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論　文（Original Article）

Real-time vibration testing method of wood during drying under high-temperature and high-humidity conditions

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Abstract

We investigated ways of conducting vibration tests under high-temperature, high-humidity conditions. Sitka spruce (*Picea sitchensis* Carr.) specimens with dimensions of 110 mm (R) × 25 mm (L) × 8 mm (T) were used. The measuring apparatus were in an airtight chamber. Vibrational properties were measured by free-free flexural vibration test and changes in the output of the displacement sensor used for the vibration test were obtained under conditions of 115 ˚C and 75 % relative humidity. Results were as follows: 1) Coating the displacement sensor with heat-resistant rubber and silicone increased its effective life. 2) Although the temperature, humidity and moisture content decreased when one displacement sensor was replaced with another one in the middle of drying, the temporal changes in the vibrational properties were not significantly affected. 3) Using coated displacement sensors with heat-resistant rubber and silicon and replacing a sensor with another one in the middle of drying were effective for obtaining vibrational properties under high-temperature, high-humidity conditions.

Key words : high-temperature and high-humidity condition, vibration test, deflection sensor, coating, replacing sensors

Introduction

In wood processing, it is important to lower drying costs by drying quickly without inducing damage such as checks, splits and honeycombs. Unfortunately, traditional and conventional high-temperature drying and vacuum drying methods can not guarantee both desirable drying speed and quality of wood products.

We have focused our attention on a high-temperature, high-humidity (more than 1 atm) treatment to develop a desirable drying method. The effectiveness of this treatment has been pointed out recently: wood is heated in non-saturated (superheated) water vapor at a controlled temperature and humidity. This should make it difficult for checks to form because the wood is softened while it is dried to some extent in this process (Saito et al., 1995; Kobayashi et al., 1995; Kobayashi et al., 1996; Kobayashi et al., 1997; Hisada, 1998).

In order to determine appropriate drying conditions, we should understand the effects on basic wood properties when water is lost by heating. For this purpose, wood properties need to be measured under high-temperature and high-humidity conditions.

One of the wood properties which is related to such wood deformation and can be measured easily *in situ* is viscoelasticity. Changes that occurred in the vibrational properties of wood during the high-temperature drying without controlling humidity had previously been investigated (Kubojima et al., 2002). So, we attempted to apply that vibration testing system to the present tests under high-temperature, high-humidity conditions. The specifications of the displacement sensor used for measuring the vibrational properties in the previous work (Kubojima et al., 2002) would not guarantee results under high-temperature, high-humidity conditions. However, because the displacement sensor is inexpensive and easy to use, we investigated ways to use it to conduct vibration tests under high-temperature, high-humidity conditions.

Materials and methods

Specimens

Sitka spruce (*Picea sitchensis* Carr.) specimens having dimensions of 110 mm (R) × 25 mm (L) × 8 mm (T) were used for the vibration test. The weight of each specimen was measured before heating and before and after the replacement of the displacement sensor mentioned below. Finally, the specimens were dried at 105 ˚C. The weight after this drying was used for the oven dried weight, which was used to calculate the moisture content. The

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initial moisture content was about 210 %.

Heating in superheated water vapor

The measuring apparatus were in an airtight chamber having a temperature range of 105 - 162.2 ˚C, relative humidity (RH) of 75 - 100 % and gauge pressure of 0.020 - 0.39 MPa. The environment in the chamber can be regarded as superheated steam (Kubojima et al., 2003).

The set temperature, relative humidity and gauge pressure were 115 ˚C, 75 % and 0.0255 MPa, respectively. The temperature and relative humidity were recorded at 1 min intervals.

Vibration test

A specimen, its supporting system, a commercially available magnetic driver and a commercially available eddy current type displacement sensor (Temperature range: − 10 to + 200 ˚C; relative humidity range: 35 to 85 %; linear range: 1 to 2 V) were in the chamber. It should be noted that this displacement sensor can be used at high-temperature and low-humidity conditions or in the humidity range of 35 - 85 % at low-temperature; in other words, it cannot be used at more than 1 atm. The displacement sensor was coated with heat-resistant rubber and silicon to keep out moisture. A displacement sensor without coating was used as a control.

To obtain the resonance frequency and loss tangent, free-free flexural vibration tests were conducted at 10 min intervals. The test beam was suspended by two wires of 0.12 mm diameter at the nodal positions of the free-free vibration corresponding to its first resonance mode. It was excited in the direction of thickness at one end by the magnetic driver. The motion of the beam was detected by the displacement sensor at the other end. The signal was processed through a commercially available fast Fourier transform (FFT) digital signal analyzer (Kubojima et al., 2001). The measuring system is shown in Fig. 1.

The loss tangent was obtained from the width at -3 dB from the peak of the resonance curve which is called the $1/\sqrt{2}$-value width in this article. It took 100 s to draw a resonance curve.

Temporal changes in the output of the displacement sensor

The displacement sensor and the supporting system described above were in the chamber. Measurements were conducted without wood specimens to investigate the maximum output of the displacement sensor (V_{max}). The output of the displacement sensor used in this study increases with the distance between the displacement sensor and a specimen (*d*) and reaches the constant value V_{max} when *d* is sufficiently large. When a wood specimen is not set in the vibration system, the output indicates V_{max}.

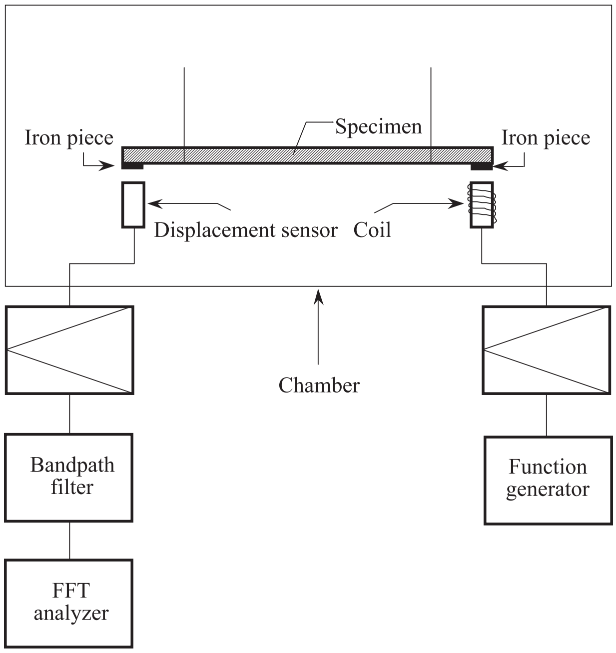

Fig. 1. Apparatus for the flexural vibration test under high-temperature, high-humidity conditions.

The voltage of the displacement sensor V_{max} was recorded at 1 min intervals during heating in the set environment. Both coated and non-coated sensors were used.

Results and Discussion

The resonance curve was desirable at the initial stage, but later it was not clear enough to define the peak and the $1/\sqrt{2}$-value width of the curve accurately (Fig. 2). Since this sensor had been used under high-temperature, low-humidity conditions without any problem (Kubojima et al., 2002), moisture which had entered the displacement sensor in the high-temperature, high-humidity condition caused this.

The output of the uncoated displacement sensor decreased to a low level, deviating from the linear range of 1V (= 2V - 1V). However, the coating allowed the outputs of the displacement sensor to remain high and valid for a longer time as shown in Fig. 3. The non-coated and coated displacement sensors were able to define the peak and the $1/\sqrt{2}$-value width for about 30 min and 400 min, respectively. The effective lives for 30 min of the non-coated sensor and 400 min for the coated sensor corresponded to the outputs of 2 V in Fig. 3. The outputs of the non-coated and coated sensors were almost completely restored by drying them after use under high-temperature, high-humidity conditions.

Unfortunately, it takes about 600 min to dry a specimen with about 190 % moisture content (Kubojima et al., 2003). So, the displacement sensor had to be

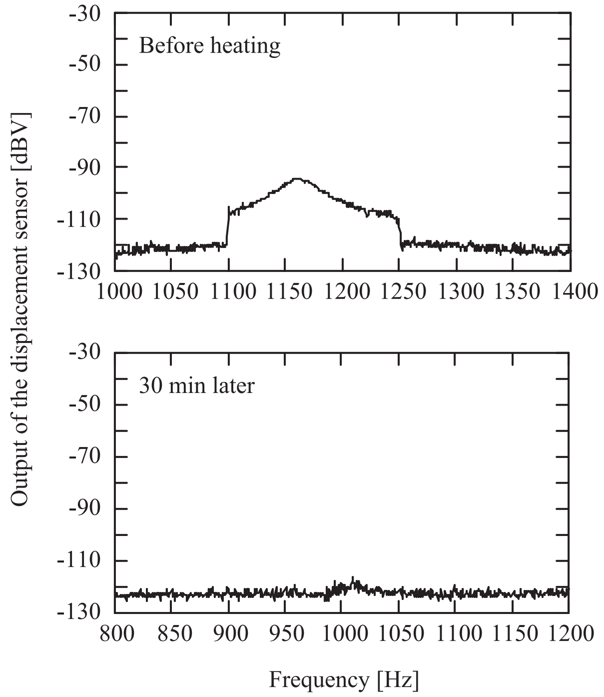

Fig. 2. Changes in resonance curves with time. The displacement sensor was not coated. Heating conditions were 115 ˚C and 75 % relative humidity.

replaced with another one in the middle of drying.

Figure 4 shows the changes that occurred in vibrational properties with time. At 360 min, the displacement sensor was replaced with another one. The resonance frequency increased and loss tangent decreased during this time because the temperature of the specimen decreased when the testing system was taken out of the chamber. After heating again, the resonance frequency decreased as the temperature increased (filled circles), then began to increase when the temperature reached the set value. The loss tangent increased with temperature (filled triangles) and started to decrease when the temperature reached the set value. Eliminating the second temperature rising process (filled symbols in Fig. 4), the changes in the resonance frequency and loss tangent with time were regarded as continuous (smoothed curves in Fig. 4). This indicates that the change in the moisture content from 39.7 % to 36.1 % while the displacement sensor was being replaced was so small that there were no significant problems to obtain the changes in vibrational properties with time.

Although the influence of replacing a displacement sensor with another one on the measurements was small, as few replacements as possible should be made. Essentially, only one displacement sensor should be used throughout drying. Hence, it is important to maintain the quality of the displacement sensor for a longer time by coating it.

Conclusions

The vibration testing method was investigated in a high-temperature, high-humidity environment. The results obtained were as follows:

1) Coating the displacement sensor with heat-resistant rubber and silicone made it effective for a longer time. This can decrease the number of sensors required for measurements.

2) The change in the moisture content that occurred when the displacement sensor was replaced with another

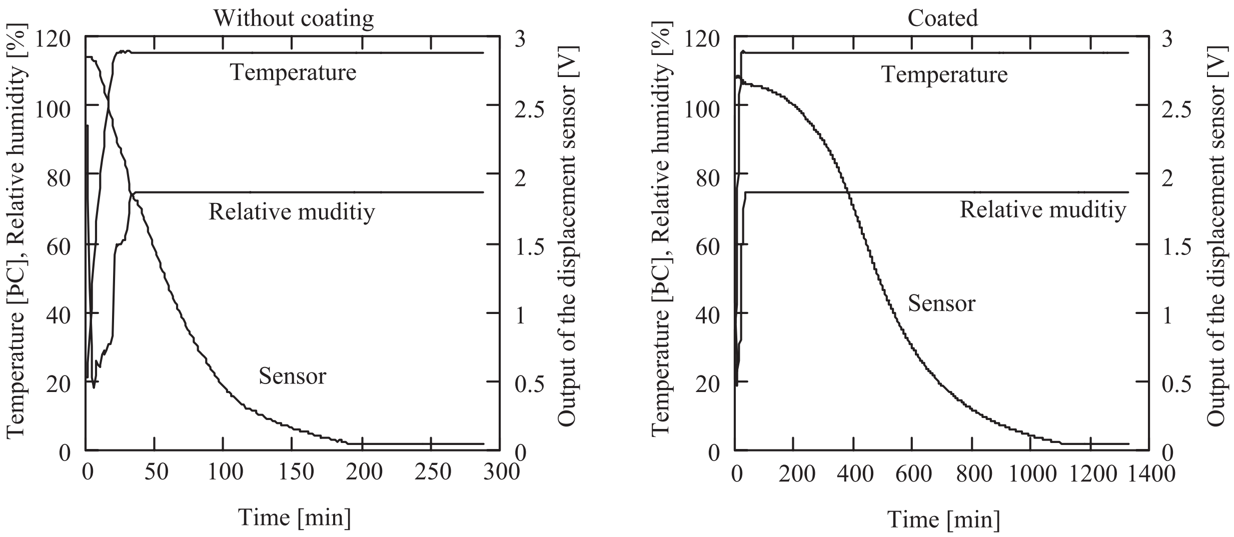

Fig. 3. Effect of coating the displacement sensor on its output with time. The output was obtained without a specimen. Temperature and relative humidity in the chamber are shown.

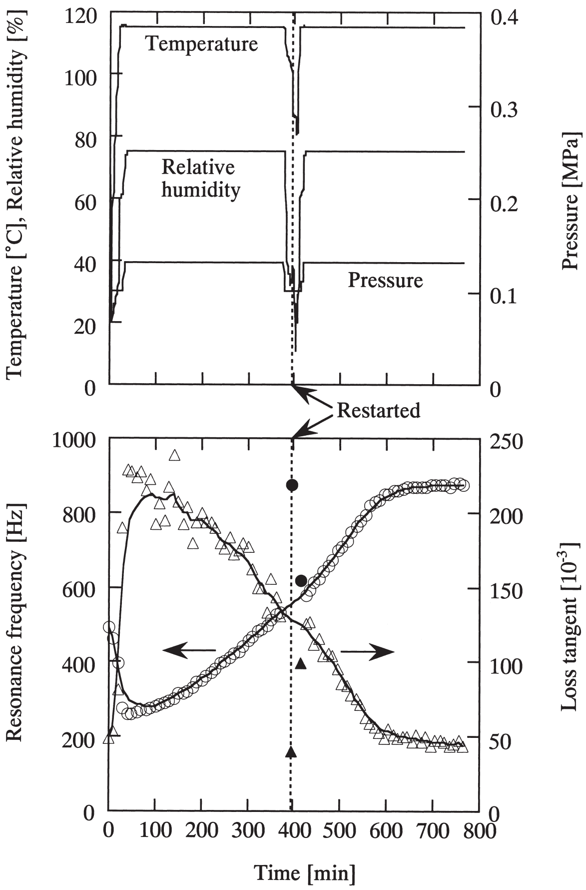

Fig. 4. Temporal changes in the temperature, relative humidity and pressure in the chamber, resonance frequency and loss tangent at 115 ˚C and 75 % relative humidity. Pressure is expressed by the sum of gauge pressure and 0.1013 MPa (atmospheric pressure). Circles and triangles denote resonance frequency and loss tangent, respectively. Filled symbols are the values in the second temperature rising process. Smoothed curves were drawn without the filled symbols.

one in the middle of drying was so small that there were no significant problems in obtaining the changes in vibrational properties with time.

3) Using coated displacement sensors with heat-resistant rubber and silicon and replacing a sensor with another one in the middle of drying is effective for obtaining vibrational properties in a high-temperature and high-humidity environment.

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高温高湿水蒸気中での乾燥過程における生材の振動試験方法の検討

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要 旨

高温高湿条件で乾燥処理中の生材の振動試験方法について検討した。110 mm（R）× 25 mm（L）× 10 mm（T）の寸法のシトカスプルース生材（*Picea sitchensis* Carr. 初期含水率約 210 %）を試験体に用いた。試験系を密閉型加熱容器内に設置し、設定温度 115℃および相対湿度 75％の条件で試験体を乾燥させた。振動特性は両端自由撓み振動試験より測定した。また、振動検出用の渦電流式変位計の出力の経時変化を測定した。結果は以下の通りであった。1）湿気による変位計の出力の低下は変位計を耐熱ゴムとシリコン剤で被覆することにより改善された。2）乾燥途中に変位計を交換することの振動特性の経時変化の傾向への影響は小さいと言えた。3）以上より、被覆した変位計を用い、乾燥途中で変位計を交換しながら試験すれば簡便に高温高湿条件での振動特性が得られることが分かった。

キーワード：高温高湿条件、振動試験、渦電流式変位計、耐熱ゴム、シリコン剤、被覆、変位計交換

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