Rheological Characterization of Wood & Wood Composites

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WBC
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Outline

• Wood rheology
• Force mode
• Instrumentation
• Sample preparation
• Moisture control
• Linear viscoelastic response (LVR)
• Example Data
Wood Rheology

**Rheology:** Study of the flow and deformation of materials.

Reflecting chemical structure, molecular and supramolecular ordering.
Static & Dynamic Force Modes

Oscillatory perturbation

Static perturbation
Instrumentation
Instrumentation

Modern instrumentation requires a choice between:

- Strain controlled machines
- Stress controlled machines

**Strain Control:** Apply displacement, and use a load cell to measure the stress.

**Stress Control:** Apply a force, and use an interferometer to measure the displacement.
Sample Preparation

1. Machine a geometry that suits your needs.
   - Grain orientation
   - Specimen size
   - Clamp modes & clamp sizes

2. Hygro-thermal history (Solvent extraction?) is extremely important.
Sample Preparation
Moisture Control

As always, moisture control during analysis is critical.

We have 3 choices:

1. **Completely dry**
   - Simple
   - Reveals weak, secondary relaxations
   - Thermal decomposition may be a concern

2. **Completely saturated**
   - Somewhat simple to difficult
   - Reveals strong, primary relaxations
   - Thermal decomposition of *less* concern

3. **RH control**
   - Difficult and very expensive
Moisture Control

Completely dry pine in single cantilever bending

Saturated yellow-poplar in parallel-plate torsion
Solvent Submersion

Storage modulus, $G'$ (Pa) vs. Temperature (°C) for different solvents:
- Glycerine
- Ethylene glycol
- Dimethylformamide

$\tan \delta$ vs. Temperature (°C) for different pH levels:
- pH = 7
- pH = 10

$pH = 7$
$pH = 10$
Linear Viscoelastic Response (LVR)

• The response (e.g. strain) is directly proportional to the mechanical input (stress).

• Within the LVR, polymer packing is not altered and the response is independent of the input level.

• Data within the LVR is easiest to describe mathematically.

• Experiments are generally performed at the highest stress/strain within the LVR, optimizing signal/noise ratio without causing an erroneous response.
Yellow-poplar submerged in DMF under parallel-plate torsion
Example Data

Phenolic latex additives

pMDI analysis
Species Dependence of pMDI Performance

Creep response of dry wood

Open-cell vacuum impregnation:
- Anhydrous acetone/pMDI solutions.
- Cure: 120°C, 2 hrs, (3 – 5 % weight gain after cure).
- Heat control samples in the same fashion.
Now… Ethylene Glycol (EG) Plasticized Wood

- pMDI-treated and control specimens (impregnations as before but resin concentration 13% for poplar, 20% for pine).
- Post-cure resin content 5.5% for poplar, 5.3% for pine.
- Saturated in EG and subjected to 3 hour creep at 50°C (initially heated 90°C for 30 min., cooled (20°C/min) to 50°C; held at 50°C for 30 min).
- 5 replications each.

\[
D(t) = D_u + (D_r - D_u) \times \left[ 1 - \exp\left( -\left( \frac{t}{\tau} \right)^{1-n} \right) \right]
\]
Time/Temperature Superposition w/ EG Plasticized Wood

Now 10 decades of time!
Time/Temperature Superposition w/ EG Plasticized Wood

- Graph showing compliance (10^-9 Pa^-1) vs. time (aT*s) and log aT vs. temperature (°C)
- Data points for Pine and Poplar samples
- Comparison between Control and PMDI-Impreg treatments
Composite Specimens with Latex Adhesive
Influence of Resol Fortifiers on Latex Durability

Fracture Toughness (J/m$^2$)

- Control
- Accel-Weather
- Control
- Accel-Weather

PVAc-AlCl$_3$
PVAc-AlCl$_3$-PF

$G_{Ic}$
$G_{Ia}$
Influence of Resol Fortifiers on Latex Durability

**FILMS**

- PVAc-AlCl₃
- PVAc-AlCl₃-PF
- Weathered PVAc-AlCl₃
- Weathered PVAc-AlCl₃-PF

**COMPOSITES**

- PVAc-AlCl₃
- PVAc-AlCl₃-PF
- Weathered PVAc-AlCl₃
- Weathered PVAc-AlCl₃-PF

Storage Modulus (Pa)

Tan δ

Temperature (°C)
Influence of Resol Fortifiers on Latex Durability

Creep master curves from time/temperature superposition
Influence of Resol Fortifiers on Latex Durability

Weathered PVAc-AlCl$_3$-50k x

Weathered PVAc-AlCl$_3$-PF-50k x
Summary

• Wood rheology deals with amorphous wood polymer relaxations.
• These relaxations reflect chemical structure, and morphology, as well as changes caused by chemical, thermal and other treatments.
• Such methods require a significant investment of funds and time, but they’re worth it.
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