The Effect of Predrying Conditions on Durable-Press Cotton Fabrics

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ABSTRACT

The effect of the predrying conditions on the physical properties and the crosslinking structure of cotton fabrics treated with dimethylolethyleneurea was studied. The physical properties and crosslinking structure of treated fabrics are obviously affected by the predrying conditions. At the same predrying temperature, a higher moisture content in the predried fabrics results in an obvious agent migration, promoting the hydrogen-bond protective effect, which improves the dry crease recovery angle (DCRA) of treated fabrics; therefore, the linear relation between the DCRA and the product of the root of the crosslinking length, the number of crosslinks and the degree of completion of the crosslinkage (\(r\sqrt{n\alpha}\)) is affected. For the same 4-5% moisture content in the predried fabrics, a lower predrying temperature results in an obvious penetration of the crosslinking agent in lamella, promoting the swelling property of fiber, which improves the wet crease recovery angle (WCRA) of treated fabrics; therefore, the relation between the WCRA and the product of the crosslinking length, the number of crosslinks, and the degree of completion of the crosslinkage (\(r\alpha\)) is affected, and this phenomenon is more obviously observed in the presence of methanol in the padding solution.

1. INTRODUCTION

In previous papers\(^1\),\(^2\), we studied the crosslinking structures and the physical properties of dimethylolethyleneurea (DMEU) durable-press fabrics treated by the pad dry cure process with changing the curing temperatures and times, and found that the dry crease recovery angle (DCRA) was related to the product of the root of the crosslinking length, the number of crosslinks, and the degree of completion of the crosslinkage; and the wet crease recovery angle (WCRA) was related to the product of the crosslinking length, the number of crosslinks, and the degree of completion of the crosslinkage. We also found that an increase in the hydrogen-bond protective effect and the swelling property in fibers could also improve the DCRA and WCRA of treated fabrics, respectively.

In fact, the physical properties of treated fabrics are affected not only by the crosslinking structure but also by the distribution of the crosslinking agent as the finishing is proceeding with a higher moisture content. For example, Pandey et al.\(^5\),\(^6\) pointed out that a higher predrying temperature could result in a higher degree of agent migration. Bertoniere et al.\(^3\),\(^4\) predried the fabrics at different temperatures and/or with two-step predrying, and showed that a lower predrying temperature and a lower rate of predrying result in a slightly higher nitrogen content, DCRA, WCRA, and a slightly lower tensile strength retention for the treated fabrics.

This study deals with durable-press finishing under some special predrying conditions, in which different distributions of the crosslinking agent in the treated fabrics will result. The crosslinking structures of the treated fabrics will be discussed first, and the effects of the crosslinking structure and the distribution of the crosslinking agent on the physical properties of the treated fabrics under the different conditions will be discussed separately.
2. EXPERIMENTAL

2.1 Materials

The cotton fabric, the crosslinking agent (DMEU), and the catalyst used in this work were the same as in the previous paper2).

2.2 Procedure

Cotton fabrics were padded with 2–8% of aqueous DMEU containing Zn(NO3)2·6H2O (10% of the resin concentration) by the two-dip, two-nip process (pick-up, about 80%), predried in an oven at different temperatures to a moisture content of 4–5% or predried at 80°C to a specific moisture content, and then cured at 150°C for 3 min. The treated fabrics were then soaped, and dried.

Some other treated fabrics were prepared by predrying in a drying dish with silicone gel at 20°C for 24 h; or by padding with the finishing solutions in which a mixture of 20% methanol and 80% water was used as the solvent instead of 100% water, then predried in an oven at 80°C. Both of the above groups of predried fabrics were predried to a 4–5% moisture content, and then cured at 150°C for 3 min.

2.3 The measurement of the physical properties and the crosslinking structures of the treated fabrics

The DCRA, WCRA, tensile strength (warp), various CH2O (F) combined links, crosslinking length (n), number of crosslinks (r), and completion of crosslinkage (a) were measured with the same methods described in the previous papers1,2).

2.4 The measurement of the wide-angle diffraction

 Bundles of the weft yarns of the treated fabrics were used to study the 2θ of the wide-angle diffraction by using a Rigaku X-Ray diffractometer (D/max-II) with Cu-Kα radiation as the source.

2.5 The measurement of the migration percentage

The padded fabrics predried under different conditions were then immediately laid on a piece of plate-glass and covered with a small watch-glass at one corner of the predried fabric, and then cured at 150°C to obtain the migration percentage by the following equation suggested by Kottes et al.11):

\[
\% \text{Agent Migration} = 100 \left[ 1 - \frac{\% N_G}{\% N_O} \right]
\]

where, \% N_G is the nitrogen content determined from the area under the watch-glass, and \% N_O is the nitrogen content determined from the area at a distance from the area under the watch-glass.

3. RESULTS AND DISCUSSION

3.1 The effect of predrying conditions on the crosslinking structures of durable-press cotton fabrics

The crosslinking structures of the treated fabrics which were predried at 80°C to a specific moisture content or predried at different temperatures to a moist content of 4–5% are listed in Table 1. The results for the treated fabrics which were padded with the finishing solutions containing 20% methanol and predried in a drying dish at 20°C for 24 h are also shown in Table 1. From the data of Table 1, the relationships between crosslinking length (n) and the number of crosslinks (r) are shown in Figures 1a and 1b.

From Table 1, it can be found that the crosslinking structures of the treated fabrics are affected by the moisture content of the predried fabrics at the same predrying temperature. The amount of CH2O combined in the N-CH2-O-Cell (Fc) is decreased, the amount of CH2O combined in the N-CH2-O-CH2-N (Fe) is slightly increased, and the amounts of CH2O combined in the N-CH2OH (Fl) and the N-CH2-N (Fm) are slightly decreased with the increase of the moisture content in the predried fabrics. With changes in the amounts of the various CH2O, the increase of the moisture content in the predried fabrics also results in the increase of n and the decrease of r (as shown by the dotted lines in Figure 1). The changes in the crosslinking structures following the changes in the moisture content of the predried fabrics may be attributed to the surface migration of the crosslinking agent as the curing proceeded.

Table 1 and Figure 1 also show that the Fe, Fl, and n of the treated fabrics are slightly increased, and the Fm, Fc, and r of the treated fabrics are slightly decreased following the elevation of the predrying temperature with the same moisture content in the predried fabrics. Additionally, the Fe and Fm in the fabrics treated by the dish predrying method are higher, and the crosslinking length (n) is longer than those of the fabrics treated by the oven predrying method. As for the fabrics treated by padding with the finishing solution containing 20% methanol, the Fc and the n are longer than those of the fabrics treated by padding with an aqueous solution. The shortening of n of the fabrics treated at a lower pre-
Table 1: The CH$_2$O combined in various links of DMEU-treated fabrics under different predrying conditions.

<table>
<thead>
<tr>
<th>Mass concentration (%)</th>
<th>Predrying temperature (°C)</th>
<th>Predried fabric (%)</th>
<th>CH$_2$O combined (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>(Ft) N-CH$_2$OH</td>
</tr>
<tr>
<td>2%</td>
<td>20*1</td>
<td>4-5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>4-5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>4-5</td>
<td>2.0</td>
</tr>
<tr>
<td></td>
<td>80*2</td>
<td>4-5</td>
<td>1.7</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>20</td>
<td>2.1</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>40</td>
<td>2.5</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>60</td>
<td>2.8</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>80</td>
<td>3.1</td>
</tr>
<tr>
<td></td>
<td>80</td>
<td>80</td>
<td>3.4</td>
</tr>
<tr>
<td>4%</td>
<td>20*1</td>
<td>4-5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>4-5</td>
<td>1.4</td>
</tr>
<tr>
<td></td>
<td>60</td>
<td>4-5</td>
<td>1.5</td>
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<tr>
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<td></td>
<td>80</td>
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<td>1.9</td>
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<td></td>
<td>80</td>
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</tr>
<tr>
<td></td>
<td>80</td>
<td>80</td>
<td>2.9</td>
</tr>
<tr>
<td>6%</td>
<td>20*1</td>
<td>4-5</td>
<td>1.5</td>
</tr>
<tr>
<td></td>
<td>40</td>
<td>4-5</td>
<td>1.4</td>
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<td></td>
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<td>80*2</td>
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<tr>
<td></td>
<td>80</td>
<td>80</td>
<td>2.9</td>
</tr>
</tbody>
</table>

*1: samples were predried with the dish predrying method. *2: samples were padded with a solution containing 20% methanol.

Drying temperature or treated by padding with the solution containing 20% methanol may be due to the increase in the reaction between the crosslinking agent and cellulose molecules caused by more inner penetration of the crosslinking agent in the fiber. The longer n of the fabrics treated by the dish predrying method may be caused by the deposition or self-condensation of the crosslinking agent in the fiber for the swelling of fiber during the longer period of predrying.
3.2 The effect of predrying conditions on the physical properties of treated fabrics

3.2.1 The effect of predrying conditions on the dry crease recovery angle

According to the same procedure shown in the previous paper\textsuperscript{2}, the relationship between the DCRA and $r\sqrt{n}$ of the fabrics treated under different predrying conditions is checked and the results are shown in Figure 2. No matter what the change in the predrying temperature (20-80°C) was, for a lower moisture content (4-5%) in the predried fabrics, the linear relation between the DCRA and the crosslinking structure index ($r\sqrt{n}$) of the treated fabrics still remains the same as shown in the previous paper, where the curing conditions were varied. That is to say, the following equation is still applicable:

$$\text{DCRA} = K_{D1}r\sqrt{n} + K_{D0}$$ \hspace{1cm} (1)

Additionally, we also found that the $K_{D1}$ and $K_{D0}$ of the above relation for the treated fabrics are almost the same after predrying to a 4-5% moisture content at various temperatures.

In Figure 2, the relation for the fabrics treated by padding with the solution containing 20% methanol is also linear, and the $K_{D1}$ appears a little lower than that of the fabrics treated by padding with the conventional aqueous...
solution for the same moisture content (4-5%) of predried fabrics. The slight decrease of $K_{D1}$ may be caused by the decrease of the hydrogen bond for the more penetration of the crosslinking agent into the lamella of the fibers. Tonami et al.\textsuperscript{12)} proved that the organic solvent of DMF could improve the penetration of the crosslinking agent into the lamella of the fibers.

However, when the moisture content of the predried fabrics is changed at the same predrying temperature (80°C), the linear relation deviates at $r \sqrt{n} \alpha > 100$, and the degree of the deviation increases with the increase of the moist content. This may be attributed to the fact that the migration of the crosslinking agent to the surface of the fiber will increase at a higher moisture content in the predried fabrics as the curing process proceeded. In the previous paper\textsuperscript{2)}, we showed that the $K_{D0}$ of the fabrics treated under different curing conditions was affected by the protective effect of the hydrogen bond with the change of the crosslinking length between cellulose molecules. The variance in the $K_{D0}$ of the treated fabrics when predried to different moisture content at the same temperature may also be attributed to the protective effect of the hydrogen bond. However, the effect of the hydrogen bond is obvious as the resin concentration becomes higher than 4%.

In order to confirm that the $K_{D1}$ and $K_{D0}$ are affected by the protective effect of the hydrogen bond in the fibers as a result of the surface migration of crosslinking agent, the migration percentages for the various concentrations of the crosslinking agent in the fabrics predried under different conditions were measured using the method suggested by Kottes et al.\textsuperscript{11)} and are shown in Figure 3. From this Figure, it can be observed that the migration percentages show the obvious increases with a higher moisture content in the predried fabrics, and increase slightly with the elevation of the predrying temperature (40-80°C). The increase of agent migration with the elevation of predrying temperature agrees with the results of other papers\textsuperscript{5,6,9,10,11}). Figure 3 also shows that for the same moisture content (4-5%) in the predried fabrics, the migration percentages for the predried fabrics treated by padding with the solution containing 20% methanol are lower than those for the predried fabrics treated by padding with the conventional aqueous solution for the inner penetration of the crosslinking agent. Because of the above effect of the moisture content in predried fabrics on the agent migration, and due to the fact that the agent migration to the fiber surface is believed to favour the formation of the hydrogen bond, the $K_{D0}$ of Equation (1) will be affected by

![Fig. 3. The plots of the migration percentages for different predrying conditions against the DMEU concentration. Symbols are the same as in Figure 1.](image1)

![Fig. 4. The plots of the migration index against the $r \sqrt{n} \alpha$ of DMEU treated fabrics under different predrying conditions. Symbols are the same as in Figure 1.](image2)
the strength of hydrogen bond under the conditions of higher moisture content in the predried fabrics.

To further quantify the effect of the migration, the migration percentages were multiplied by the nitrogen contents of the treated fabrics (expressed as migration indexes) and plotted against the crosslinking structure index ($r_{\alpha}$), as shown in Figure 4. At the same predrying temperature, the migration indexes increase rapidly with the increase of $r_{\alpha}$ for the case of the higher moisture content of the predried fabrics especially at $r_{\alpha} > 100$. Therefore, it can be concluded that the rapid increase of the agent migration will result in differences in the hydrogen-bond protective effect in the fibers so that the linear relations will deviate with a higher moisture content of the predried fabrics at $r_{\alpha} > 100$.

Figure 4 also shows the plots of the results for the fabrics treated by predrying to a lower moisture content (4-5%) at various temperatures or treated by padding with the solution containing 20% methanol. It reveals that the migration indexes relating to the lower moisture content of the predried fabrics are smaller than those relating to the higher moisture content of the predried fabrics at the same predrying temperature, and the migration indexes relating to treatment by the padding solution containing 20% methanol are slightly lower than those relating to treatment by the aqueous solution. The effect of the hydrogen bond protective effect on the deviation of the linear relation of Equation (1) for the treated fabrics with a lower moisture content in the predried fabrics is not obvious.

3.2.2 The effect of predrying conditions on the wet crease recovery angle

As for the effect of the crosslinking structure index ($r_{\alpha}$) on the WCRA of treated fabrics, the relationship between the WCRA and the $r_{\alpha}$ under different predrying conditions as described in the previous paper$^{2)}$ is also shown in Figure 5. From this figure, it can be found that no matter what the change in the moisture content of the predried fabrics was, the relation between the WCRA and the $r_{\alpha}$ of the treated fabrics by predrying at a higher temperature (80°C) is still almost linear, as in the previous paper, where the curing conditions were changed. That is to say, the following equation is still applicable:

$$WCRA = K_{W1} r_{\alpha} + K_{W0}$$  \hspace{1cm} (2)

In the previous paper$^{2)}$, we concluded that the $K_{W1}$ of the treated fabrics with changes in the curing conditions was affected by the swelling of fibers. The approximation of the $K_{W1}$ for the fabrics treated by predrying to different moisture contents at a higher temperature can be attributed to the way that the following two effects on the swelling property offset each other: (a) the higher surface migration of the agent with the higher moisture content in the predried fabrics (Figure 4) will decrease the swelling property of the fibers, and (b) the formation of a longer crosslinking length with the higher moisture content in the predried fabrics (Figure 1a) will increase the swelling property of the fibers.

Figure 5 also shows the relation between the WCRA and the $r_{\alpha}$ of DMEU treated fabrics under different predrying conditions. Symbols are the same as in Figure 1.
result in a difference in the inner penetration of the crosslinking agent in the fibers as predrying proceeds, and this difference will be more obvious in the case of the lower predrying temperature. In addition, the effect of the agent migration on the swelling property in this case will not be an important factor, since the agent migration for the fabrics predried to a lower moisture content are not obvious, as shown in Figure 4.

Additionally, in the case of the fabrics treated by padding with the solution containing 20% methanol, the turning phenomenon of the relation appears steeper and the $K_{w1}$ is larger than that of the fabrics treated by padding with the aqueous solution for the same moisture content of the predried fabrics. This is obviously due to the fact that the crosslinking agent can penetrate more into the lamella of the fibers to enhance the swelling of fibers, and the swelling improves the WCRA of the treated fabrics. Tonami et al.\textsuperscript{12} also showed that the organic solvent (DMF) could improve the WCRA of the treated fabrics.

The $2\theta$ was measured and the distances between the (103) planes of the fabrics treated under different predrying conditions were calculated to examine the penetration of the crosslinking agent into the lamella of the fibers. The results are listed in Table 2. The samples A, B, C, D and E represent the untreated fabric, the fabric treated by predrying to a 4-5% moisture content at 80°C, the fabric treated by predrying to an 80% moisture content at 80°C, the fabric treated by predrying with the dish predrying method, and the fabric treated by padding with the solution containing 20% methanol, respectively. The nitrogen contents of all the above treated fabrics are about 600 µmole/g. It is found that the distances between the (103) planes vary slightly for different predrying conditions and the sequence of the variance of the distances is shown as $E > D = C > B > A$.

We can suggest that the distances between the (103) planes of the treated fabrics are related to the degree of the penetration of the crosslinking agent in the fibers, i.e., predrying at a lower temperature and in the presence of methanol in padding solution, the crosslinking agent can penetrate more into the lamella of the fibers to promote the swelling property so as to enhance the WCRA of the treated fabrics.

3.2.3 The effect of predrying conditions on the tensile strength

Figure 6 shows the relationship between the strength loss caused only by the crosslinkage ($SL'$) and the crosslinking structure index ($ra$) under different predrying conditions. The relations for all the predrying conditions are almost the same, i.e., the $SL'$ (%) is not obviously affected by the changes in the predrying conditions. Thus, the following equation is still applicable, as was true in the case with the changes in the curing conditions in the previous paper\textsuperscript{2}:

$$SL' = Ksr\alpha$$

![Fig. 6](image-url)

Table 2 The $2\theta$ and the distances between (103) molecular layers in crystals of DMEU treated fabrics under different predrying conditions.

<table>
<thead>
<tr>
<th>Samples</th>
<th>$2\theta$</th>
<th>distances (Å) between (103) molecular layers in crystals</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>35.2°</td>
<td>2.551</td>
</tr>
<tr>
<td>B</td>
<td>35.0°</td>
<td>2.560</td>
</tr>
<tr>
<td>C</td>
<td>34.6°</td>
<td>2.594</td>
</tr>
<tr>
<td>D</td>
<td>34.6°</td>
<td>2.594</td>
</tr>
<tr>
<td>E</td>
<td>34.2°</td>
<td>2.621</td>
</tr>
</tbody>
</table>

(A): untreated fabric; (B) fabric treated by predrying at 80°C to 4-5% moisture content in predried fabric; (C) fabric treated by predrying at 80°C to 80% moisture content in predried fabric; (D) fabric treated by predrying with dish drying method; and (E) fabric treated by padding with a solution containing 20% methanol.
treated by predrying to a low moisture content at various temperatures. The relation for treatment by the padding solution containing 20% methanol is also linear, but the slope of the relation appears a little lower than that for treatment by the aqueous solution with the same lower moisture content of predried fabrics. Additionally, as the moisture content changes for the predried fabrics treated at the same predrying temperature, the above linear relation deviates at $r \sqrt{n} \sigma > 100$, and the degree of the deviation increases with the increase in moisture content.

(3) The relations between the WCRA and the $r \sigma$ for fabrics predried to different moisture content at the same temperature are almost linear and are almost the same. The relations when predrying to a low moisture content at various temperatures show a turnabout at $r \sigma = 150$, which is gradually more obvious with the descent of the predrying temperature; the slopes of the relations increase with the descent of the predrying temperature. In addition, when padded with the solution containing 20% methanol, the above turning phenomenon appears steeper and the $K_{Wi}$ is larger than when padding with the aqueous solution with the same low moisture content in the predried fabrics.

(4) The strength loss caused only by the stiffening is related almost linearly to $r \sigma$ for all different predrying conditions.

(5) An obvious migration of agent and a slightly stronger penetration of the crosslinking agent into the lamella result for the treated fabrics when predried to a higher moisture content at the same temperature so as to improve the DCRA. An obviously stronger penetration of the crosslinking agent into the lamella and a lower agent migration result for the fabrics treated by predrying to the same moisture content at a lower temperature so as to improve the WCRA, and this phenomenon is more obvious in the presence of methanol in the padding solution.

**LITERATURE**


**4. CONCLUSION**

The physical properties and the crosslinking structures of DMEU treated fabrics predried under different conditions were investigated and shown to be as follows.

(1) A higher moisture content in the predried fabrics treated by predrying at the same temperature or a higher predrying temperature for a low moisture content in the predried fabrics results in a longer crosslinking length and a smaller number of crosslinks in the treated fabrics. Additionally, the crosslinking length increases for the fabrics treated by the dish predrying method compared with that for fabrics treated by the oven predrying method, and decreases for the fabrics treated by padding with the solution containing 20% methanol compared with that for fabrics treated by padding with the aqueous solution.

(2) The linear relations between the DCRA and the $r \sqrt{n} \sigma$ do exist, and are almost the same for the fabrics.
耐久プレス加工織布に及ぼす予備乾燥条件の効果

国立台湾工業技術学院織機工学技術系 順 明雄・陳 進智

ジメチロールエチレン亜素で処理した織布の物性と橋かけ構造に及ぼす予備乾燥の効果を検討した。
加工布の物性と橋かけ構造は明らかに予備乾燥の条件に影響される。予備乾燥において温度を一定として布の水分率を高めると、加工布における加工剤の移行が激しくなった。その結果、水素結合の保護が助長され、より良い乾燥回復角が得られた。このことから乾燥回復角と、橋かけ長さの平方根、橋かけ数と橋かけ完成度の積との直線性が満たされなくなった。

次に、予備乾燥において、加工布の水分率を4-5％で固定して温度を変えたとき、温度が低いほど加工剤がよりラメラの内部に浸透した。その結果、織維の膨潤性が高まり、より良い湿しろ回復角が得られた。このことから湿しろ回復角と、橋かけ長さ、橋かけ数と橋かけ完成度の積との間の直線性が満たされなくなった。この現象は加工液にメタノールを含めた時により顕著であった。