Comparative Study of Moisture Absorption and Dimensional Stability of Chinese Cedar Wood with Conventional Drying and Superheated Steam Drying

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Comparative study of Moisture Absorption and Dimensional Stability of Chinese cedar wood with Conventional drying and Superheated Steam drying

Yongze Bao¹, Yongdong Zhou¹

¹Research Institute of Wood Industry, Chinese Academy of Forestry, Beijing, P.R. China

Address correspondence to Yongdong Zhou, E-mail: zhouyd@caf.ac.cn

Abstract

The effects of drying method on equilibrated moisture content (MC) and swelling efficiency of Chinese cedar (Cryptomeria fortunei) wood were studied in this paper. Drying experiments were conducted with conventional (CON) drying and superheated steam (SHS) drying under atmospheric pressure. Specimens were equilibrated at two environment conditions to measure moisture and dimensional changes, and then the moisture excluding efficiency (MEE) and anti-swelling efficiency (ASE) were determined. Results showed that the equilibrated MC of artificial-dried wood was lower than control samples (air drying), and the equilibrated MC of wood with SHS drying was lower than that with CON drying, which indicated that MEE was enhanced in SHS drying process. Similar result was found in swelling efficiency and ASE of artificial-dried wood and the control. The mechanism was studied by dynamic mechanical analysis (DMA) and X-ray diffraction analysis (XRD). The DMA results showed that both of relative storage modulus and relative loss modulus were the highest for SHS-dried wood and the lowest for the control samples. As for the crystalline structure assessed by changes of XRD, the results showed that the cellulose crystallinity and crystallite size of Chinese cedar wood with SHS drying were the highest, and control specimens were the
lowest. All the analysis showed that Chinese cedar wood with low hygroscopic and high dimensional stability could be gotten through superheated steam drying process.

**KEYWORDS:** Conventional drying; Superheated Steam drying; equilibrated MC; Dimensional Stability; DMA; XRD

**INTRODUCTION**

Chinese cedar (*Cryptomeria fortunei*) is widely planted in southern China. It belongs to the Taxodiaceae genus of *Cryptomeria fortunei* as same as Japanese cedar (*Cryptomeria japonica*), which is widely planted in Japan.[1] Traditionally, Chinese cedar wood is used as building materials, tools, and furniture manufacturing, etc.[2] Drying is a key process to improve physical and mechanical properties of wood, and it can influence energy consumption and cost of wood products. Most research works were focused on the drying quality (checks, deformation, and drying residual stress), color change and mechanical properties of Japanese cedar. Drying methods include high temperature drying,[3,4] radio frequency/vacuum (RFV) drying,[5] vacuum-drying,[6] and conventional (CON) drying.[7] However, Chinese cedar wood exhibits poorer quality than Japanese species,[8] and the difference of moisture content and wood properties between sapwood and heartwood of Chinese cedar wood is significant. Drying quality was difficult to control in conventional kiln drying or high temperature drying process.[9]

CON drying is the most widely used drying method in wood drying.[10] The application of superheated steam (SHS) drying has been exhibited obvious advantage in reducing
both drying defects and drying time of softwoods.\textsuperscript{[11-13]} SHS drying was able to increase drying rate and evaporation rate resulted from the high heat and mass transfer coefficient, and improve drying quality; the energy efficiency was high due to re-use of the latent heat of evaporation; and the risks of explosions and burning was reduced for absence of oxygen.\textsuperscript{[14-17]} The studies in SHS drying of rubberwood\textsuperscript{[18]} and radiata pine\textsuperscript{[19]} under atmospheric pressure showed advantages in improving drying quality and reducing drying time in comparison with CON drying.

Dimensional stability and equilibrated moisture content (MC) are important physical properties, it can influence the application range of wood products. The equilibrated MC of wood can be reduced greatly, and the dimensional stability of wood can be improved after drying.\textsuperscript{[20,21]} This is resulted from the changes of wood chemical constituent, i.e. cellulose (contains crystalline and amorphous regions), hemicellulose, and lignin. High temperature in drying process affects crystallinity of cellulose and hemicellulose in different aspects, which can be revealed by dynamic mechanical analysis (DMA).\textsuperscript{[22]} The cellulose crystallinity and crystallite size determined by X-ray diffraction analysis (XRD) increased with temperature increasing in drying of rubberwood\textsuperscript{[23]} and Black Spruce.\textsuperscript{[24]}

In this paper, the effects of SHS drying and CON drying on dimensional stability and equilibrated MC of Chinese cedar wood were studied, and its mechanism was explained based on its physical and morphological properties.
MATERIALS AND METHODS

Sample Preparation

Chinese cedar (*Cryptomeria fortunei*) logs were collected from Sichuan Province, China. The small-end diameter of log is at least 25 cm. The lumber was sawn to dimension 900 mm (longitudinal) × 120 mm (tangential) × 50 mm (radial), the initial MCs are in the range of 120 - 140%. The lumber was stored in refrigerators to keep in green condition. Forty-two heart-sap-mixed wood specimens were used in each drying experiment.

Drying Procedure

Drying experiments were conducted in a kiln (HD74/TA II HILDBRAND Co, LTD. Japan) with a 0.58 m³ timber capacity. The drying schedules for CON drying and SHS drying under atmospheric pressure are listed in Table 1 and 2 respectively. The dry-bulb temperatures, wet bulb depression and the degree of superheat were based on the temporal MC of sample board. The temporal MC value was calculated from temporal weight and oven-dried weight. The oven-dried weight was predetermined by average MC of two 10-mm-thick test sections collected from sample board, and the initial weight of sample board. Six pieces of sample board were selected and placed in stacks for each drying run at full kiln capacity. The final MC was set at about 8% in drying experiments.

Sorption and Swelling of Wood at Two Environment Conditions

The artificial dried specimens and the control (air drying) specimens were cut into a size of 20 mm (longitudinal) × 20 mm (radial) × 20 mm (tangential) for determination of adsorption behavior. Thirty specimens from each drying methods and the control were
used in experiment.

All specimens were oven dried at 103°C in an oven (DKN611 Yamato Scientific Co.LTD. Tokyo Japan) to measure the weight and dimension in longitudinal, radial and tangential direction in oven-dry state. Dimension and MC of specimens were investigated at 20°C / 65% relative humidity (RH) condition (12% EMC equivalent) in a constant temperature–humidity chamber (LHU-113 ESPEC CORP Tokyo Japan), and the numerical values of individual samples were measured periodically until constant reading reached. Then the condition was set to 40°C / 90% RH (19.32% EMC equivalent), and repeat former mentioned measuring until equilibrium state.

According to the standards GB/T 1931-2009[25] and GB/T 1934.2-2009,[26] equilibrated MC (Eq.(1)) and swelling efficiency in longitudinal, radial and tangential direction (Eq.(2)) were determined. Moisture excluding efficiency (MEE) and anti-swelling efficiency (ASE) were calculated according to equation (3) and (4).[27]

\[
X = \frac{M_E - M_0}{M_0} \times 100\% \quad (1)
\]

\[
\alpha_w = \frac{l_E - l_0}{l_0} \times 100\% \quad (2)
\]

\[
\text{MEE} = \frac{X_C - X_A}{X_C} \times 100\% \quad (3)
\]

\[
\text{ASE} = \frac{\alpha_{v_c} - \alpha_{v_A}}{\alpha_{v_c}} \times 100\% \quad (4)
\]
Where $M_E$ is the weight of sample at equilibrium condition, $M_0$ is the weight of sample in oven-dry condition; $l_E$ is the dimension of sample at equilibrium condition, $l_0$ is the dimension of sample in oven-dry condition, $X_C$ is the moisture content of control samples, $X_A$ is the moisture content of samples with artificial drying methods; $\alpha_{VA}$ is the volumetric swelling efficiency of samples with artificial drying methods, $\alpha_{VC}$ is the volumetric swelling efficiency of control samples.

$$\alpha_v = \frac{V_E - V_0}{V_0} \times 100\%$$

(5)

Where $V_E$ is the volume of specimen at equilibrium condition, $V_0$ is the volume of specimen in oven-dry condition.

**Measurement of Wood Dynamic Viscoelastic Properties**

Specimens were cut into size of 60 mm (longitudinal) × 12 mm (radial) × 2.5 mm (tangential), and were equilibrated at 20°C / 65% RH condition. Tests were conducted with a TA instrument Dynamic Mechanical Analysis (DMA2980 TA Instruments USA) using a dual-cantilever bending mode with a span of 35 mm. The test parameters were the frequency of 1Hz, the temperature range from -120 to 40°C with heating rate of 2°C/min, and displacement amplitude was 15 μm. All experiments were replicated three times.

In DMA, molecules of the samples perturbed store a portion of the imparted energy elastically and dissipate a portion of that energy in the form of heat by the repeated small-amplitude strains in a cyclic manner. The modulus acquired involves two parameters: $E'$ and $E''$. The storage modulus $E'$ is defined as the in-phase or elastic response, proportional to the recoverable or stored energy. The loss modulus $E''$ is the imaginary or
viscous response, proportional to the irrecoverable or dissipated energy. In order to reduce variation of wood nonhomogeneity, the relative $E'\ (E'/E'_0)$ and the relative $E''\ (E''/E''_0)$ normalized with reference to $E'$ and $E''$ at $-120^\circ C\ (E'_0, E''_0)$ were used instead of the real values of $E'$ and $E''$, respectively.$^[28]$

**Measurement of Wood Crystallinity**

Specimens were milled into 100 mesh powder for X-ray diffraction analysis. The crystallinity of SHS-dried, CON-dried wood and the control were evaluated using diffractometer (NL-7602 EA PANalytical B.V. Almelo Netherlands). Tests were conducted under following condition, $2\theta$ value is from $5^\circ$ to $40^\circ$ with $0.05$ step, scanning speed is $2^\circ$/min, Cu-ka radiation, $35$ kV voltage, $30$ mA electric current. Each sample was replicated three times.

The crystallinity was determined by crystallinity index, which was the ratio of the integral intensity of crystalline portions to the total intensity. The following equation (Eq. (6)) was proposed by Segal method.$^[29]$

$$C_r = \frac{I_{002} - I_{am}}{I_{002}} \times 100\% . \tag{6}$$

Where $I_{002}$ is the maximum intensity of 002 lattice diffraction angle, $I_{am}$ is the scattering intensity of non-crystallinity region diffraction

The apparent crystallite size (nm) of cellulose (Eq. (7)) was calculated with Scherrer equation (Eq. (7)).$^[30]$
\[ D = \frac{K \cdot \lambda}{\beta \cos \theta}. \] 

(7)

Where \( K \) is a constant value 0.9, \( \lambda \) is the X-ray wavelength (0.15406 nm), \( \beta \) is the half-height width of the diffraction band, \( \theta \) is the Bragg angle corresponding to the (002) plane.

**Data Analysis**

Experimental data were analyzed with an analysis of variance (ANOVA) with IBM SPSS Statistics 19.0 software. Tukey’s HSD tests were performed to compare the mean values obtained from the two environment conditions, and analyze the significant effect between different drying methods at 0.05 levels.

**RESULTS AND DISCUSSION**

**Equilibrated MC of Chinese Cedar Wood at Humid Environment**

Equilibrated MC of Chinese cedar with different drying methods and the control are shown in Table 3. The results showed that the equilibrated MC was influenced by drying methods significantly. The equilibrated MC of SHS-dried and CON-dried specimens was decreased by 2.96% and 1.88% compared to that of the control samples at 20°C /65% RH condition, while the reductions were 4.33% and 2.21% at 40°C / 90% RH condition. SHS-dried specimens were equilibrated at the lowest MC among the three kinds of samples, and MC value of the control was the highest. It showed that wood was less hygroscopic after drying and MC decreased as the drying temperature increased.

MEE was used for gauging hydrophobic characteristics through drying process which
related to the reduction of MC,[31] the higher MEE means the higher hydrophobicity. The MEE values are presented in Table 4, the results showed that the SHS-dried specimens became more hydrophobic than CON-dried specimens and this ultimately increased MEE of wood. It was indicated that high temperature condition could reduce the moisture up taking properties of wood. This phenomenon was caused by reduction of cleavage of the chains or OH-groups during heating, which led to a limited interaction with water compared to control samples,[32] or hemicellulose were partly degraded during the SHS drying process.[33]

**Dimensional Stability**

Swelling efficiency and ASE were selected to evaluate dimensional stability of Chinese cedar wood. The results in Table 5 showed that the effect of SHS drying on dimensional stability was significantly at 0.05 levels. Dimensional stability of Chinese cedar wood was improved by artificial drying in comparison with the control group, and the dimensional stability of SHS-dried specimens was better than that with CON-dried. Swelling efficiency in tangential/radial directions and volumetric value decreased as drying temperature increasing. Moisture absorption decreasement of wood caused the reduction of swelling efficiency. The physical damage of wood cell wall may occurred to a certain extent during drying process, which effectively decreased the adsorption area of the cell wall and led to swelling efficiency decreased.[34]

The ASE of wood was listed in Table 6. The volume changes during adsorption stage were due to the adsorbed bound water, which contribute to wood swelling.[35] The results
showed that drying treatment was able to improve ASE, the higher the drying
temperature was, and the higher the improved extent was. The ASE of SHS-dried wood
was considerably higher than that of CON-dried wood at both environment conditions,
and this was more significant at higher humid conditions.

The analysis from swelling efficiency and ASE can induce that swelling efficiency of
SHS-dried wood was greater than that of CON-dried wood and the controls. Additionally,
SHS-dried wood exhibited greater ASE than that of CON-dried wood. Therefore, it was
concluded that the SHS drying was able to improve dimensional stability.

**Wood Dynamic Viscoelastic Properties**

The temperature dependencies of \( E'/E'_0 \) and \( E''/E''_0 \) were shown in Fig. 1 for SHS-dried, CON-dried, and control specimens. It showed that \( E'/E'_0 \) decreased as temperature
increasing (Fig 1a), it was due to softening of wood as temperature increasing.\(^{[29]}\)
However, the extent of decreasing was different among three kinds of samples from -100
to 40°C; the decreasing rate for CON-dried wood and the control were larger. The \( E'/E'_0 \)
of SHS-dried and CON-dried wood was higher than that of control. In Fig. 1a, the values
of \( E'/E'_0 \) for SHS-dried, CON-dried and the control specimens were 82, 78 and 76%,
respectively at temperature of 0°C, which indicated that the MC of SHS-dried samples
was lower than that of CON-dried and control samples at the same condition. The
stiffness of wood was decreased with the presence of water, and induced the softening of
wood.\(^{[36]}\) Therefore, the less dropped in \( E'/E'_0 \) the lower the MCs with the increased
temperature.
As for \( E''/E'_{0} \), two relaxation processes, which labeled as \( \alpha \) and \( \beta \) relaxation process respectively, were observed for artificial drying and the controls. The \( \alpha \) relaxation process, ranging between 34 and 36°C, was attributed to the local motion of wood components, especially hemicellulose related to moisture. In addition, the \( \beta \) relaxation process between -104 and -101°C indicated that the reorientation of methyl groups in amorphous region of the cell wall and reorientation of absorbed moisture molecule.

Fig 1b showed that the intensity of \( \alpha \) loss peak of SHS-dried wood was obviously higher than those with CON-dried wood and the controls, resulting from the glass transition of hemicellulose with low molecular weight.

Whereas the intensity of \( \beta \) loss peak of the control was slightly higher than those of artificial dried samples. This may be caused by the motions of methyl groups, which requires more activation energy and occurred easily in the amorphous region of wood cell wall. However, the \( \beta \) loss peak of SHS-dried samples occurred at a slightly higher temperature than that of CON-dried and the controls at the same humid condition, which indicated that the MC of SHS-dried samples was lower. Therefore, the results of \( E'/E'_{0} \) and \( E''/E''_{0} \) were the same which all confirmed the greater MEE of SHS-dried samples than that of CON-dried samples.

**Wood Crystallinity**

X-ray diffraction curves were demonstrated in Fig 2. There were three typical type I cellulose patterns with 101, 002 and 040 peaks which observed near \( 2\theta=15^\circ, 22^\circ \) and \( 34^\circ \) respectively. The most significant diffraction peak (002) at \( 2\theta=22.40^\circ \) for the control
specimen, whereas the diffraction peak at 2θ=20.32° and 20.37° for SHS-dried and CON-dried wood, respectively. These shifts of peak positions could be attributed to thermal expansion.[43]

Cellulose crystallinity and crystallite size is the most important crystalline structure parameters. The results were shown in Table 7. The cellulose crystallinity (Cr) of artificial dried Chinese cedar was higher than that of the control; this indicates the increment of wood crystallinity. The cellulose crystallinity of SHS-dried wood was higher than that with CON-dried wood. The increase in crystallinity was due to crystallization of the amorphous regions, which caused by rearrangement or reorientation of cellulose molecules.[24] On the other hand, the decreasing of hydroxyl groups was caused by the chemical reaction, allowing the formation of ether bonds led to reduce distance of cellulose molecular.[44] This phenomenon is more significant in SHS-dried wood.[45] Therefore, ASE and MEE were increased from the earlier results. A similar trend was also observed in the crystallite size (D_{002}), and the same crystal type (002) but different crystallite size was suitable to investigate the relationship between drying and the structure of cellulose. The cellulose crystallinity increased with increasing crystallite sizes because of the crystallites surface corresponding to amorphous region diminished.[46,47] This is consistent with the $^{13}$C NMR result that the amorphous signal in the spectra could be considered to be due to the chain conformation on the crystallite surface.[48]
The $E'/E'_0$ of SHS-dried wood was higher than that of CON dried and the controls from Fig.1a, which indicated that wood dynamic elastic modulus was positively correlated to the increase of cellulose crystallinity.[31] Amorphous regions of the cellulose may crystallize to a certain extent in high temperature environment. These results indicate that artificial dried samples contain more ordered cellulose structure and cellulose chains in a highly organized order than the controls.[49]

**CONCLUSIONS**

The effect of drying methods on moisture absorption and dimensional stability of Chinese cedar wood was investigated at two humid conditions. The analysis with DMA and XRD were used to explain the changing mechanism of ASE and MEE for artificial dried wood. The following conclusions were drawn:

1. The equilibrated MC of Chinese cedar wood with superheated steam drying and conventional drying was decreased compared to that of the control in the selected humid environment, and MEE of wood with superheated steam drying was higher than that of conventional drying. The high temperature in superheated steam drying process decreased the moisture absorption of Chinese cedar wood.

2. The swelling efficiency of Chinese cedar wood with superheated steam drying and conventional drying was decreased in tangential direction, radial direction, and volumetric in comparison with that of the control in humid environment. ASE of wood with superheated steam drying was higher than that of conventional drying. The dimensional stability of Chinese cedar wood with superheated steam drying is guaranteed in service.
3. The analysis from DMA and XRD indicated that glass transition and crystallization were occurred in hemicellulose of artificial dried wood, and hydroxyl groups were decreased. The cellulose crystallinity and crystallite size were increased with increasing temperature. These resulted in the low hygroscopic and high dimensional stability.

ACKNOWLEDGEMENTS
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Table 1. Superheated steam drying schedule for Chinese cedar Lumber

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Degree of superheat (°C)</th>
<th>Relative humidity (%)</th>
<th>Equilibrium moisture content * (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;60</td>
<td>3</td>
<td>90</td>
<td>13.3</td>
</tr>
<tr>
<td>60-40</td>
<td>5</td>
<td>84</td>
<td>10.9</td>
</tr>
<tr>
<td>40-30</td>
<td>10</td>
<td>71</td>
<td>7.2</td>
</tr>
<tr>
<td>&lt;30</td>
<td>15</td>
<td>60</td>
<td>5.8</td>
</tr>
</tbody>
</table>

* mean the equilibrium moisture content of climate
Table 2. Conventional drying schedule for Chinese cedar Lumber

<table>
<thead>
<tr>
<th>Moisture content (%)</th>
<th>Dry bulb temperature (°C)</th>
<th>Wet bulb depression (°C)</th>
<th>Relative humidity (%)</th>
<th>Equilibrium moisture content (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&gt;60</td>
<td>55</td>
<td>2</td>
<td>90</td>
<td>15.6</td>
</tr>
<tr>
<td>60-40</td>
<td>58</td>
<td>4</td>
<td>81</td>
<td>13.8</td>
</tr>
<tr>
<td>40-30</td>
<td>61</td>
<td>7</td>
<td>70</td>
<td>10.6</td>
</tr>
<tr>
<td>30-20</td>
<td>65</td>
<td>11</td>
<td>57</td>
<td>8</td>
</tr>
<tr>
<td>20-15</td>
<td>70</td>
<td>15</td>
<td>47</td>
<td>6.4</td>
</tr>
<tr>
<td>&lt;15</td>
<td>75</td>
<td>22</td>
<td>34</td>
<td>4.4</td>
</tr>
</tbody>
</table>
**Table 3.** The equilibrated MC at two humid conditions

<table>
<thead>
<tr>
<th>Drying method</th>
<th>20°C/65%RH</th>
<th>40°C/90%RH</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean value</td>
<td>HG*</td>
</tr>
<tr>
<td>SHS drying</td>
<td>9.18 ± 0.71</td>
<td>a</td>
</tr>
<tr>
<td>CON drying</td>
<td>10.26 ± 0.62</td>
<td>b</td>
</tr>
<tr>
<td>Control</td>
<td>12.14 ± 0.28</td>
<td>c</td>
</tr>
</tbody>
</table>

*HG: Homogeneity groups, mean with the same letter in “Tukey’s HSD test” are not significantly different at 0.05 level. Standard deviation is indicated at “±”. The same below.*
Table 4. Effects of drying methods on moisture excluding efficiency of Chinese cedar wood

<table>
<thead>
<tr>
<th>Drying method</th>
<th>Moisture Excluding Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C/65% RH</td>
</tr>
<tr>
<td>SHS drying</td>
<td>24.38</td>
</tr>
<tr>
<td>CON drying</td>
<td>15.49</td>
</tr>
</tbody>
</table>
Table 5. The swelling efficiency at two set conditions

<table>
<thead>
<tr>
<th></th>
<th>T</th>
<th>R</th>
<th>V</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean value</td>
<td>HG</td>
<td>Mean value</td>
</tr>
<tr>
<td>20°C/65%RH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHS drying</td>
<td>2.62 ±0.39</td>
<td>a</td>
<td>2.08 ±0.38</td>
</tr>
<tr>
<td>CON drying</td>
<td>3.38 ±0.39</td>
<td>b</td>
<td>2.36 ±0.43</td>
</tr>
<tr>
<td>control</td>
<td>3.82 ±0.62</td>
<td>c</td>
<td>2.55 ±1.13</td>
</tr>
<tr>
<td>40°C/90%RH</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SHS drying</td>
<td>3.03 ±0.75</td>
<td>a</td>
<td>2.40 ±0.45</td>
</tr>
<tr>
<td>CON drying</td>
<td>3.81 ±1.11</td>
<td>b</td>
<td>2.87 ±0.67</td>
</tr>
<tr>
<td>control</td>
<td>4.39 ±0.95</td>
<td>b</td>
<td>3.15 ±1.13</td>
</tr>
</tbody>
</table>

*T mean tangential R mean radial V mean volumetric
Table 6. Effects of drying methods on anti-swelling efficiency of Chinese cedar wood

<table>
<thead>
<tr>
<th>Drying method</th>
<th>Anti-Swelling Efficiency (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>20°C/65% RH</td>
</tr>
<tr>
<td>SHS drying</td>
<td>17.68</td>
</tr>
<tr>
<td>CON drying</td>
<td>6.22</td>
</tr>
</tbody>
</table>
Table 7. Effects of drying methods on XRD parameters of Chinese cedar wood

<table>
<thead>
<tr>
<th>Drying method</th>
<th>Peak position at $2\theta$ (°)</th>
<th>$C_r$ (%)</th>
<th>$D_{002}$ (nm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SHS drying</td>
<td>22.32</td>
<td>36.32</td>
<td>3.13</td>
</tr>
<tr>
<td>CON drying</td>
<td>22.37</td>
<td>29.00</td>
<td>2.25</td>
</tr>
<tr>
<td>control</td>
<td>22.40</td>
<td>21.65</td>
<td>1.81</td>
</tr>
</tbody>
</table>
Figure 1. (a) The temperature dependencies of $E'/E'_0$ for Chinese cedar wood equilibrated at 12% EMC condition. (b) The temperature dependencies of $E''/E''_0$ for Chinese cedar wood equilibrated at 12% EMC condition.
**Figure 2.** Effects of drying methods on X-ray diffraction patterns of Chinese cedar wood
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