CHANGES IN VIBRATIONAL PROPERTIES OF WETWOOD OF JAPANESE FIR (*ABIES SACHALINENSIS* MAST) WITH TIME DURING DRYING

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ABSTRACT

Temporal changes in vibrational properties of wetwood of Japanese fir (*Abies sachalinensis* Mast.) during a drying process were investigated. Specimens were cut from wetwood defined as heartwood with extremely high moisture content and normal wood whose moisture content was not so high, and matched in the R-direction. Green and water-saturated wood specimens were prepared. The specimens and the vibration testing system were put in an electric drying oven, where a free-free vibration test was conducted at intervals of 5 to 20 minutes. When the green specimens were used, the resonance frequency and loss tangent of both wetwood and normal wood reached the minimum and maximum, respectively, early in the drying. The minimum and maximum of the wetwood were smaller and larger than those of the normal wood. These differences between the wetwood and normal wood were mainly caused by the differences in initial moisture content because such differences, which existed in the green wood, disappeared once a water-saturated condition was reached.

Keywords: Wetwood, Japanese fir, vibrational properties, high-temperature drying.

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INTRODUCTION

In Hokkaido prefecture, which is located at the northern end of Japan, todomatsu (*Abies sachalinensis* Mast.), a kind of Japanese fir, is one of the main plantation-grown wood species (Hokkaido 2000). However, several issues make effective utilization of todomatsu difficult, the most serious of which is the wetwood included in the todomatsu trees.

Wetwood, defined as heartwood with extremely high moisture content, increases the time and costs for drying and can induce drying checks, cracking, and other damage. At the Forest Products Laboratory in the United States, a drying schedule for cottonwood lumber with wetwood has been proposed separately from that without wetwood. Once a proper drying schedule is established for todomatsu lumber with wetwood, these obstacles can be overcome and greater utilization of todomatsu will be accelerated.

To establish the drying schedule of lumber, it is important to understand the changes that occur in elasticity and viscoelasticity during heating, because these properties often dominate the strength of wood. Although there are several studies examining the strength after drying of lumber with wetwood (Kitamura 1941; Takizawa et al. 1976; Yoshimoto and Shida 2001), there are few studies of wood properties during the drying process.

From this point of view, the vibration test is an effective method for monitoring elastic and viscoelastic properties without breaking the specimens. Thus, the object of this study is to determine whether or not the temporal changes in the vibrational properties of wetwood are different from those of normal wood during drying.

EXPERIMENT

Specimens

Todomatsu (*Abies sachalinensis* Mast.) lumber in green condition was used in the experiment. Specimens were cut from the wetwood and normal wood of the same lumber. The dimensions of the specimens were 180 mm (longitudinal direction, L) by 25 mm (radial direction, R) by 10 mm (tangential direction, T). The wetwood and normal wood were matched in the R-direction with each other.

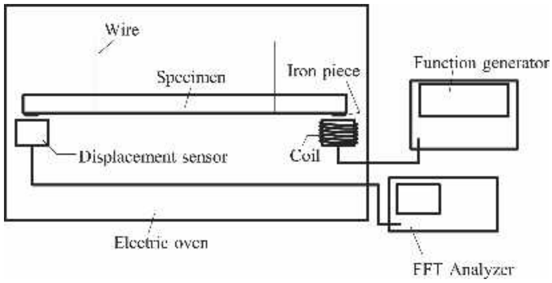

FIG. 1. Apparatus for the vibration test.

Some green wood specimens were water-saturated. The average moisture content of the green wood specimens was 141% for the wetwood and 76% for the normal wood. The average moisture content of the water-saturated wood specimens was 221% for the wetwood and 208% for the normal wood. The specimens were heated at a constant temperature (100°C, 120°C, or 140°C) and then oven-dried at 105°C.

Vibration test

Using the same method as in a previous study (Kubojima et al. 2001), a free-free flexural vibration test was conducted to obtain resonance frequency and loss tangent. Figure 1 shows the apparatus of the vibration test. The test beam was suspended by two wires of 0.12-mm diameter at the nodal positions of the free-free flexural vibration corresponding to its first resonance mode. It was excited in the T-direction at one end by a magnetic driver (ELECTRO Corporation, High Temperature Speed Sensor 3030

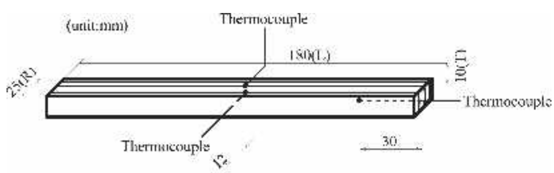

FIG. 2. Thermocouples for measuring the surface and interior temperatures of the specimens. Thermocouples were placed on the LR-plane and inserted in the R-direction at a depth of 12 mm from the central point of the LT-plane and in the L-direction at a depth of 30 mm at the central point of the RT-plane.

HTB, temperature range: −73 to +273°C). The motion of the beam was detected by a displacement sensor (KEYENCE Corporation, High Accuracy Positioning Sensor SH-816, temperature range: −10 to +200°C, linear range 1 to 2 V) at the other end. The signal was processed through a fast Fourier transform (FFT) digital signal analyzer (ONO SOKKI Corporation, Multi-Purpose FFT Analyzer CF-5220).

The loss tangent was calculated from the width at −6 dB from the peak of the resonance curve. The resonance frequency range of the specimens was about 880–1650 Hz. In this frequency range, the loss tangent does not depend on frequency (Yano et al. 1986a; 1986b; 1992; Ono and Kataoka 1979). It took 100 s to draw a resonance curve.

Measurement of wood properties during heating

The temperatures were measured at three points with T-type thermocouples as shown in Fig. 2. Thermocouples were placed on the LR-

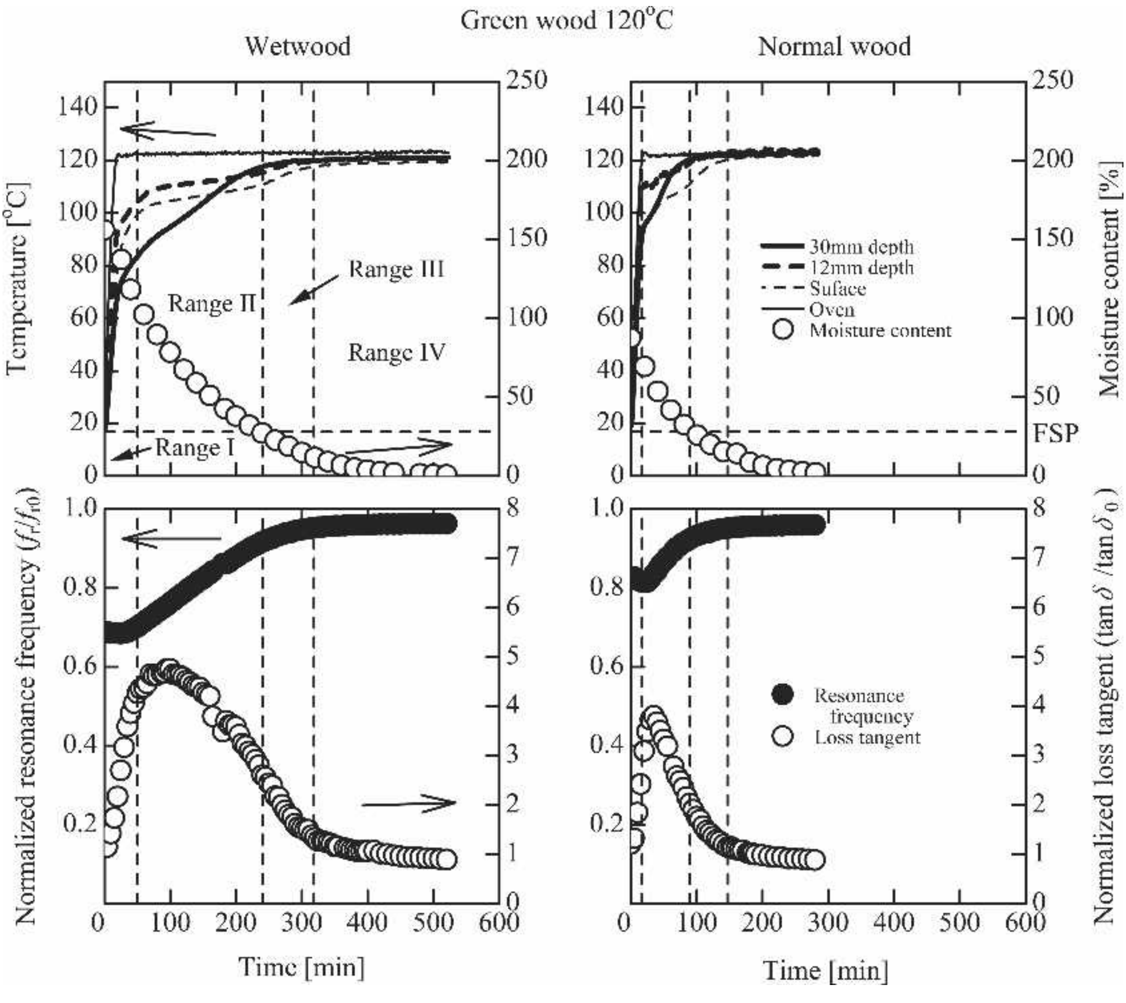

FIG. 3. Temperatures, moisture content, and vibrational properties of specimens of green wood during the drying process. Set temperature was 120°C. Changes in the specific resonance frequency (f_r/f_{r0}) and loss tangent ($\tan\delta/\tan\delta_0$) were expressed using the ratio based on the value measured at room temperature after oven-drying. Values after oven-drying are shown by the suffix 0.

plane and inserted in the R-direction at a depth of 12 mm from the central point of the LT-plane and in the L-direction at a depth of 30 mm at the central point of the RT-plane. To measure the dimensions and weight, the specimens were taken out of the oven at an interval of 20 min.

In the vibration tests, a specimen, the magnetic driver and the displacement sensor were arranged in the oven as shown Fig. 1. First, the vibration tests were conducted at room temperature (about 24°C), and then the temperature was raised to the set temperature. The vibration testing intervals were 5 to 20 minutes. After all vibration tests had been completed at the set temperatures, the specimens were oven-dried at 105°C, and then the vibration tests were conducted again at room temperature. Changes in the resonance frequency (f_r) and loss tangent (tanδ) with time were expressed using normalized values based on measurements at room temperature after oven-drying. Values after oven-drying are shown by the suffix 0.

RESULTS AND DISCUSSION

Vibrational properties of green wood

Figures 3–5 show the changes in the temperatures, moisture content, and the vibrational prop-

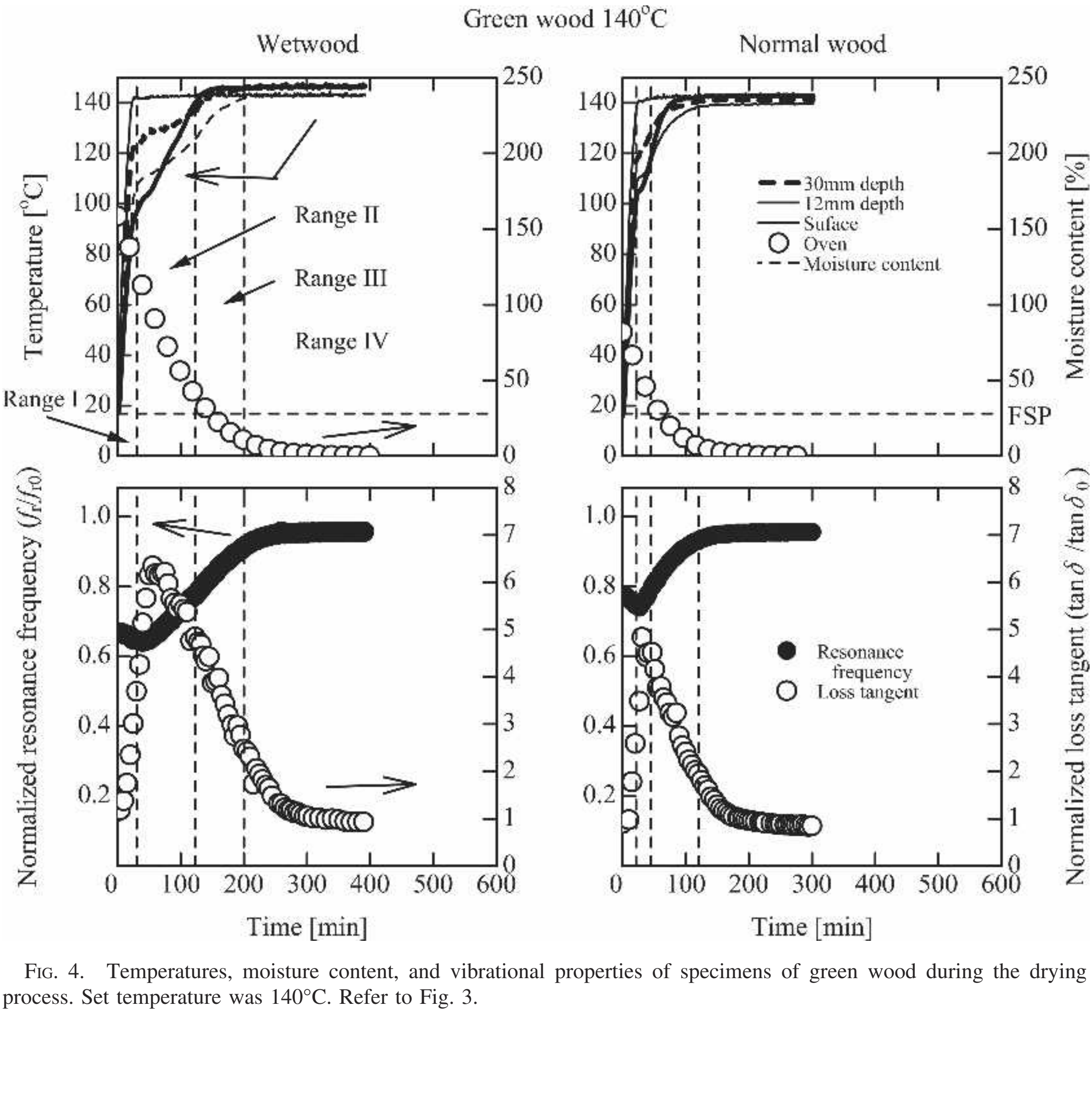

FIG. 4. Temperatures, moisture content, and vibrational properties of specimens of green wood during the drying process. Set temperature was 140°C. Refer to Fig. 3.

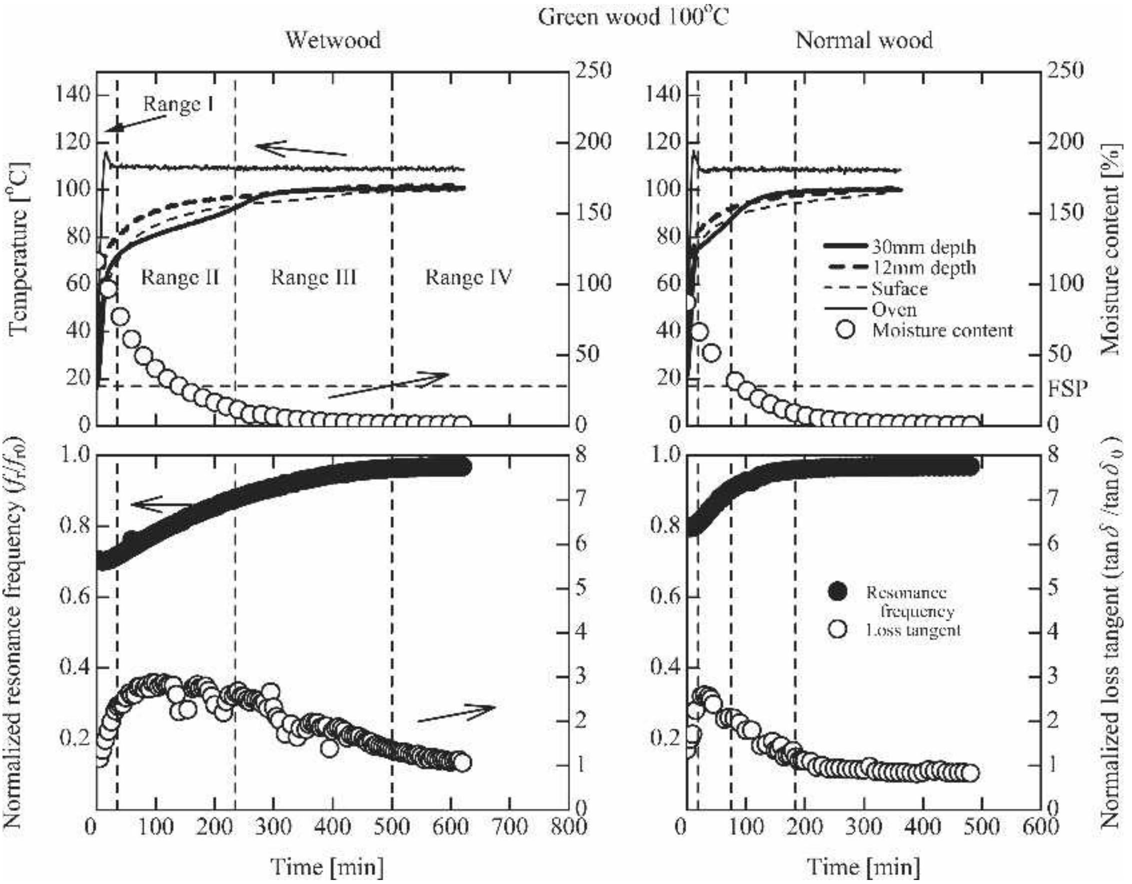

FIG. 5. Temperatures, moisture content, and vibrational properties of specimens of green wood during the drying process. Set temperature was 100°C. Refer to Fig. 3.

erties of green wood. A typical example of each set temperature is shown. The changes in the temperatures of the wetwood could be roughly divided into the following four ranges. In Range I, the temperatures rose quickly. In Range II, they were constant or rose more slowly than in Range I. In Range III, the temperatures began to rise faster than in Range II. In Range IV, they were constant at the set values.

The moisture content of the wetwood decreased with time. It reached the fiber saturation point at the end of Range II or the beginning of Range III. Moisture content was constant in Range IV. The tendencies were similar to those of the previous study (Kubojima et al. 2001). The temporal changes in temperature and moisture content of the normal wood were similar to those of the wetwood.

The value of f_r/f_{r0} of the wetwood decreased in Range I, then started to increase at the beginning of Range II after reaching its minimum, and kept increasing in Range III. In Range IV, it became constant. Since the changes in dimensions were much smaller than those in the resonance frequency, the resonance frequency reflects the specific Young's modulus. On the other hand, $\tan\delta/\tan\delta_0$ increased in Range I, had a maximum at the beginning of Range II, decreased in Range III, and became constant in Range IV. Thus, the temporal change in the specific Young's modulus corresponded to that in the loss tangent. This tendency was similar to that of spruce (Kubojima et al. 2001). Temporal changes in the vibrational properties of the normal wood were similar to those of the wetwood.

The above results indicate the following: In Range I, the changes in the vibrational properties seem to have been due to thermal softening and some mechano-sorptive effects of the swelling wood. In Range II, the outer wood of the specimens was dried to some extent. The effect of the moisture decrease was larger than that of the temperature increase in Range III. In Range IV, the resonance frequency and loss tangent became constant since the temperature and moisture content were stable.

As increments of the set temperature, the minimum of f_r/f_{r0} and the maximum of $\tan\delta/\tan\delta_0$ became smaller and larger, respectively for both wetwood and normal wood. This suggests that the wood softened more at higher temperature. In heating at the same set temperature, it took longer for the wetwood to dry at each range than the normal wood. In addition, f_r/f_{r0min} and $\tan\delta/\tan\delta_{0max}$ of the wetwood were smaller and larger than the normal wood, respectively. We think that these differences between the wetwood and normal wood were caused by the initial moisture content because there were no remarkable differences in the temperature depen-

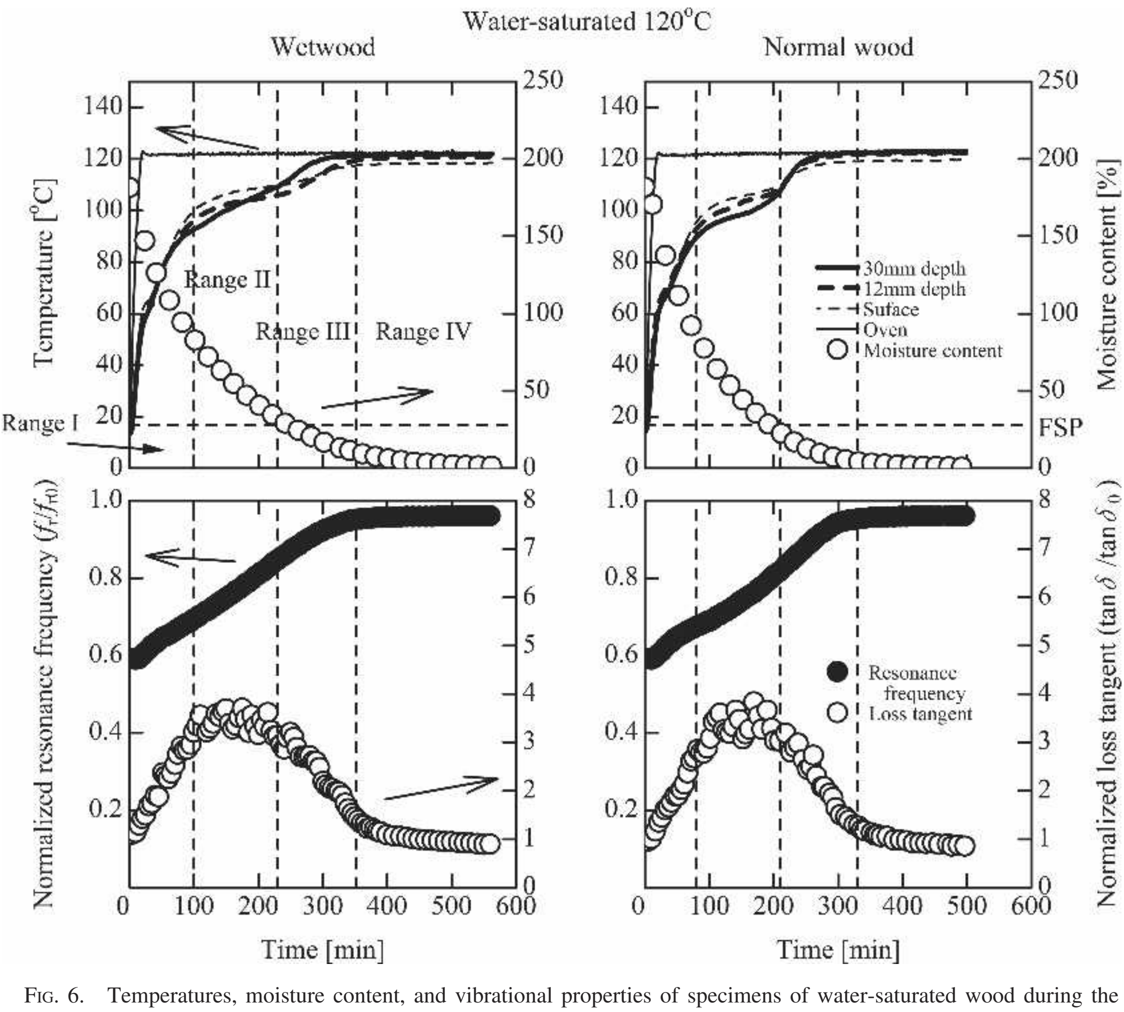

FIG. 6. Temperatures, moisture content, and vibrational properties of specimens of water-saturated wood during the drying process. Set temperature was 120°C. Refer to Fig. 3.

dencies of the vibrational properties between the wetwood and normal wood (Ohsaki et al. accepted).

Vibrational properties of water-saturated wood

The vibrational properties of the water-saturated specimens during heating were also investigated. A typical example of each set temperature was shown as with the green wood.

As shown in Figs. 6–8, trends in the temperature and moisture content were similar to those of the green wood. Moreover, the difference between wetwood and normal wood, which was seen in the drying of the green wood, disappeared. Vibrational properties also showed similar temporal changes to the green wood, and there were no significant differences between the wetwood and normal wood (Figs. 6–8). Furthermore, the values of f_r/f_{r0min} and $\tan\delta/\tan\delta_{0max}$ were similar between the wetwood and normal wood. Therefore, we concluded that the differences in the vibrational properties of todomatsu between the wetwood and normal wood during the drying process were not derived from the differences in anatomical properties of wood, that is, properties of cell walls, but instead mainly from the initial moisture content.

Hence, for lumber such as todomatsu which

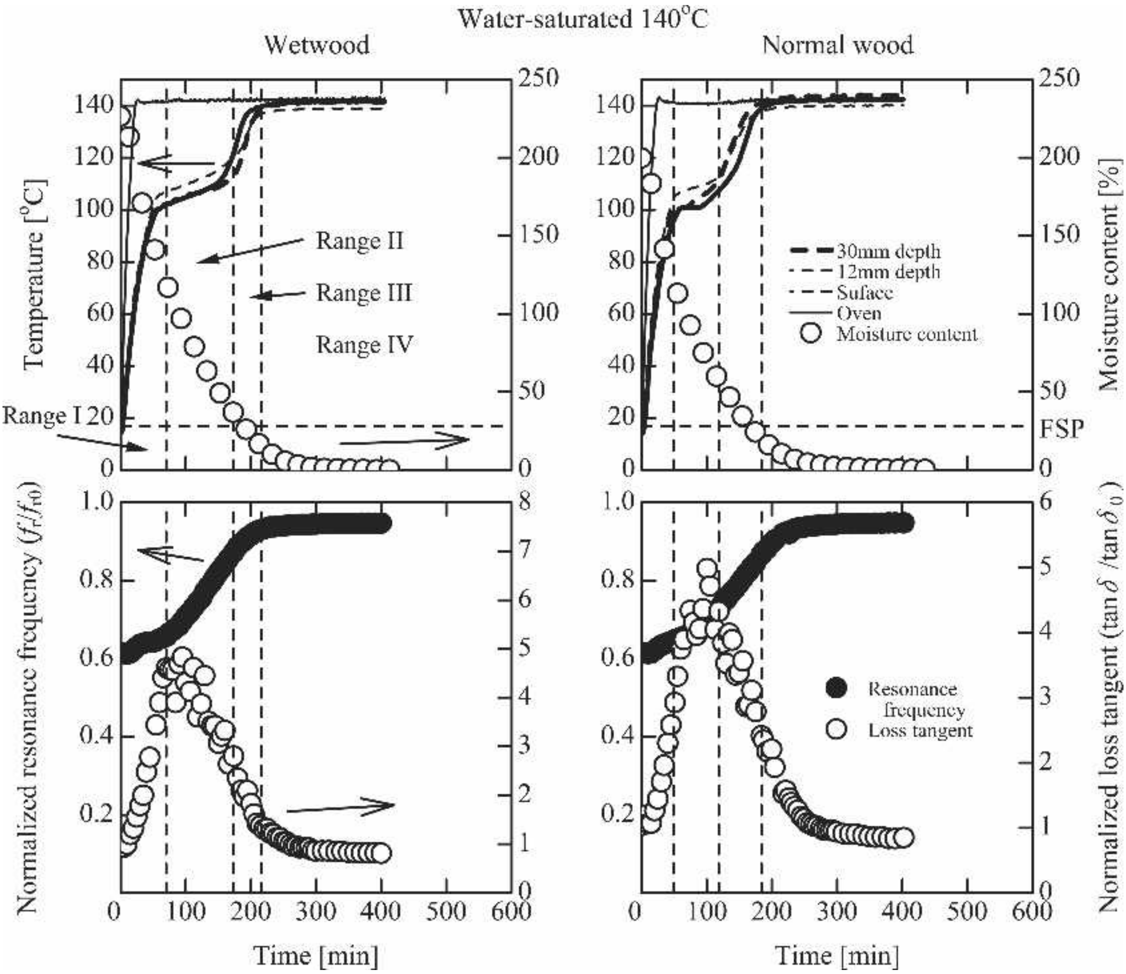

FIG. 7. Temperatures, moisture content, and vibrational properties of specimens of water-saturated wood during the drying process. Set temperature was 140°C. Refer to Fig. 3.

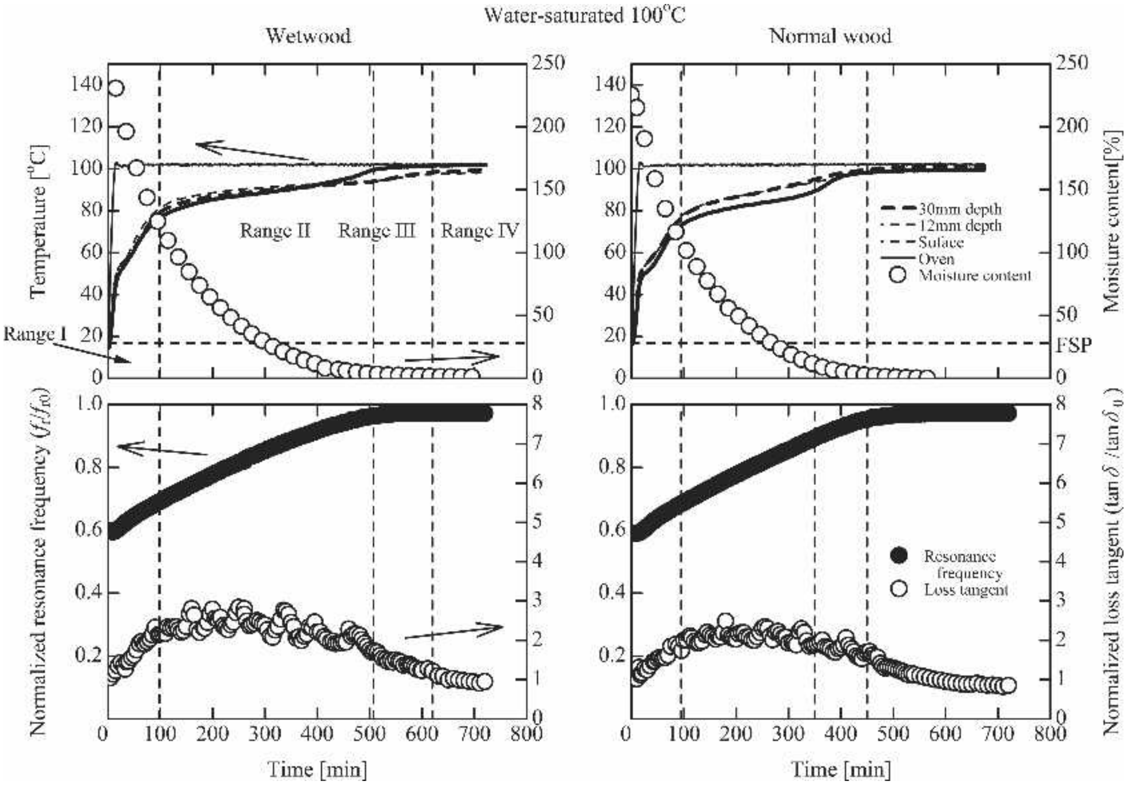

FIG. 8. Temperatures, moisture content, and vibrational properties of specimens of water-saturated wood during the drying process. Set temperature was 100°C. Refer to Fig. 3.

includes wetwood, it is necessary to develop a drying schedule that enables the difference between the wetwood and normal wood to be as small as possible. Proper drying would make wetwood suitable for structural uses.

When the set temperature was low or moisture content was high, the time point where the loss tangent reached the maximum peak lagged behind the time point where specific Young's modulus reached the minimum. Since the specimen was dried from the surface, this result suggests that specific Young's modulus was affected by moisture content of the surface, and loss tangent was affected by moisture content of the whole specimen. However, more examinations are necessary at this point.

CONCLUSIONS

We examined the temporal changes that occurred in wood of Japanese fir (*Abies sachalinensis* Mast.) during drying. The results were as follows:

1. The specific Young's modulus was minimum, and the loss tangent was maximum early in drying.
2. The difference between the wetwood and normal wood was caused mainly by the difference in the initial moisture content because there was no such difference under the water-saturated condition.
3. It is necessary to develop a drying schedule that enables the difference between the wetwood and normal wood of todomatsu to be as small as possible.
4. Wetwood of todomatsu will be suitable for various uses if it is dried appropriately.

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