Preliminary

Modelling the Effects of Chemical Modification on Dynamic Mechanical Properties of Wood

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The dynamic mechanical properties of the cell wall of chemically modified woods were analyzed by using the model shown in Fig. 1, in which amorphous isotropic matrix is disposed in parallel along the axis of cellulosic fibrils (the 1 direction) inclining at θ to the longitudinal direction of wood. The complex dynamic modulus of the model in the longitudinal direction, $E_L{}^*$, is expressed by

$$E_L{}^* = \left[\frac{1}{E_1{}^*}\cos^4\theta + \left(\frac{1}{G^*} - \frac{2\mu_{12}}{E_1{}^*}\right)\sin^2\theta\cos^2\theta + \frac{1}{E_2{}^*}\sin^4\theta\right]^{-1}, \tag{1}$$

where $E_1{}^*$ and $E_2{}^*$ are the complex dynamic moduli in the 1 and 2 directions, G^* is the complex shear modulus in the 1-2 plane, and μ_{12} is the Poisson's ratio, respectively. If θ is small enough to ensure $\sin^4\theta \simeq 0$, $\cos^4\theta \simeq 1$, $\sin^2\theta\cos^2\theta \simeq \theta^2$, and μ_{12} is much smaller than the real part of $E_1{}^*$, the dynamic modulus, E', and the loss tangent, $\tan\delta$, of wood in the longitudinal direction, as first approximation, can be expressed by

$$E' \simeq \frac{\Delta\gamma}{\gamma_w}\left[\frac{1}{E_1{}'} + \frac{\theta^2}{G'}\right]^{-1} \text{ and } \tan\delta \simeq \left[\frac{E_1{}''}{E_1{}'^2} + \frac{\theta^2 G''}{G'^2}\right]\left[\frac{1}{E_1{}'} + \frac{\theta^2}{G'}\right]^{-1}, \tag{2}$$

where Δ is the volume fraction of the S_2 layer in the cell wall, γ and γ_w are the specific gravities of wood and the cell wall, $E_1{}'$ and $E_1{}''$ are the dynamic modulus and the loss modulus in the 1 direction, and G' and G'' are the dynamic shear modulus and the loss shear modulus in the 1-2 plane, respectively. $E_1{}'$ and $E_1{}''$ are expressed by

$$E_1{}' = \Psi E_f + (1-\Psi)E_m \simeq \Psi E_f \text{ and } E_1{}'' \simeq (1-\Psi)E_m\tan\delta_m, \tag{3}$$

where Ψ is the volume fraction of fibrils in the cell wall, E_f is the dynamic modulus of fibrils, E_m and $\tan\delta_m$ are the dynamic modulus and the loss tangent of matrix, respectively. In the model, fibrils with square cross section are embedded in matrix, so that fibrils and matrix are aligned partly in series and partly in parallel to the direction of shear force. According

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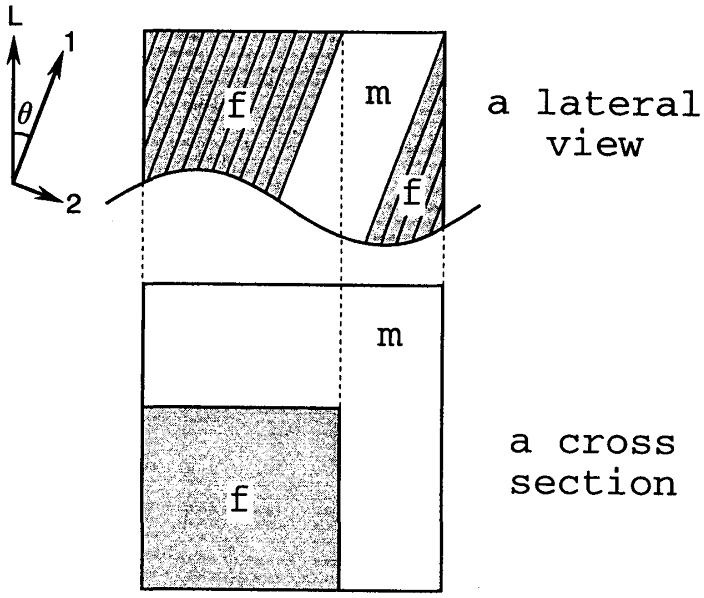

Fig. 1. A model for the S_2 layer of wood.
Note: L: the longitudinal direction, 1: the axis of cellulosic fibrils, 2: the direction perpendicular to the axis of fibrils, θ: microfibril angle, f: cellulosic fibrils, m: amorphous isotropic matrix.

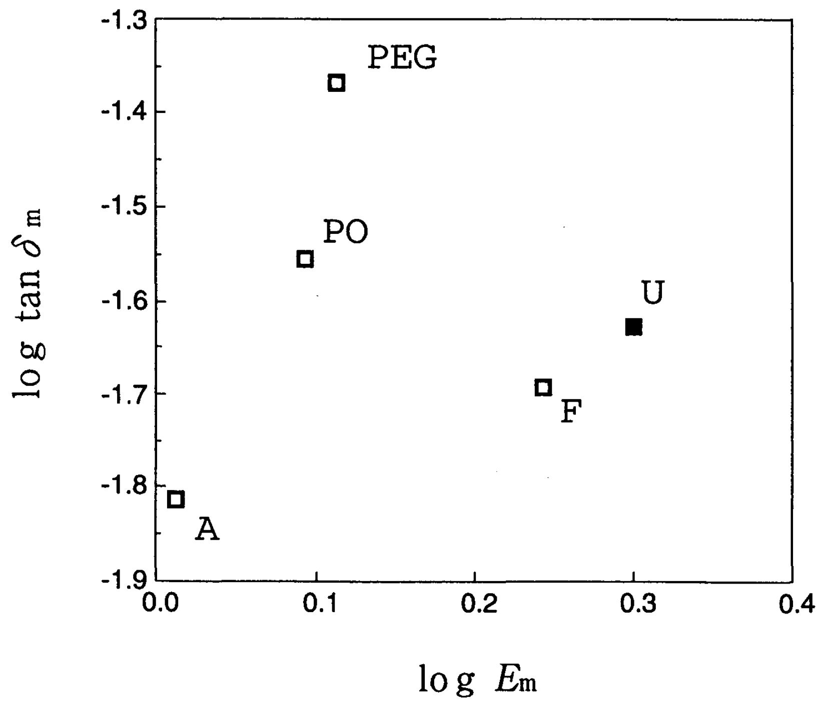

Fig. 2. The relationships between the logarithms of the dynamic modulus and the logarithm of the loss tangent of matrix for untreated and chemically modified woods.
Note: U: untreated, F: formalized, A: acetylated, PO: etherificated, PEG: polyethylene glycol impregnated.

to the law of mixtures[1], G' and G'' can be expressed by

$$G' \simeq G_m\left(1+\frac{\Psi}{1-\sqrt{\Psi}}\right) \text{ and } G'' \simeq G_m\left(1+\frac{\Psi}{1-\sqrt{\Psi}}\right)\tan\delta_m. \quad (4)$$

The experimental values of E', tan δ, and γ at 20°C and 60% R.H. for the untreated and chemically modified woods reported by Akitsu et al.[2] were adapted in calculation. For the untreated wood, $\Psi=0.5$, $\gamma_w=1.45$, $\Delta=0.84$, $\theta=0.09$ (rad), $E_f=134$(GPa), and $E_m=2$(GPa) were used[2,3]. For the modified wood, $\Psi=0.33$ to 0.45 and $\gamma_w=0.92$ to 1.29 were estimated from both weight gains and volume swellings.

The values of E_m and tan δ_m for untreated (U), formalized (F), acetylated (A), etherificated (PO), and polyethylene glycol impregnated (PEG) woods were calculated. The relationships between the logarithm of tan δ_m and the logarithm of E_m are shown in Fig. 2. In PO and PEG treatments, the decrease in E_m and the increase in tan δ_m might be explained by the hydrophilic nature of the bulking agents. In acetylation, however, the introduced hydrophobic bulking agents might decrease both E_m and tan δ_m. On the other hand, in formalization, the decrease in tan δ_m was attributed to matrix crosslinking.

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