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NOTE

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Vibrational properties of heat-treated green wood

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Abstract To investigate the influence of water on heat treatment, green wood was heat-treated. Sitka spruce (*Picea sitchensis* Carr.) with about 60% moisture content (MC) was used. Young's modulus and loss tangent were measured by the free–free flexural vibration test. The specimens were heated in nitrogen at 160°C for 0.5h. The results were as follows. (1) Recognizing that the effects of heat treatment are mild and that the same specimens cannot be used for both heat treatment and as controls, it was necessary to investigate the effects of the heat treatment based on the variations of properties in the whole of the test lumber. (2) Young's modulus increased and the loss tangent decreased due to heat treatment. When the vibrational properties were measured at various MCs, the MCs at the maximum value of Young's modulus and the minimum value of the loss tangent were lower in heat-treated specimens than in controls. The effects of heat treatment in green wood were similar to those in air-dried wood. (3) The loss tangents of heat-treated specimens were smaller than those of controls at about 0% MC but were larger than those of controls at about 10% MC. We thought that this resulted from the decreased MC at the minimum loss tangent after the heat treatment mentioned above. (4) The properties measured at several MCs were more useful than those at only one moisture content for investigating the effects of heat treatment.

Key words Green wood · Heat treatment · Vibrational properties · Variation in wood · Moisture content

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Introduction

In a previous paper[1] we examined the vibrational properties of sitka spruce heat-treated in nitrogen gas or in air. The density decreased at high temperature and with a long heating time. Roughly, the specific Young's modulus, specific shear modulus, crystallinity index, and crystalline width increased with time at the initial stage and then decreased later. The loss tangent in the longitedinal (L)-direction increased at all condition, whereas that in the radial (R)-direction decreased.

It is well known that various damage, such as collapse and checking of wood lumber, is caused when the lumber is dried at high speed. On the other hand, study of the structural changes of cellulose molecules in a noncrystalline region by hydrothermal treatment showed that the presence of water markedly enhanced depolymerization and crystallization to cellulose IV.[2]

We thought that the effects of heat treatment on wood properties are influenced by its moisture content before the heat treatment, as well as by oxidation in air or temperatures during the heating. Therefore, we investigated the influence of water on heat treatment.

In this study, the same specimen could not be used for both heat treatment and as the control. It is notable that the effects of heat treatment on wood properties are not as drastic as those of chemical treatments. Hence, comparing the properties of heat-treated specimens with those of controls simply is not reasonable. Therefore, we tried eliminating the variable of vibrational properties in the test lumber.

Experiment

Specimen

Sitka spruce (*Picea sitchensis* Carr.) with 60% moisture content (MC) were used. L-direction and R-direction specimens for the vibration tests were carefully cut to the dimensions of 180mm (L) × 25mm (R) × 8mm (T) and 110mm (R) × 25mm (L) × 8mm (T), respectively.

The specimens were matched in the L-direction as shown in Fig. 1. The specimens with odd numbers were used for the heat treatment and those with even numbers for the control in both L-direction and R-direction specimens. The oven-dried weight was measured after all the vibration tests.

Vibration tests

To obtain Young's modulus and the loss tangent, the free–free flexural vibration test was conducted by the same method as described in our previous paper.[1]

Heat treatment

As in our previous paper,[1] the specimens were encapsulated in a pressure-resistant stainless steel potable reactor. The gases in the potable reactors were not refreshed during the heat treatment. The reactor was then heated in a constant-temperature (160°C) oven for 0.5h. After the heat treatment, the specimens were vacuum-dried at room temperature. The moisture content of the specimens was then increased by leaving the specimens at 20°C and 11%, 33%, 65%, 75%, and 98% relative humidity (RH). When the weight of the specimens became constant at each relative humidity, they were tested.

Results and discussion

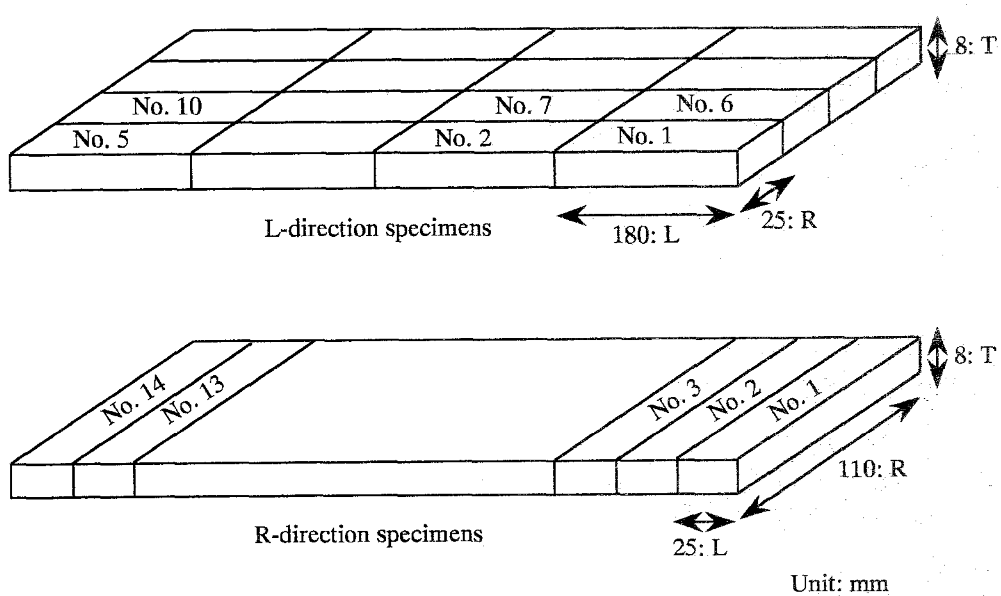
Figure 2 shows the variation in Young's modulus. Young's modulus in the R-direction (E_R) decreased with the increase in specimen number because the angle between the thickness direction and the tangential direction (annual ring angle) increased from 0° to 10° with the increase in specimen number.

It is believed that the effect of heat treatment on E_R is not clear by this variation of E_R because the effects of heat treatment are mild and different specimens must be used for controls and for the heat treatment. Therefore, we tried to eliminate the variation as follows.

It is possible that all the values of E_R of heat-treated specimens are larger than those of controls when the matching pairs are (no. 1, no. 2), (no. 3, no. 4).... On the other hand, those of the heat-treated specimens may be smaller than those of controls when the matching pairs are (no. 2, no. 3), (no. 4, no. 5).... Here, variations of wood properties are usually thought to be gradual in the L-direction. We then noted that E_R was changed by the heat treatment when the E_R of the heat-treated specimens was not the original variation of E_R in the lumber, which is expressed by the controls in this study. The same method was adopted for the E_L in Fig. 2, specific Young's modulus in Fig. 3, and loss tangent in Fig. 4.

In regard to the variation of Young's modulus in the L-direction, (E_L) was increased by the heat treatment at nos. 6–10, whereas there were no clear effects of the heat treatment at nos. 1–5. In the region of nos. 1–5, the E_R was increased by the heat treatment, whereas there were no clear effect of the heat treatment at nos. 6–14. The specific Young's modulus behaved similarly to Young's modulus, as shown in Fig. 3. The Young's modulus and specific Young's

Fig. 1. Preparation of specimens



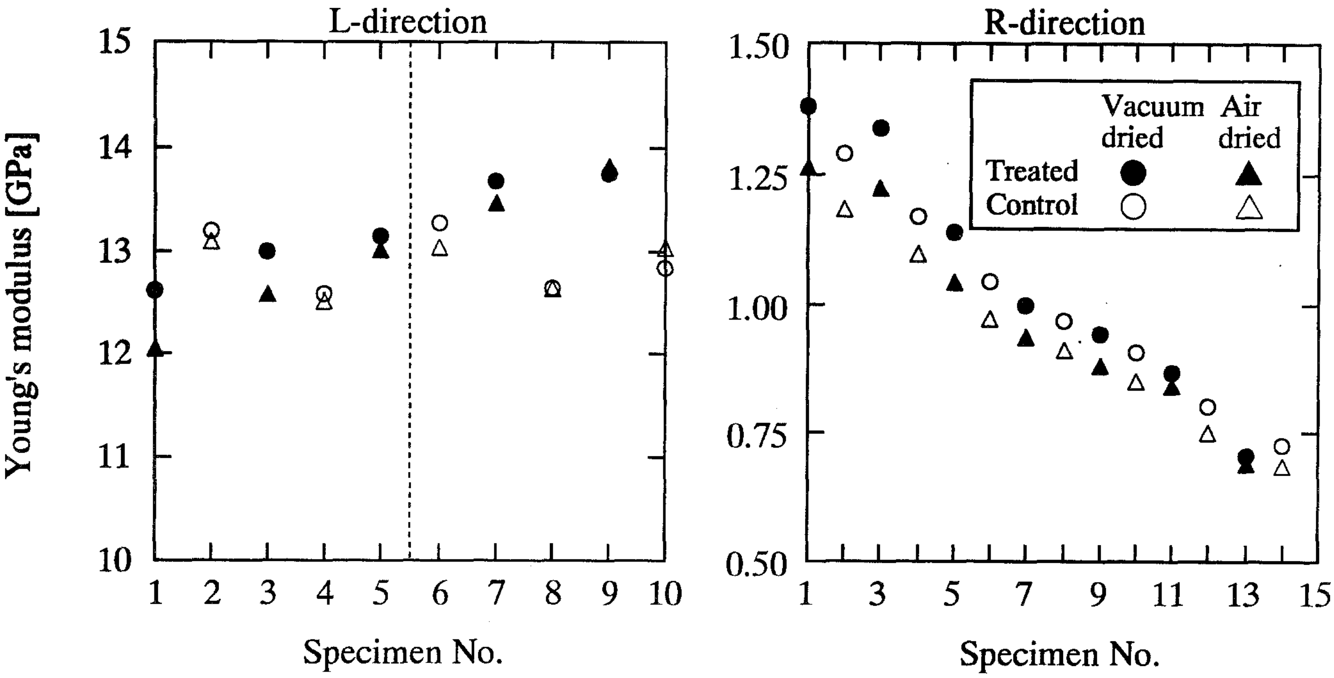


Fig. 2. Variation of Young's modulus. *Filled circles*, heat-treated, measured in a vacuum-dried state, *open circles*, control, measured in a vacuum-dried state; *filled triangles*, heat-treated, measured at 20°C and 65% RH; *open triangles*, control, measured at 20°C and 65% RH

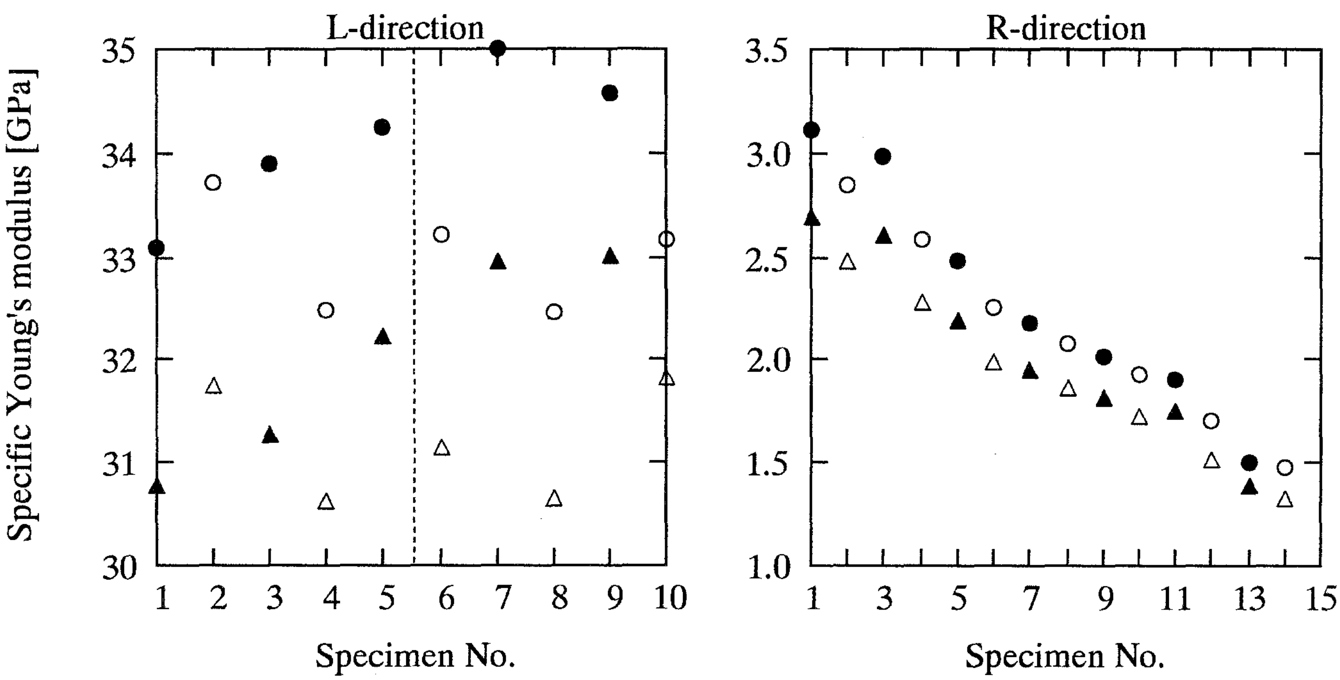


Fig. 3. Distribution of specific Young's modulus. Symbols: refer to Fig. 2

modulus were measured in an oven-dried state or air-dried state, and the tendencies of their changes by the heat treatment were similar.

Figure 4 shows the variation of loss tangent. In terms of the variation of loss tangent in the L-direction ($\tan\delta_L$) of vacuum-dried specimens, the $\tan\delta_L$ was decreased by heat treatment at nos. 6–10, whereas there were no clear effects of the heat treatment at nos. 1–5. The loss tangent in the R-direction, $\tan\delta_R$, of vacuum-dried specimens decreased in almost all regions. On the other hand, loss tangents of the specimens conditioned in 65% RH increased in several cases, such as the $\tan\delta_L$ in nos. 1–4 and the $\tan\delta_R$ of nos. 1–5. This difference in the loss tangent due to relative humidity is discussed later.

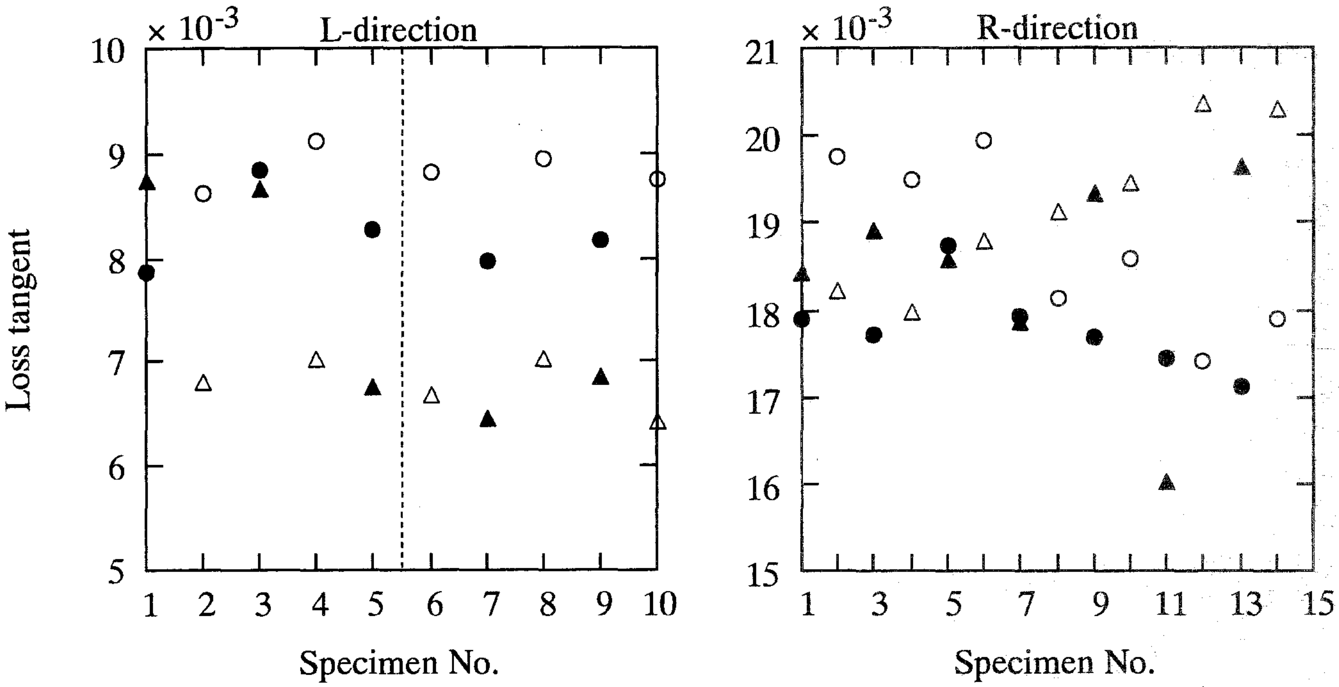


Fig. 4. Distribution of loss tangent. Symbols: refer to Fig. 2

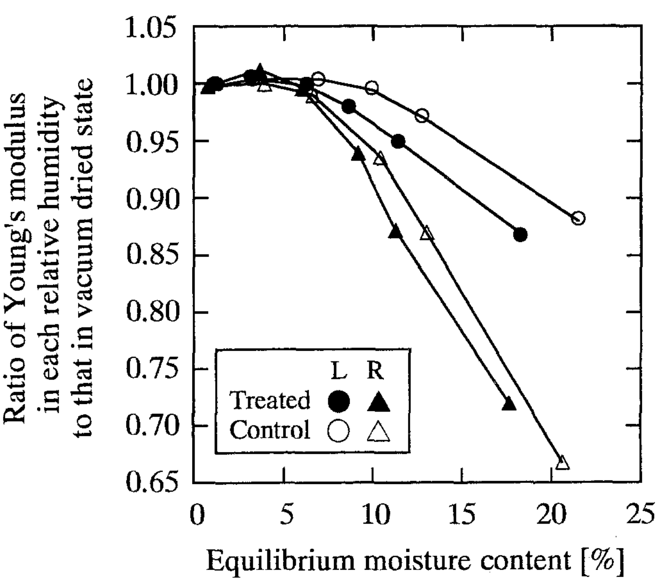


Fig. 5. Changes in Young's modulus at various moisture contents. *Filled circles*, values for L-direction of heat-treated specimens; *open circles*, values for L-direction of controls; *filled triangles*, values for R-direction of heat-treated specimens; *open triangles*, values for R-direction of controls

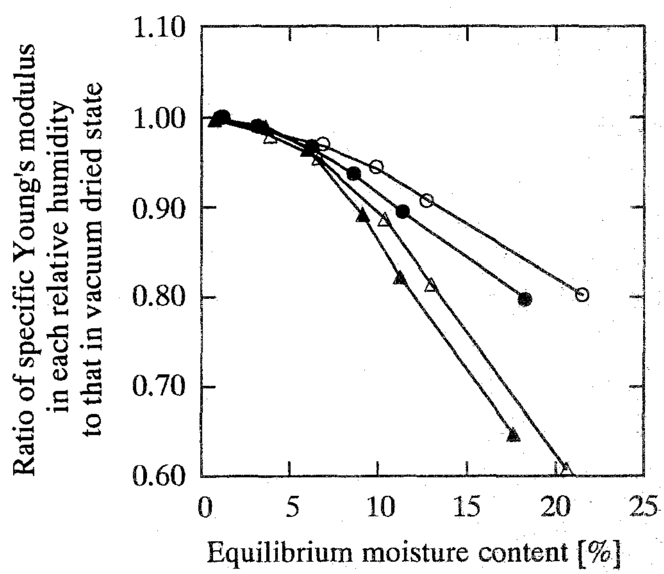


Fig. 6. Changes in specific Young's modulus at various moisture contents. Symbols: refer to Fig. 5

Figure 5 shows the change in Young's modulus at various moisture contents. The values in Figs. 5–7 are averages of the heat-treated specimens or controls. Both E_L and E_R had their peak values during the initial stage, decreasing later with an increase in moisture content as previously reported.[3] Comparing the curves of heat-treated specimens and controls, it was found that the moisture contents at the peak value were lower in the heat-treated specimens than in controls. Suzuki and Nakato[4] have reported that the moisture content at the maximum Young's modulus decreased toward a lower moisture content with an increase in the heating temperatures.

Specific Young's modulus decreased monotonically, as shown in Fig. 6. Comparing the curves of the heat-treated specimens and controls, it was found that the curves of the heat-treated specimens bent more to the left; that is, the values of specific Young's moduli of the heat-treated specimens were lower than those of the controls.

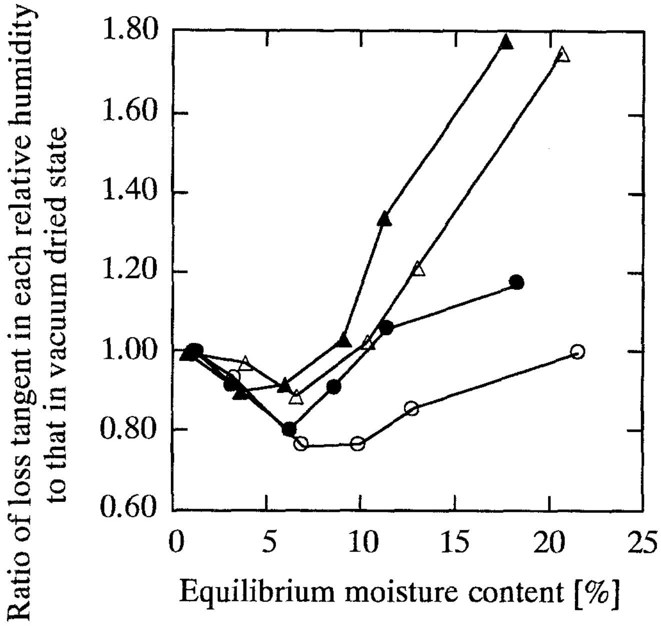


Fig. 7. Changes in loss tangent at various moisture contents. Symbols: refer to Fig. 5

Figure 7 shows the change in loss tangent at various moisture contents. Both $\tan\delta_L$ and $\tan\delta_R$ had their minimum values during the initial stage, increasing later with an increase in moisture content as previously reported.[5] Comparing the curves of the heat-treated specimens and the controls, it was found that the moisture content at the minimum value of the loss tangent was lower in heat-treated specimens than in controls. This finding has also been reported by Suzuki and Nakato.[4]

The shift in moisture content at the maximum Young's modulus and the minimum loss tangent to lower values were related to a decrease in absorption points by the heat treatment.[4] Hence, it is thought that the decrease of absorption points was caused by the heat treatment of green wood (Figs. 5–7).

It is thought that this shift in moisture content influences the difference in the tendency of the loss tangent shown in Fig. 4. When the moisture content at the minimum loss tangent of the heat-treated specimens decreased, loss tangents at 5%–10% MC consequently become larger than those of controls. Although the loss tangents of heat-treated specimens were smaller than those of controls in the vacuum-dried state, in the region of 5%–10% MC the loss tangents of heat-treated specimens increased more than those of the controls with an increase in moisture content. It is thought that this produced the differences in tendencies of the moisture content of the specimens during the vibration tests, as shown in Fig. 4.

The change in Young's modulus due to the moisture content in the region of 0–10% MC is not as large as that of the loss tangent. Hence, it is thought that the variations of Young's modulus in the test lumber which consist of the heat-treated specimens and the controls (Fig. 2) are independent on the relative humidity in measuring them.

The shift mentioned above was found by measuring these properties at several relative humidities. Hence, the properties measured at various moisture contents were more useful than those measured at only one moisture content for investigating the effects of heat treatment.

Conclusions

Green wood of sitka spruce was heated in nitrogen at 160°C for 0.5 h. Results obtained were as follows: (1) Because the effects of heat treatment are mild and the same specimens cannot be used for both heat treatment and as controls, it is necessary to investigate the effect of the heat treatment by the variations of properties in the entire test lumber. (2) Young's modulus was increased and the loss tangent was decreased by heat treatment. When the vibrational properties were measured at various moisture contents, the moisture contents at the maximum value of Young's modulus and the minimum value of the loss tangent were lower in heat-treated specimens than in controls. These effects of heat treatment on green wood were similar to those on air-dried wood. (3) The loss tangents of heat-treated specimens were smaller than those of controls at about 0% MC, whereas they were larger at about 10% MC. We believer this resulted from the decreased moisture content at the minimum loss tangent after the heat treatment mentioned above. (4) The the properties measured at various moisture contents were more useful than those at only one moisture content for investigating the effects of heat treatment.

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