaction between the reactive dye and wool fibres. Microwave irradiation does not significantly affect the crystallinity and the chemical structure of wool fibres. The breaking strength increases slightly after modification. Microwave modification technique has significant potential for industrial application as microwave is a clean and environment-friendly heating technology.

References