

Acoustic Converting Efficiency and Anisotropic Nature of Wood

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It is accepted that both the acoustic converting efficiency and the degree of anisotropy of wood are important factors for the sound board of musical instruments^{1,2)}. In this paper, the relationship between these factors were clarified experimentally and theoretically. The specific dynamic Young's modulus (E'/ρ) and the loss tangent ($\tan \delta_L$) in the longitudinal (L) direction, and the dynamic shear modulus (G') and the loss tangent ($\tan \delta_S$) in the LT plane (T: tangential direction) for 101 kinds of woods were measured by using flexural and torsional vibration methods.

There was a negative correlation between E'/ρ and $\tan \delta_L$ as shown in Fig. 1. This fact indicates that smaller mean microfibril angles give larger E'/ρ and lower $\tan \delta_L$ values³⁾. Fig. 2 shows the relationships between the ratio of loss tangents ($\tan \delta_S/\tan \delta_L$) and that of elastic moduli (E'/G'). Relatively large E'/G' and $\tan \delta_S/\tan \delta_L$ values of wood reflect its anisotropic nature. Fig. 3 shows the relationship between (E'/G') ($\tan \delta_S/\tan \delta_L$) and $\sqrt{E'/\rho}/\tan \delta_L$. The former reflects the degree of anisotropy and the latter relates to the acoustic converting efficiency ($\sqrt{E'/\rho^3}/\tan \delta_L$). There was a positive correlation between them. These acoustic properties can be calculated by using a uniaxial cell wall model in which amorphous isotropic matrix is disposed in parallel along the axis of cellulosic fibrils inclining at θ to the L direction of wood⁴⁾. The E'/ρ , $\tan \delta_L$, G'/ρ and $\tan \delta_S$ can be expressed by

$$\frac{E'}{\rho} \approx \frac{\nu}{\rho_w} \left(\frac{1}{E_{w1}'} + \frac{\theta^2}{G_{w12}'} \right)^{-1}, \quad \tan \delta_L \approx \left(\frac{E_{w1}''}{E_{w1}'^2} + \frac{G_{w12}''}{G_{w12}'^2} \right) \left(\frac{1}{E_{w1}'} + \frac{\theta^2}{G_{w12}'} \right)^{-1},$$
$$\frac{G'}{\rho} \approx \frac{\nu}{\rho_w} \left(\frac{\sin^2 2\theta}{E_{w1}'} + \frac{\cos^2 2\theta}{G_{w12}'} \right)^{-1}$$

and

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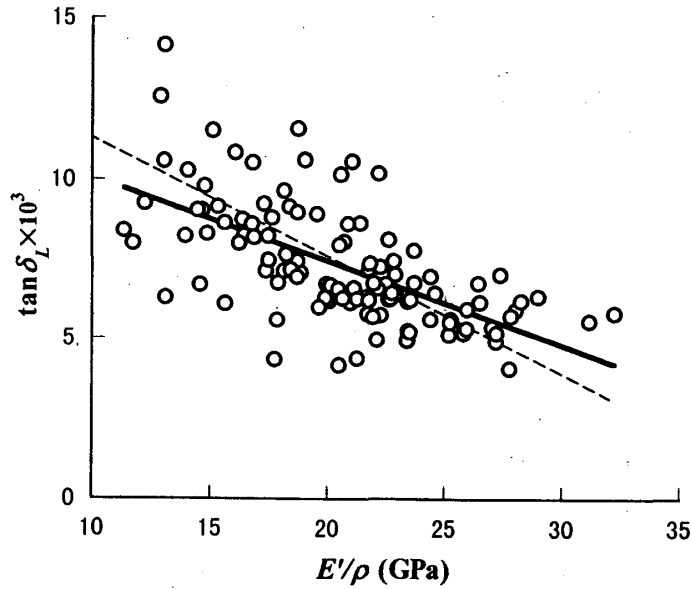


Fig. 1. The relationship between the loss tangent ($\tan \delta_L$) and the specific dynamic Young's modulus (E'/ρ) in the longitudinal direction of wood. Note: O, Experimental values; solid line, the regression line of experimental values ($r = -0.632$); dotted line, calculated values.

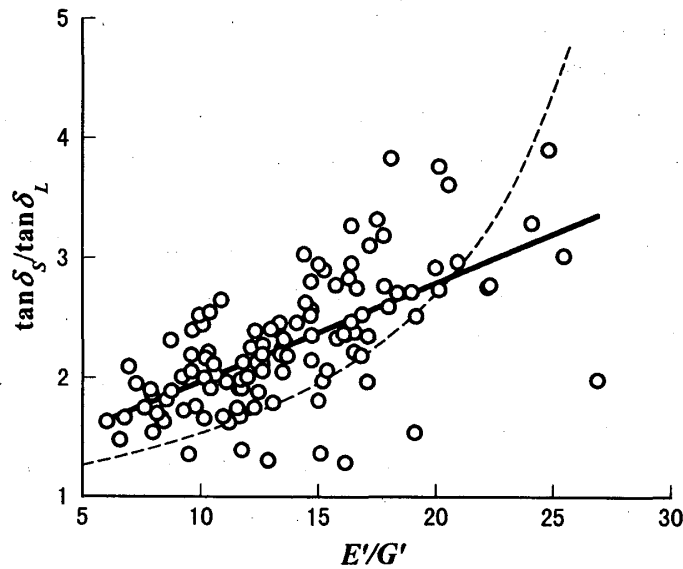


Fig. 2. The relationship between the ratio of loss tangent ($\tan \delta_S / \tan \delta_L$) and that of elastic moduli (E'/G') of wood. Note: O, Experimental values; solid line, the regression line of experimental values ($r = 0.648$); broken line, calculated values.

$$\tan \delta_S \approx \left(\frac{E_{w2}'' \sin^2 2\theta}{E_{w2}'^2} + \frac{G_{w12}'' \cos^2 2\theta}{G_{w12}'^2} \right) \left(\frac{\sin^2 2\theta}{E_{w2}'} + \frac{\cos^2 2\theta}{G_{w12}'} \right)^{-1},$$

where ν is the volume fraction of S_2 layer, E_{w1} and E_{w2} are the Young's moduli of the cell wall in the parallel (1) and perpendicular (2) to the axis of fibrils, G_{w12} is the shear modulus

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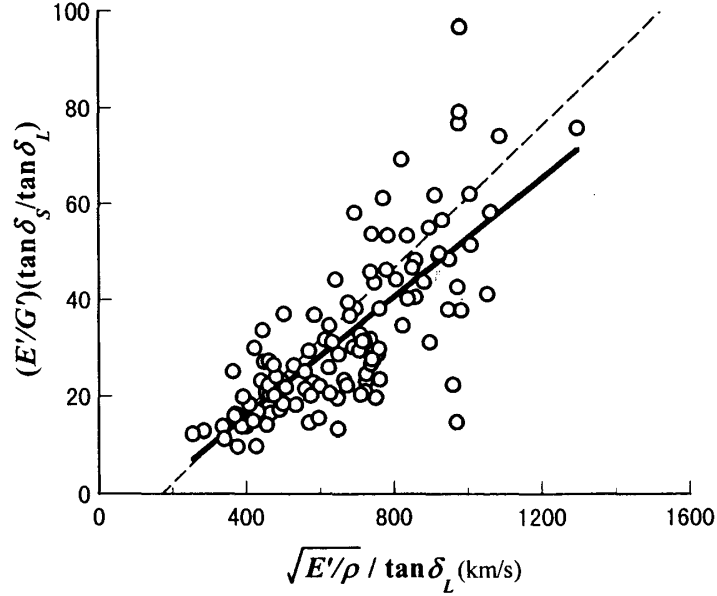


Fig. 3. The relationship between the $(E'/G') (\tan \delta_s / \tan \delta_L)$ and the sound velocity divided by the loss tangent $(\sqrt{E'/\rho} / \tan \delta_L)$ of wood. Note : O, Experimental values ; line, the regression line of experimental values ($r=0.752$) broken line, calculated values.

cell wall in the 1–2 plane, ρ_w is the density of the cell wall, respectively. Single and double primes indicate the dynamic modulus and loss modulus, respectively. According to the law of mixtures, E_{w1}' , E_{w1}'' , E_{w2}' , E_{w2}'' , G_{w12}' and G_{w12}'' can be expressed by

$$\begin{aligned} E_{w1}' &= \varphi E_{f1} + (1 - \varphi) E_m, \quad E_{w1}'' = (1 - \varphi) E_m'' = (1 - \varphi) E_m' \tan \delta_m, \\ E_{w2}' &\approx E_m' \left(1 + \frac{\varphi}{1 - \sqrt{\varphi}} \right), \quad E_{w2}'' \approx E_m' \left(1 + \frac{\varphi}{1 - \sqrt{\varphi}} \right) \tan \delta_m, \\ G_{w12}' &\approx G_m' \left(1 + \frac{\varphi}{1 - \sqrt{\varphi}} \right) \quad \text{and} \quad G_{w12}'' \approx G_m' \left(1 + \frac{\varphi}{1 - \sqrt{\varphi}} \right) \tan \delta_m, \end{aligned}$$

where E_{f1} is the Young's modulus of fibrils along the axis, φ is the volume fraction of fibrils, E_m' , G_m' and $\tan \delta_m$ are the Young's modulus, shear modulus and loss tangent of the matrix, respectively. Values of $\nu=0.84$, $E_{f1}=134$ GPa, $\varphi=0.5$, $E_m=2$ GPa, $G_m=0.77$ GPa, and $\tan \delta_m=0.015$ were adopted. Dotted lines in Figs. 1–3 show the calculated values. The calculated values in Fig. 3 predicted that smaller microfibril angles give higher values of acoustic converting efficiency as well as higher degrees of anisotropy.

References

- 1) M. NORIMOTO: *Mokuzai Gakkaishi*, **28**(7), 407–413 (1982).
- 2) T. ONO: *J. Acoust. Soc. Jpn. (E)*, **17**(4), 183–193 (1996).
- 3) M. NORIMOTO *et al.*: *Wood Res. and Tech. Notes*, No. **22**, 53–65 (1986).
- 4) E. OBATAYA, M. SUGIYAMA and M. NORIMOTO: *Wood Res.*, No. **83**, 40–42 (1996).