

were determined. The specimens were then swollen using DMSO solvent, and then completely dried after the solvent exchange with water at room temperature. Their HTR strains were then compared with their DMSO swelling and drying shrinkage strains. The volumetric HTR strains in the CW were about twice as large as those in the NW. A clear commonality between the HTR behavior and both DMSO swelling and drying shrinkage behavior was identified, which indicates that HTR of softwood is caused by volumetric changes in the matrix substances. The HTR has been defined as a phenomenon due to the release of locked-in growth stress when a wood specimen is hygrothermally treated. To determine whether DMSO treatment has a similar effect as hygrothermal treatment, both hygrothermally-untreated and hygrothermally-treated specimens were swollen using DMSO, and their dimensional changes during and after DMSO treatment were compared. The results showed that DMSO treatment is a possible alternative for releasing locked-in growth stress.

Changes in vibrational properties of softwood due to hygrothermal treatment and their relationship with hygrothermal recovery strain

The changes in vibrational properties of CW and NW of softwood (hinoki and sugi) in longitudinal (L)-direction were measured after hygrothermal treatment at 60, 80, and 100 °C. The relationship between those changes and HTR strains were discussed. The hygrothermal treatment induced an increase in mechanical loss tangent ($\tan\delta$) and a decrease in specific dynamic Young's modulus (E'/ρ). It seems that the changes in vibrational properties due to hygrothermal treatment had a time-temperature dependency: longer treatment durations and higher treatment temperatures induce larger increases in $\tan\delta$ and larger decreases in E'/ρ . In contrast to the quenching effect, $\tan\delta$ and E'/ρ did not recover to their original state even after long-term conditioning of hygrothermally treated wood in water at 20 °C. For CW with a large microfibril angle (MFA), there was a clear relationship between the changes in vibrational properties and HTR strains. The $\tan\delta$ increased and E'/ρ decreased with hygrothermal treatment, corresponding to dimensional changes in the L-direction. The most likely mechanism of HTR for softwood is that the hygrothermal treatment softens the lignin to release locked-in growth stress. Subsequently, irreversible structural changes in lignin induce both the changes in vibrational properties and HTR. For NW, because of a small MFA, HTR strains due to irreversible structural changes in lignin in the L-direction are possibly restricted by rigid crystalline cellulose. As a result, the relationship

between the changes in vibrational properties and HTR is uncertain.

Changes in vibrational properties of hardwood due to hygrothermal treatment and their relationship with hygrothermal recovery strain

The changes in vibrational properties of konara tension wood (TW) and NW in L-direction were measured after hygrothermal treatment at 60, 80, and 100 °C. The relationship between those changes and HTR strains were discussed. The hygrothermal treatment induced an increase in $\tan\delta$ and a decrease in E'/ρ . An extremely large decrease in E'/ρ of TW was found after hygrothermal treatment. The changes in vibrational properties due to hygrothermal treatment exhibited a time-temperature dependency: longer treatment durations and higher treatment temperatures induce larger increases in $\tan\delta$ and larger decreases in E'/ρ . Almost no quenching effect was found even after the long-term conditioning of hygrothermally treated wood in water at 20 °C. For TW with extremely small MFA, there was a clear relationship between the changes in vibrational properties and HTR strains. The $\tan\delta$ increased and E'/ρ decreased with hygrothermal treatment, corresponding to dimensional changes in the L-direction. The most likely mechanism of HTR for TW is that the hygrothermal treatment induces the qualitative changes of cellulose crystalline in gelatinous (G)-layer to release the locked-in growth stress, which results in both changes in vibrational properties and HTR. The mechanism of HTR for normal hardwood is similar to that of softwood. Because of a small MFA, HTR strains due to irreversible structural changes in lignin in the L-direction are possibly restricted by rigid crystalline cellulose. As a result, the relationship between the changes in vibrational properties and HTR is uncertain.

Those findings observed in this study provide important information for developing a novel method to control and utilize the HTR for the wood industry.