TECHNICAL NOTE: ANALYSIS OF MECHANICAL RELAXATION INTENSITY OF WOOD AT VARIOUS MOISTURE CONTENTS

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Abstract. This study analyzed mechanical relaxation data by the well-known Gaussian function from which the relaxation intensity was determined for various moisture contents over a range of temperatures (–81-0°C). These data were used to suggest a range of bonding mechanisms for sorbed water.

Research on mechanical relaxation of wood is very helpful in providing insight into the condition of adsorbed water in wood and interactions between water and wood substance. This report investigated mechanical relaxation data from a previous study (Cheng et al 1999). Temperature spectra of loss modulus at 1 kHz for spruce were analyzed by a Gaussian function, and mechanical relaxation intensity was determined for various moisture contents over –81-0°C.

ANALYSIS AND DISCUSSION

The Gaussian function can be written as:

$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \tag{1}$$

where $\frac{1}{\sqrt{2\pi}\sigma}$ is the height of the curve's peak, μ is the position of the center of the peak, and σ^2 is variance and represents the width of the curve. It is convenient to consider that a Gaussian function represents a relaxation process to which a simple form of Eq 1 was applied as follows:

$$E'' = A\exp(B(T - T_p)^2) \tag{2}$$

where E'' is loss modulus (GPa), $A = \frac{1}{\sqrt{2\pi}\sigma}$, the relaxation intensity (GPa), $B = -\frac{1}{2\sigma^2}$, T is temperature (°C), and T_p is the point that the relaxation takes place (°C).

The values of T_p are –81, –67, –55, –40, –26, –10, and 0°C, and B is taken as –0.01 for all cases.

Considering the shape of experimental temperature spectra of loss modulus, seven peaks were expected for every moisture content (MC) condition. The superposition of these seven relaxation processes, given by Eq 3, was used to describe the total dynamic loss modulus.

$$E'' = \sum_{i=1}^{7} A_i \exp(B(T - T_{pi})^2) + \varphi(T), \tag{3}$$

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$$\varphi(T) = a(T - 20)^2 + b \qquad (4)$$

where a, b are two constants and $\varphi(T)$ is considered as the dynamic loss caused by wood substance rather than adsorbed water, eg the internal friction of lignin, etc. By fitting the observed loss modulus data using Eq 3, the relaxation intensity A and values of constants a and b could be determined for each MC (Table 1).

Figure 1 shows temperature dependence of observed and calculated loss modulus at 6.5% MC as an example. It is obvious that the theoretical curve agrees well with the experiment results. Good agreements were also obtained for the other moisture contents. Figure 2 presents the relation between MC and mechanical intensity at different temperatures. The figure suggests that the intensity curves can be divided into three groups based on the mechanical intensity peaks. The first group is 0-–40°C (β1) having the highest intensity value at 4.8% MC. The second group is –55 and –67°C (β2) with a maximum at 6.5% MC. The third group is at –81°C (β3), rising monotonically with MC.

To clarify the relationship quantitatively, a nonlinear regression equation relating MC with the relaxation intensities β1, β2, and β3 was developed in which the values of the constants were determined by the least-squares technique:

$$\begin{aligned} mc &= mc_{\beta 1} + mc_{\beta 2} + mc_{\beta 3} \\ &= 21.1A_{\beta 1} + 6.3A_{\beta 2} + 14344A_{\beta 3}^3 \end{aligned} \qquad (5)$$

Calculated moisture contents of β1, β2, and β3 from Eq 5 were plotted against RH and the results are given in Fig 3. As shown in this figure,

Table 1. Mechanical relaxation intensity A and values of constants a and b at various moisture contents (MCs).

	Mechanical relaxation intensity (GPa)				
T (°C)	0% MC	4.8% MC	6.5% MC	8.6% MC	16% MC
−81	0.018	0.035	0.06	0.074	0.1
−67	0.03	0.05	0.076	0.074	0.071
−55	0	0.063	0.076	0.064	0.055
−40	0.018	0.07	0.063	0.058	0.027
−26	0.006	0.056	0.038	0.035	0.007
−10	0	0.026	0.015	0.09	0.001
0	0.002	0.004	0.003	0.002	0
a ($\times 10^{-6}$)	2.8	2.8	3.8	3.8	3.3
b	0.079	0.083	0.071	0.072	0.084

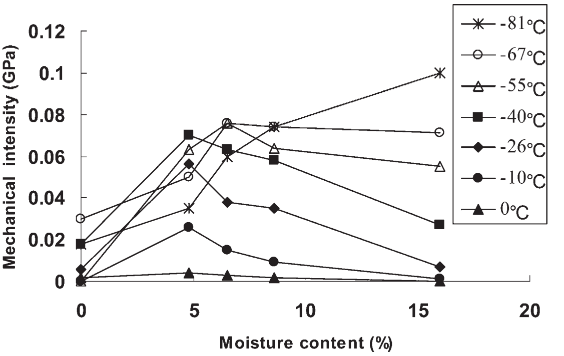

Figure 2. Relation between moisture content and mechanical relaxation intensity A at different temperatures.

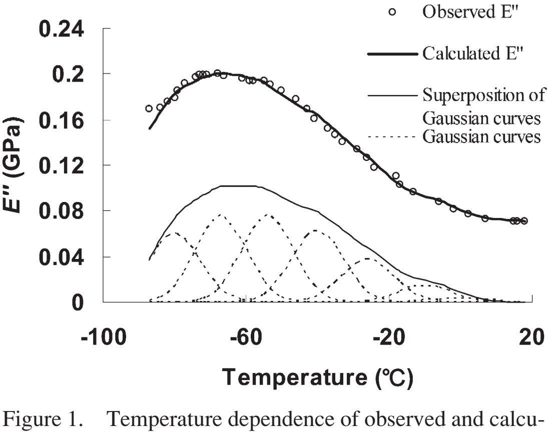

Figure 1. Temperature dependence of observed and calculated loss modulus E'' at 6.5% moisture content.

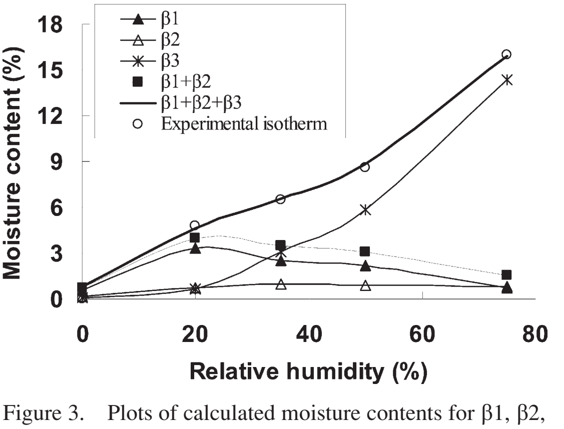

Figure 3. Plots of calculated moisture contents for β1, β2, and β3 vs RH and an experimental isotherm.

β1 + β2 could be regarded as "monomolecular adsorbed water" and β3 is similar to "multilayer adsorbed water" in the sorption theory (Skaar 1988). What should be noted is that the monomolecular water still exists in two forms, β1 and β2. The behavior of β1 serves as good evidence to the unexpected phenomenon that dynamic Young's modulus increases slightly in the low MC region (Takahashi and Nakayama 1995). This indicates that β1 is probably related to water molecules bonding at more than one wood sorption sites, whereas β2 might correspond to the condition in which only one bond forms between a water molecule and sorption site.

The three existing forms of adsorbed water in wood proposed in this study from the analysis of mechanical relaxation results is needed to be further proven by sorption isotherm data, dimensional change measurements, etc. However, it is felt to be worthy of presenting the idea at this stage.

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