Thermal/Mechanical Properties of Wood-PVC Composites – Effect of Maleation

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Introduction

- **Maleation in wood-polymer composites helps create chemical bridges at the interface.**
  - **Improving compatibility between polar wood and non-polar polymer**
  - **Helping transfer stresses at the interface**
  - **Improving interfacial adhesion strength**

- Maleation influences mechanical and thermal properties of resultant composites.
  - Heat flow, heat capacity, and enthalpy
  - Glass transition
  - Moduli and bonding strength

Objectives

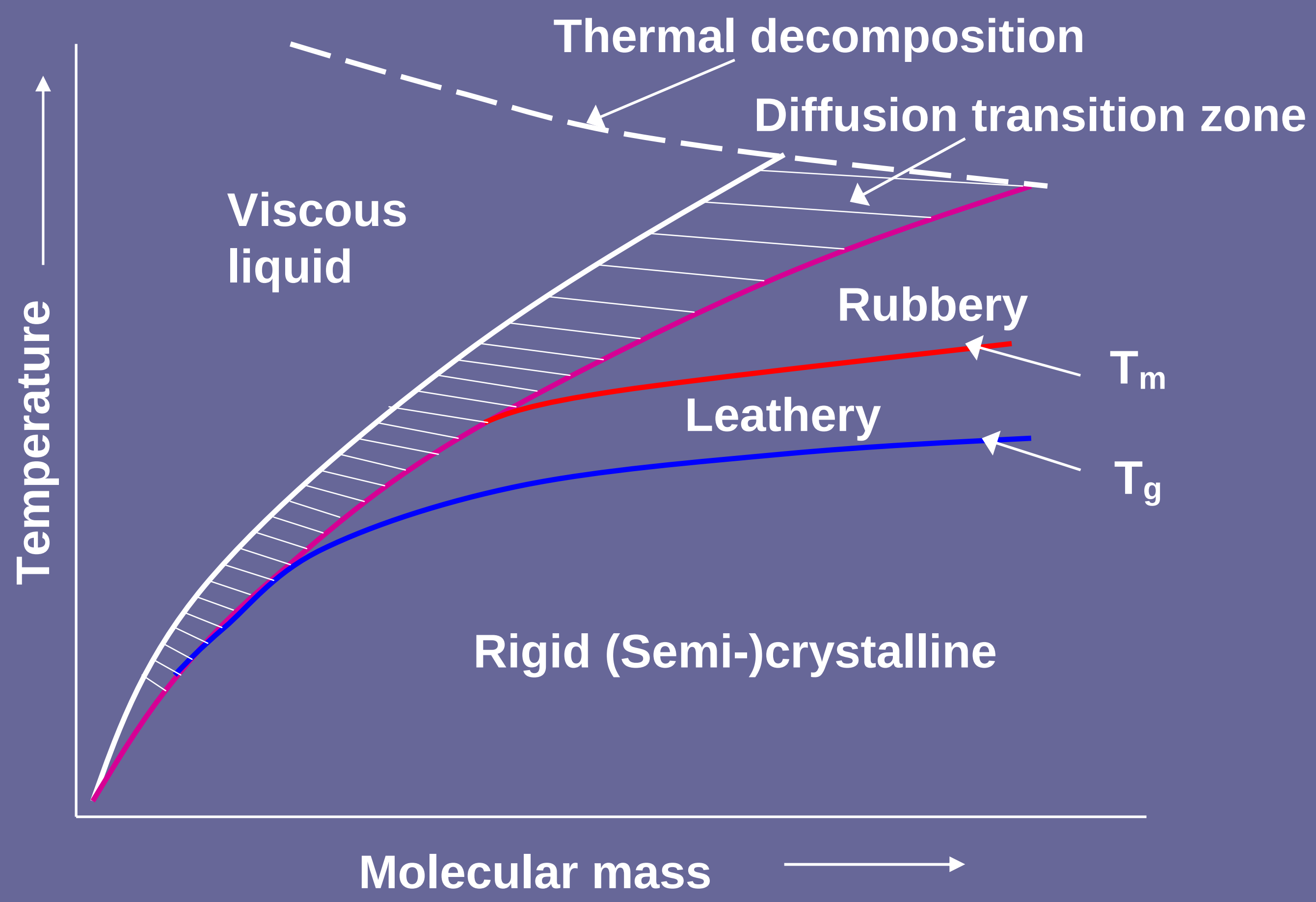
- To investigate thermal / mechanical characteristics of maleated wood-PVC composites.
- To study the relationship between measured properties and coupling agent performance in resultant composites.

Background

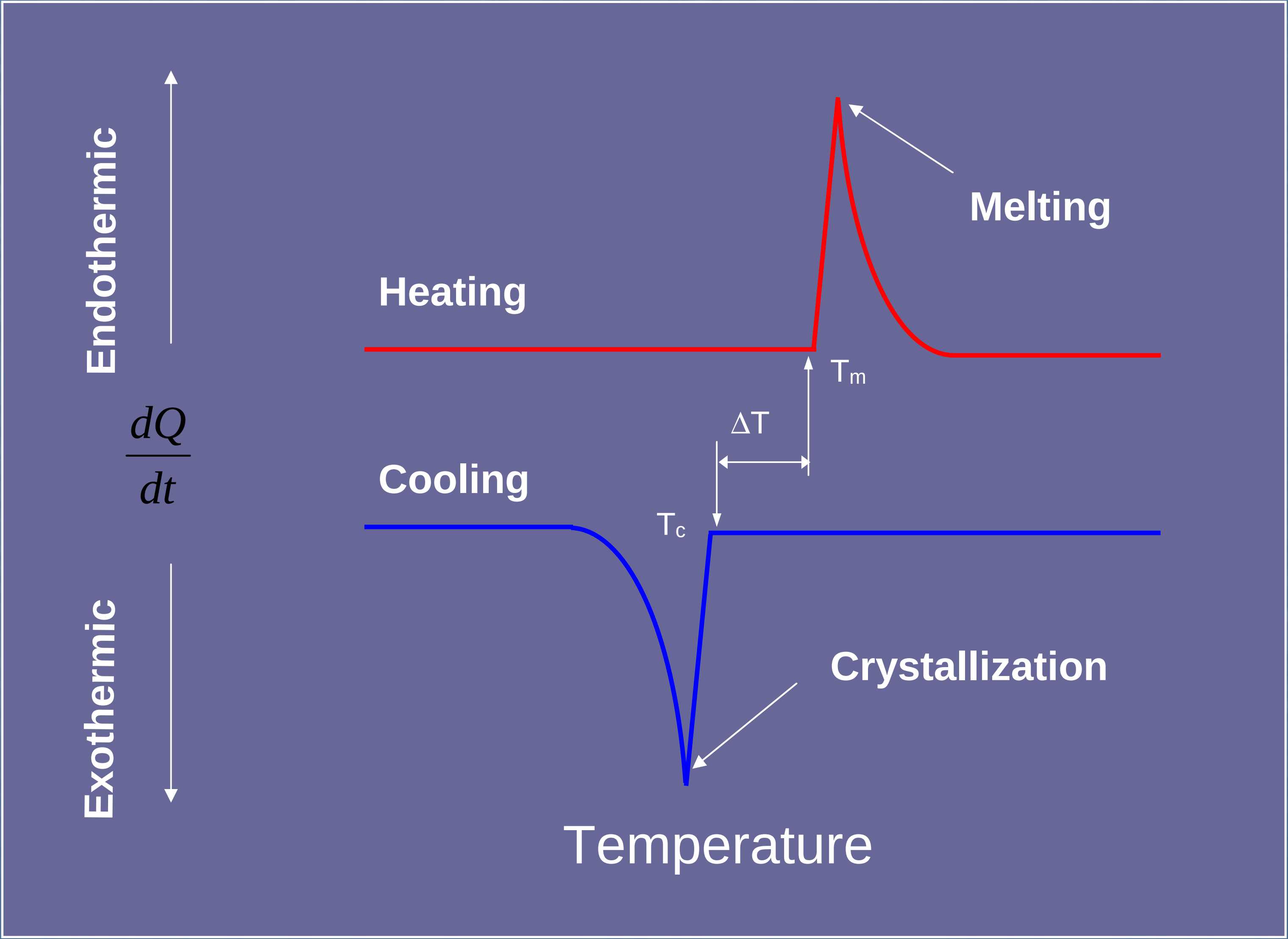
Thermal / Mechanical Analysis Techniques

Temperature-molecular Mass Diagram

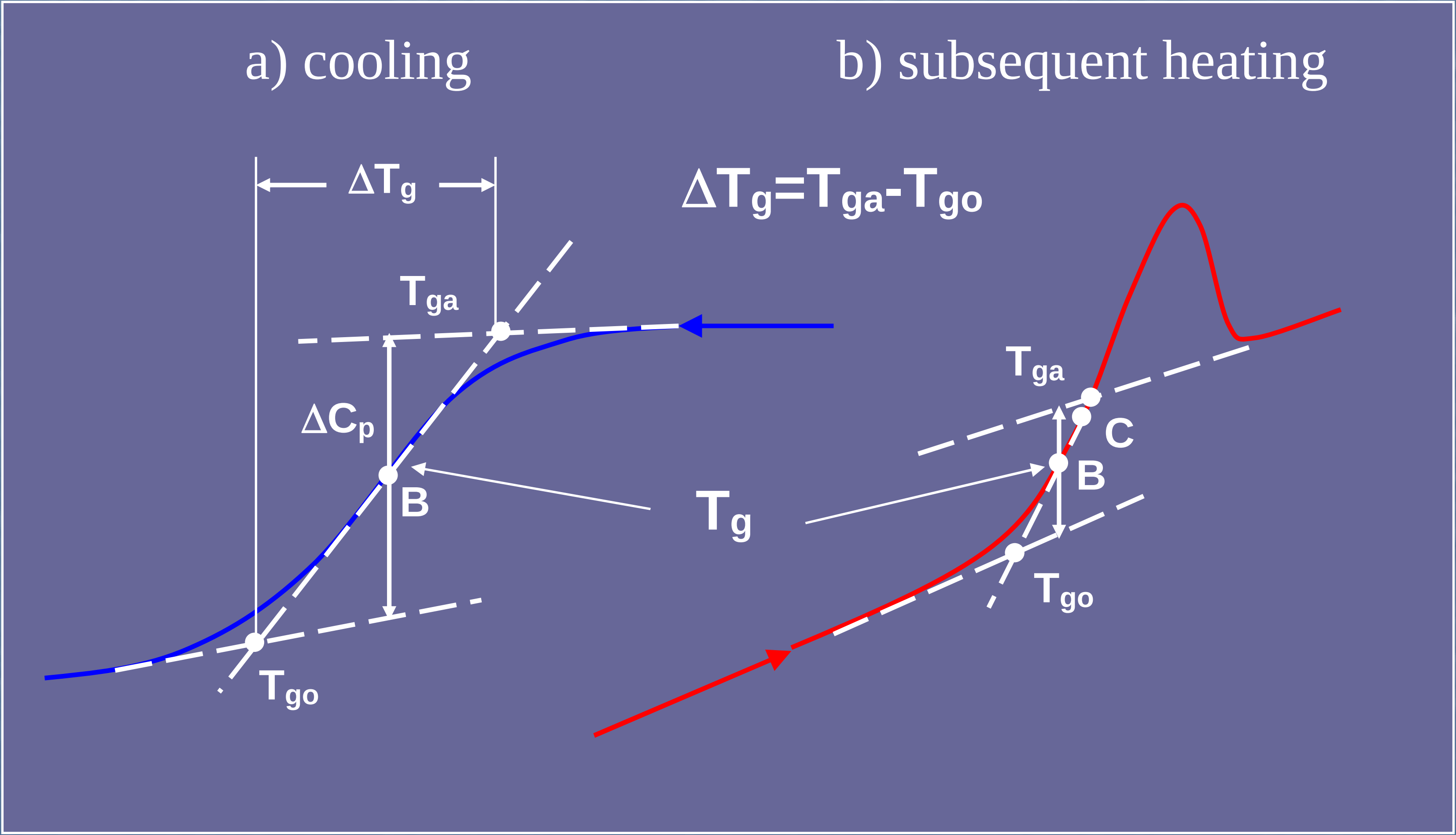
Semi-polymers (e.g., PVC and Lignin)



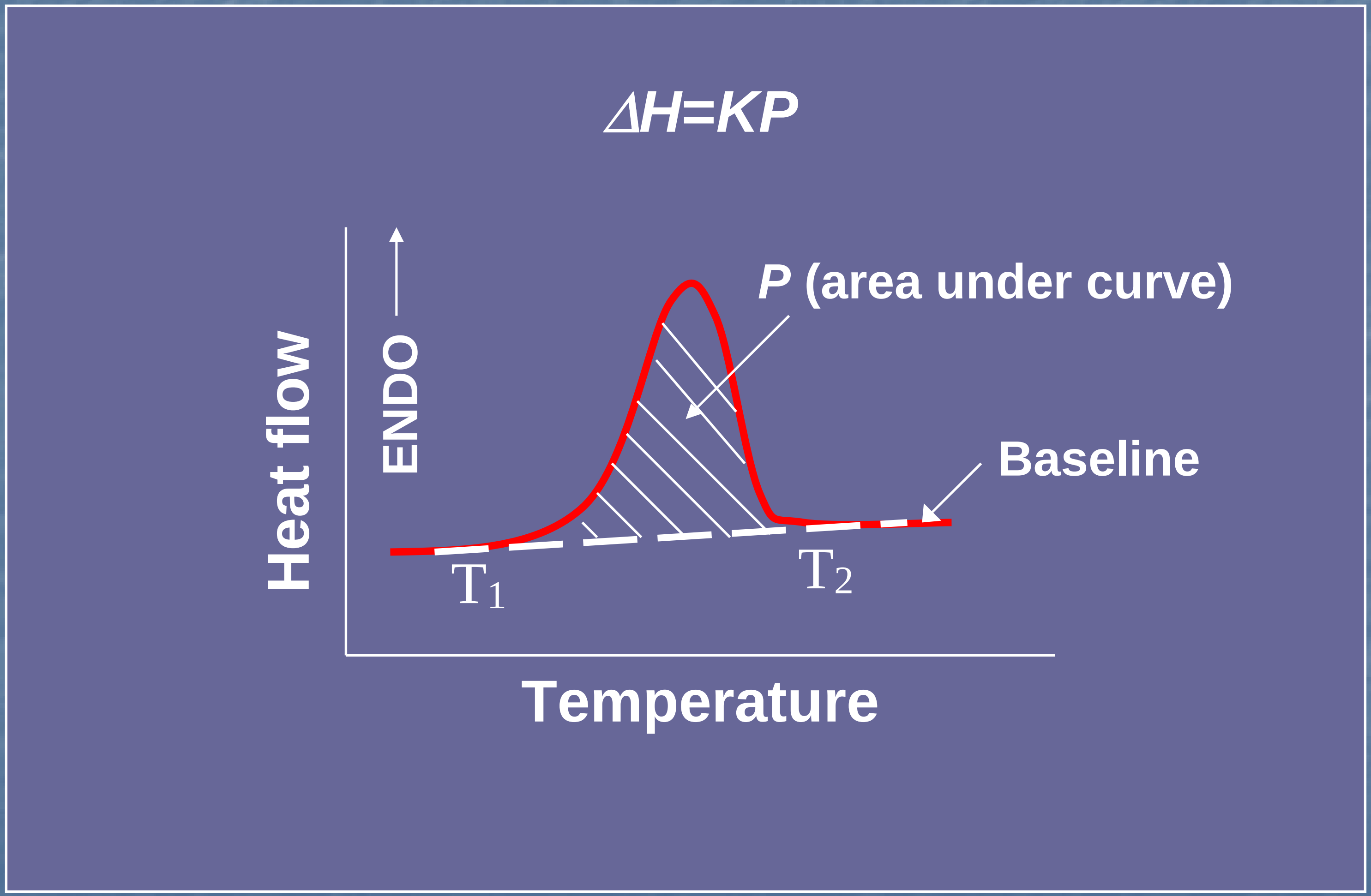
Transition Temperatures



Glass Transition Temperature T_g



Enthalpy

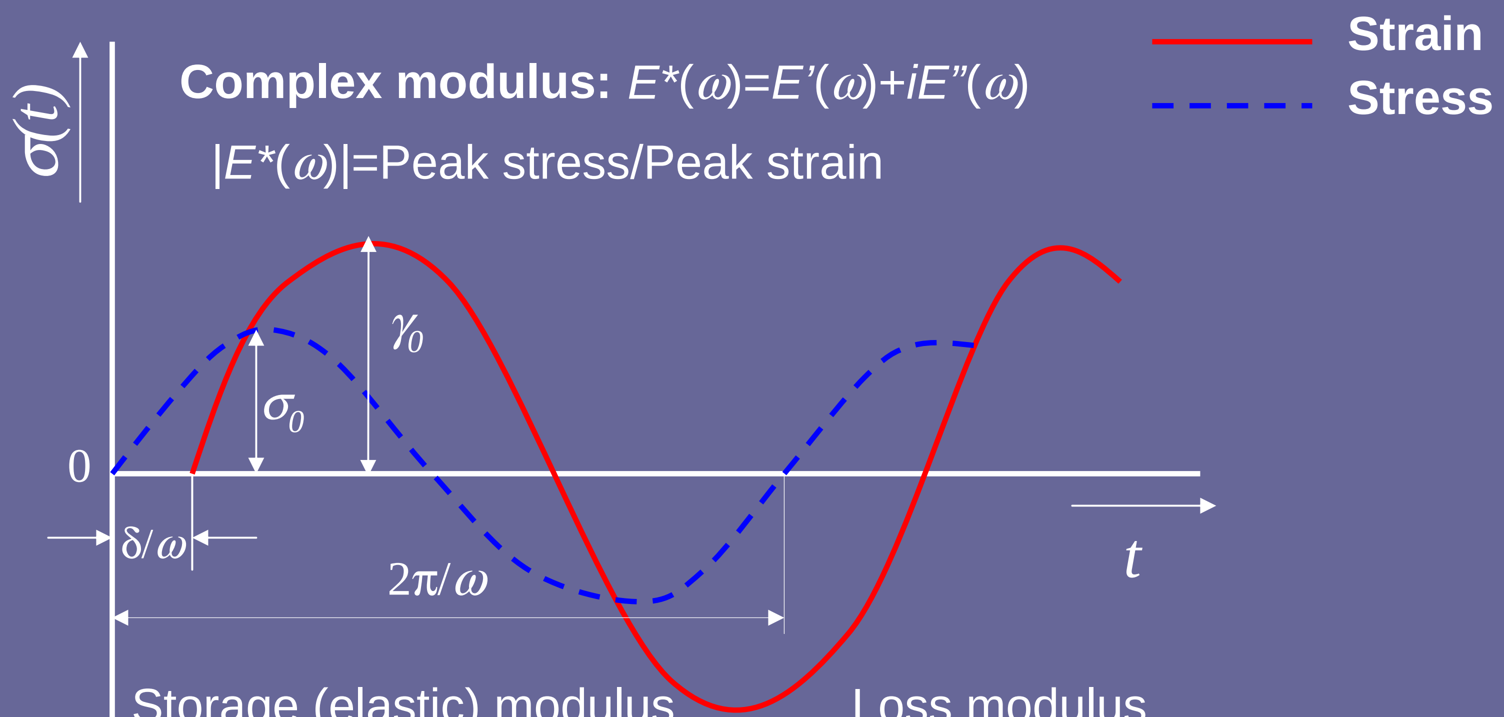


ΔH=KP
P (area under curve)
Baseline
Heat flow
ENDO
T1
T2
Temperature

Stress-strain Relationship Under Dynamic (sinusoidal) Loading

Complex modulus: $E^*(\omega)=E'(\omega)+iE''(\omega)$

$|E^*(\omega)|$=Peak stress/Peak strain



Storage (elastic) modulus

$|E'(\omega)|=|E^*(\omega)|\cos\delta$

Loss modulus

$|E''(\omega)|=|E^*(\omega)|\sin\delta$

Dynamic Stress-strain Relationship

Stress $\sigma(t)$ under a sinusoidal load:

$$\sigma(t) = \sigma_0 \sin(\omega t + \delta)$$

Strain $\gamma(t)$ by a phase angle δ corresponding to the stress $\sigma(t)$:

$$\gamma(t) = \gamma_0 \sin(\omega t)$$

Dynamic modulus E^*:

$$E^*(\omega) = \frac{\sigma(t)}{\gamma(t)}$$

Relationship among complex, storage, and loss moduli:

$$E^*(\omega) = E'(\omega) + iE''(\omega)$$

Phase angle δ :

$$\tan\delta = \frac{E''(\omega)}{E'(\omega)}$$

Thermal/Mechanical Properties

- Glass transition temperature T_g
  - DSC and DMA
- Melting temperature T_m
  - DSC
- Heat flow (dQ/dt) and enthalpy (ΔH)
  - DSC
- Bonding moduli (E', E'', and E^*) and the phase angle (δ)
  – DMA
- Thermal stability (weight loss under heat)
  - TGA

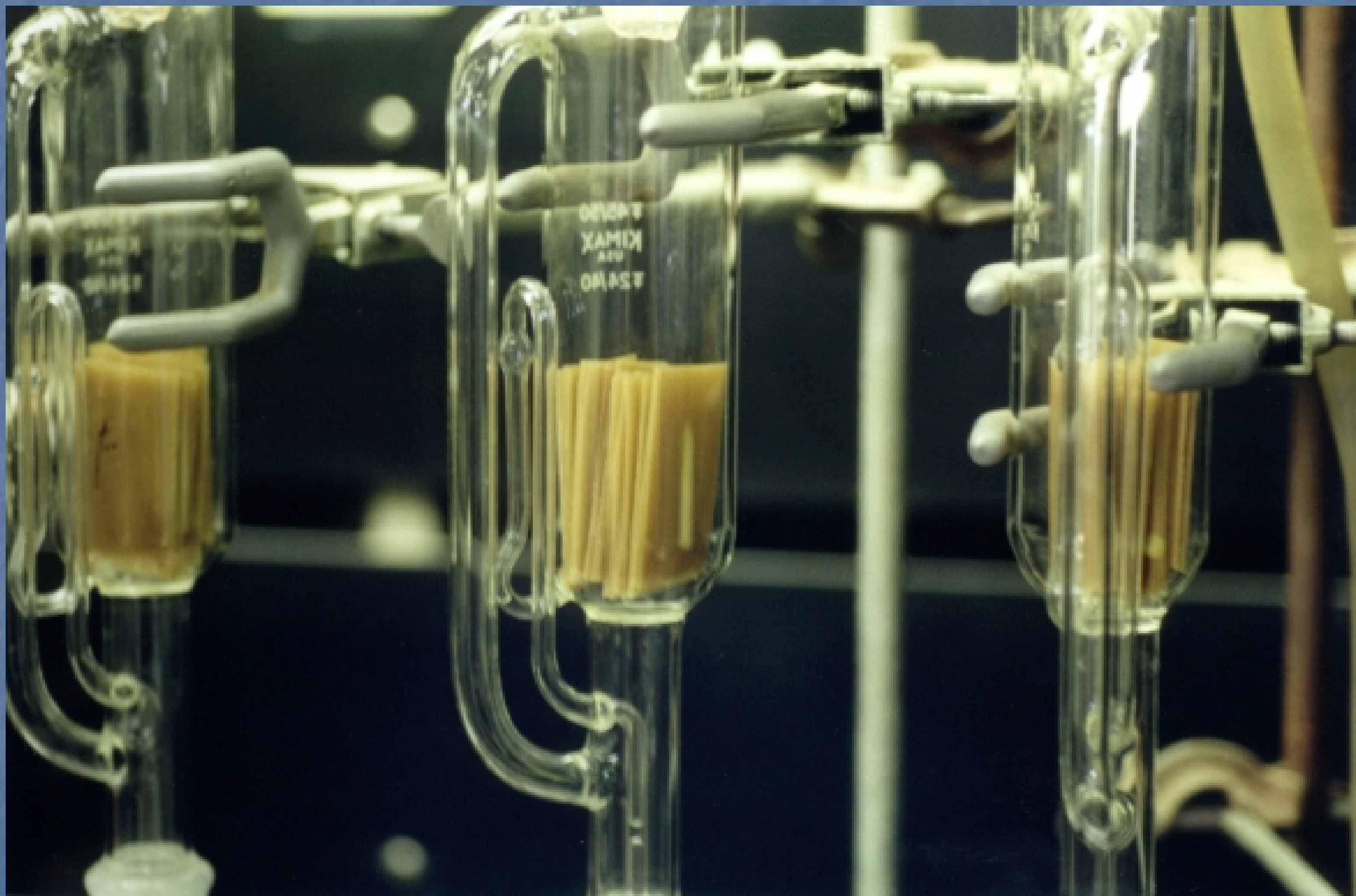
Experimental

- Materials

  - Wood Veneer - Yellow poplar (0.91 mm Thick)
  - PVC film - Clear (0.0762 mm Thick)
  - Maleated polypropylene (MAPP)
    - Epolene E-43 (Mw =9,100)
    - Epolene G-3015 (Mw =47,000)
  - Initiator - Benzyol peroxide
  - Solvent - Toluene

- **Sohxlet Extraction**
  - **ASTM standard D1105-96. Wood specimens were extracted for 4 hours with two sets of solvents.**
- **Coupling Treatment**
  - **Wood specimens were dipped in the coupling solutions of 0, 12.5, 25, and 50 g/L MAPP at 100°C for 5 min under a continuous stirring with a magnetic stirrer.**

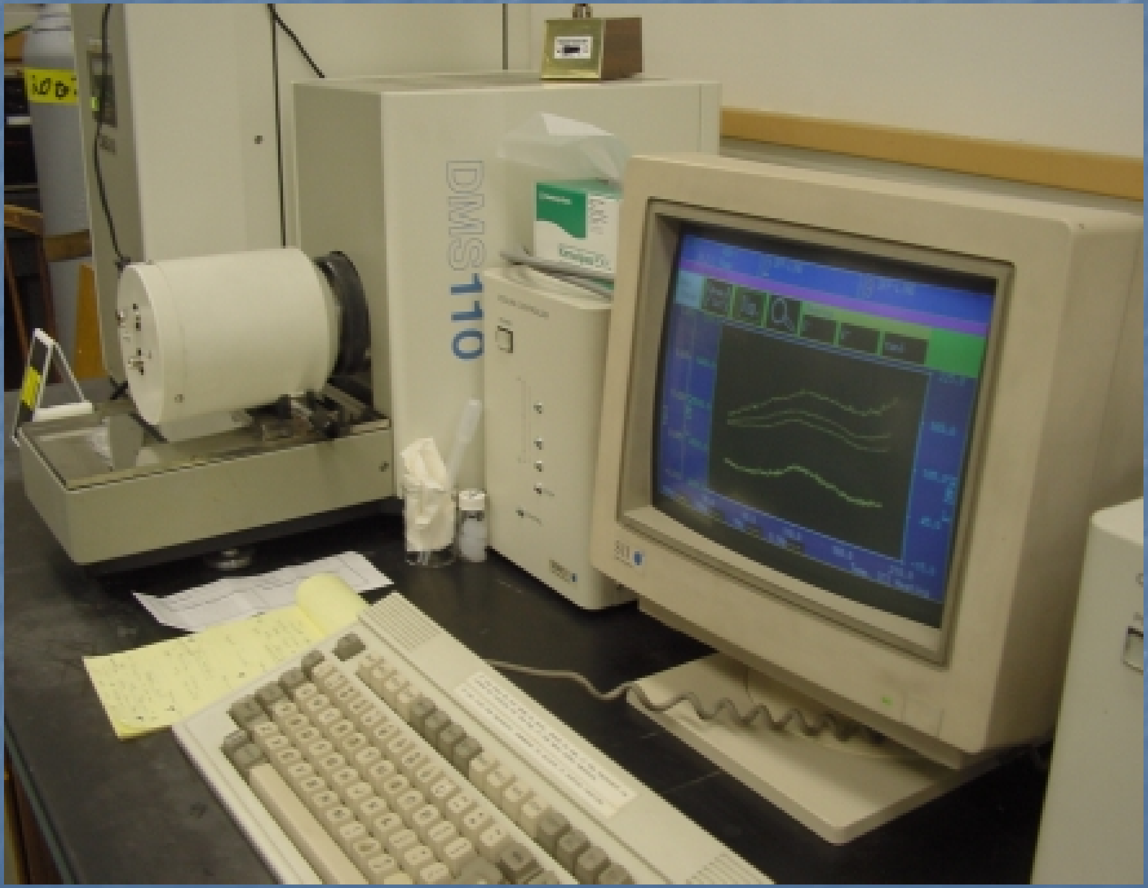
Wood Veneer under Sohxlet extraction

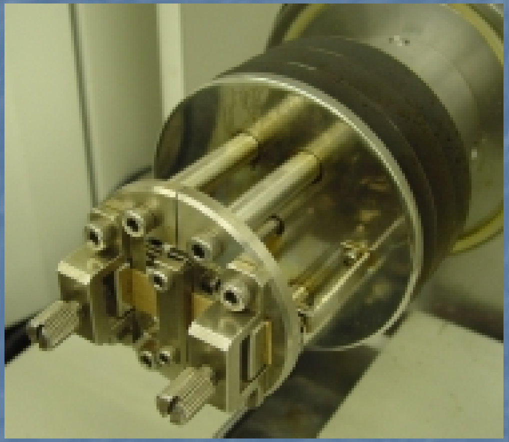


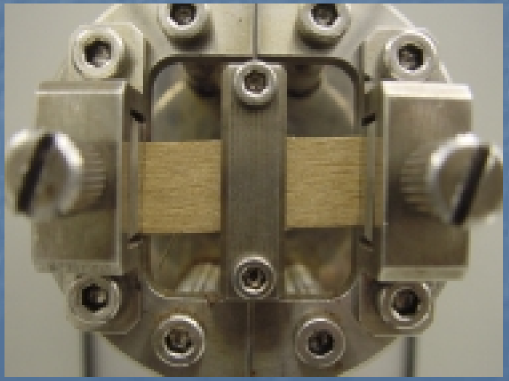
- Manufacture of wood-PVC composites
  - Pressure: 0.276 MPa
  - Pressing procedure: Heating 3 min at 178°C and then cooling at 70°C for 1 min
- Shear strength measurement
  - Shear tests followed the ASTM standards D3163 and D3165

Wood-PVC Laminates under Shear Testing

DMA (Seiko Instruments, Model DMS 110)







DMA Procedure

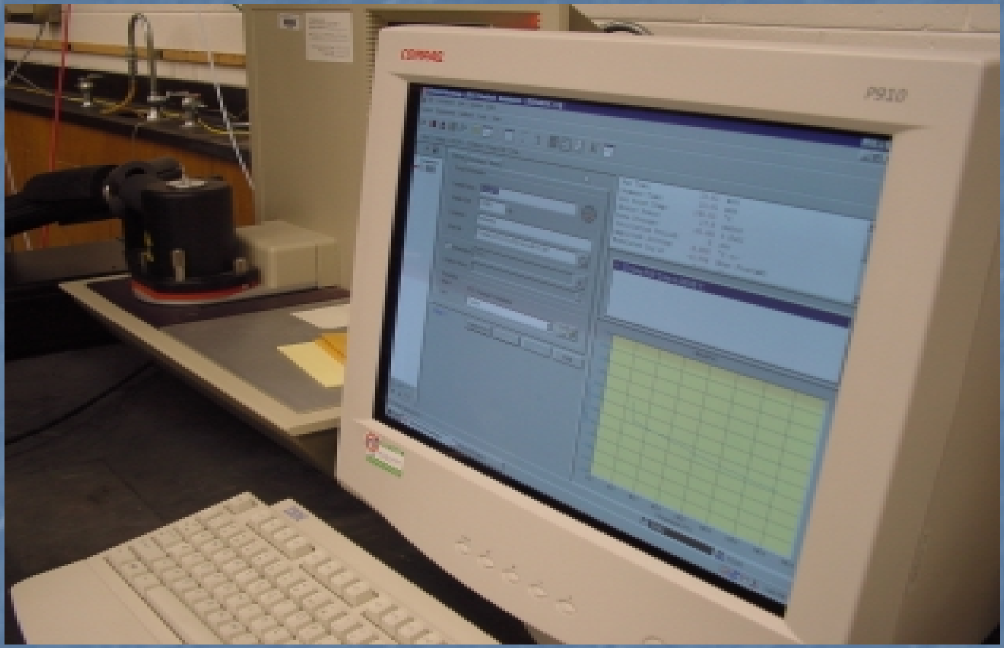
- Using three cycles

Specimen	Test mode	Test cycle	Temperature [°C]		Rate [°C/min]
			Start	Stop	
Wood	Bending	First heating	20	220	0.50
		First cooling	220	30	0.25
		Second heating	30	220	0.50
PVC	Bending	First heating	20	100	0.50
		First cooling	100	30	0.25
		Second heating	30	100	0.50
Woo-PVC composites	Bending	First heating	20	150	0.50
		First cooling	150	30	0.25
		Second heating	30	150	0.50

TGA system
(TA Instruments, Model TGA2950)

Procedure: Heating from 25°C to 600°C under a N_2 flux at a pressure of 8 KPa

DSC (TA Instruments, Model DSC2920)



Procedure

For interphase samples, heating from 25ºC to 200ºC under a N_2 flux at a pressure of 8 KPa

For modified wood veneer and wood-PVC composite samples, cooling at -10ºC for a while and then heating up to 200ºC in a N_2 flux

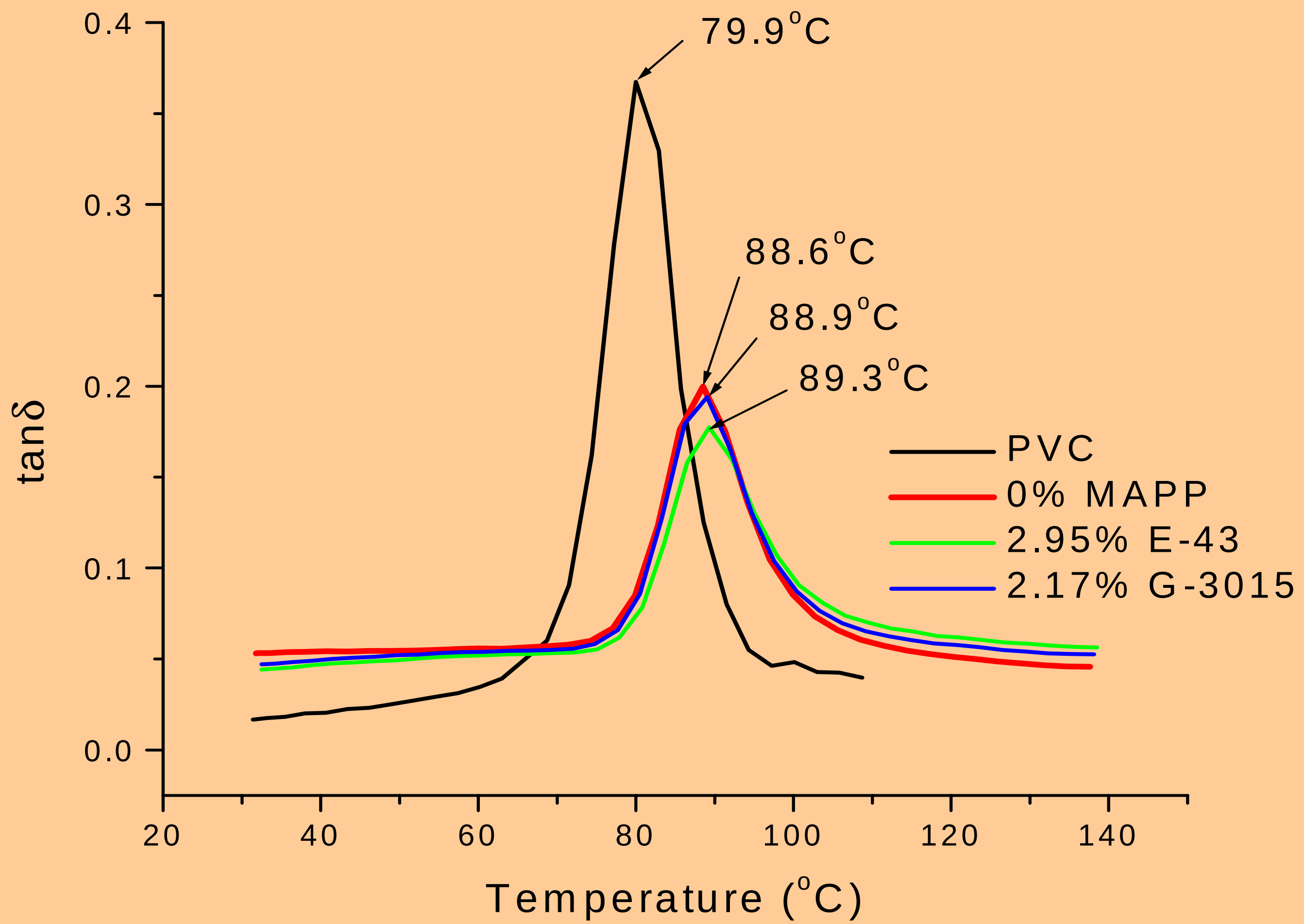
Summary Results on Thermal/Mechanical Properties

Material	E' (GPa)[a]	E" (GPa)[a]	Glass transition (°C)[a]	tanδ [a]	Shear strength (MPa)	Enthalpy (J/g)[b]	TG at 600°C (%)	DTG_{max} (%/°C)[c]
PVC	5.73	0.44	76.1	0.39	-	0.81 @79.6°C	10.3	2.37 @257°C
Wood	10.43	0.41	67.2	0.05	-	21.69 @50.7°C	18.8	1.47 @356°C
Wood-PVC composites:								
0% MAPP	7.85	1.04	85.1	0.22	3.14	-	16.8	0.80 @266°C, 0.65 @329°C
2.95% E-43	7.96	0.97	85.9	0.22	2.90	-	17.9	0.75 @270°C, 0.62 @340°C
4.12% E-43	9.45	1.23	83.0	0.24	3.03	15.95 @88.0°C	18.2	0.69 @266°C, 0.61 @339°C
6.83% E-43	9.16	1.15	82.6	0.23	3.32	-	16.5	0.67 @275°C, 0.63 @344°C
2.17% G-3015	7.08	0.8	85.5	0.23	2.90	-	16.5	0.72 @266°C, 0.75 @344°C
3.64% G-3015	8.98	1.16	83.9	0.24	2.94	15.99 @81.8°C	15.4	0.72 @258°C, 1.07 @350°C
6.35% G-3015	8.56	1.09	84.3	0.24	3.61	-	17.0	0.71 @276°C, 0.58 @335°C

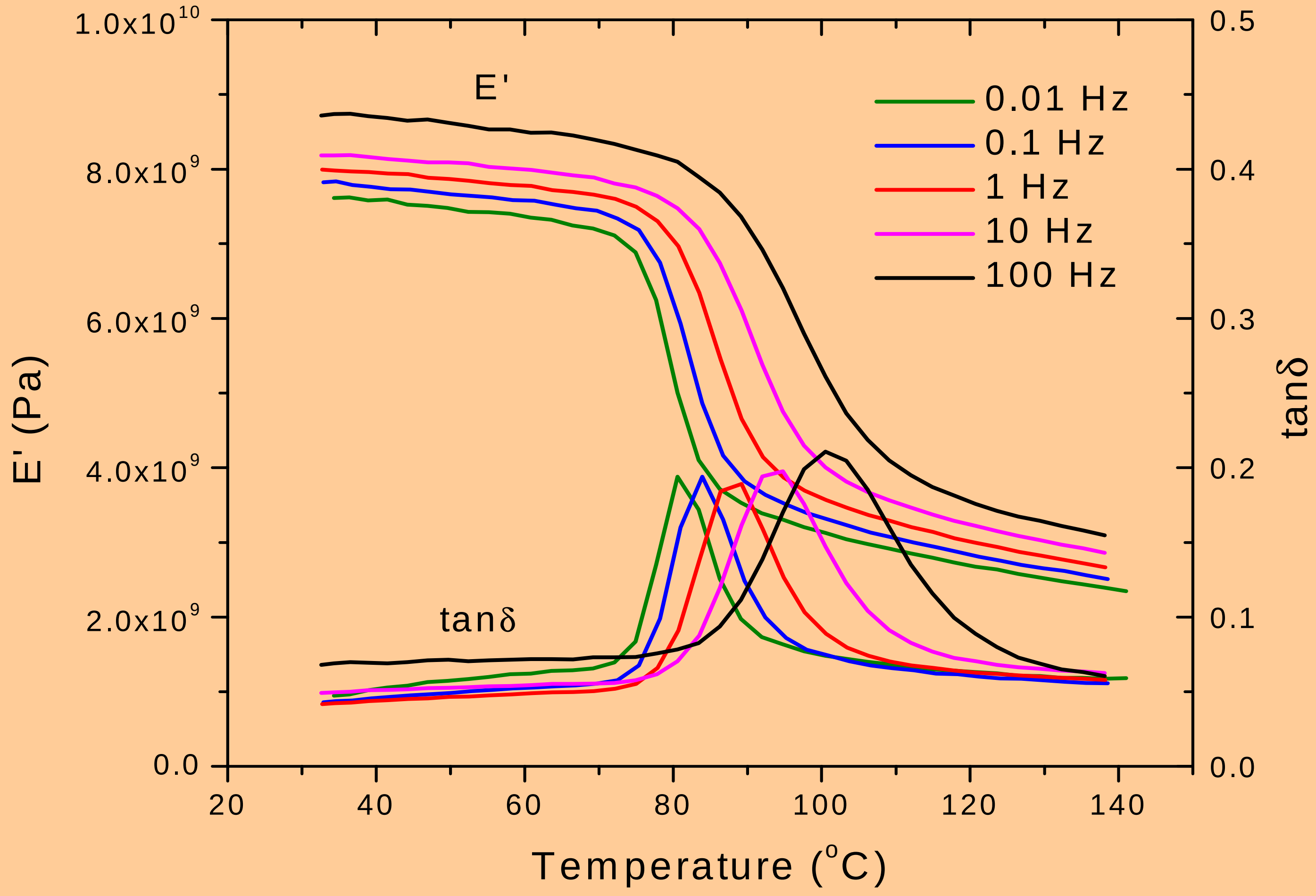
[a] The value was measured in first heating at 1 Hz;
[b] The value was measured at the glass transition;
[c] Two maximum peaks were selected for wood-PVC composites.

DMA Results

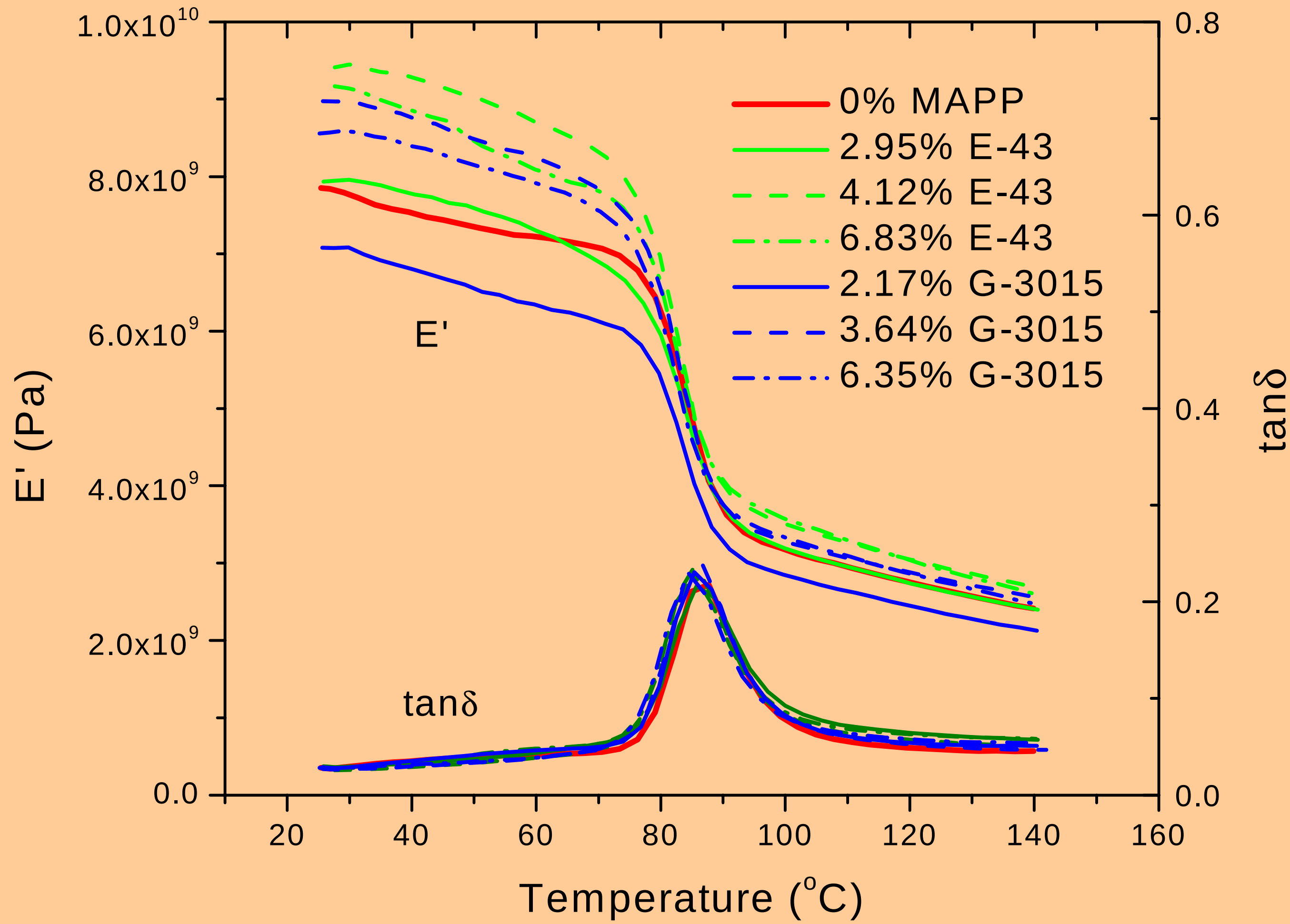
Glass Transitions of Wood-PVC Composites



Influence of Frequency on E' and tanδ of Wood-PVC Composites with 6.83% E-43

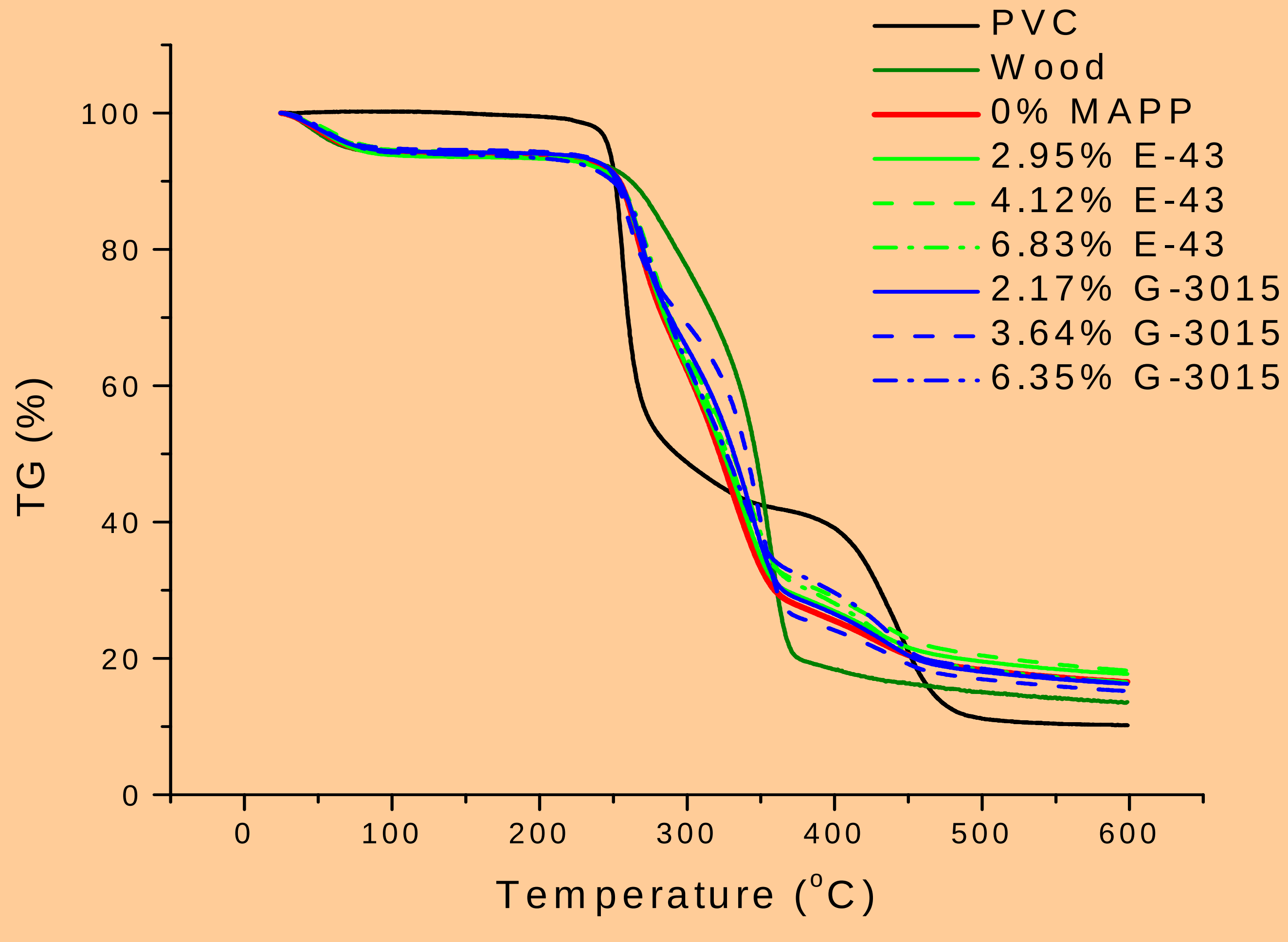


Influence of MAPP Retention on E' and tanδ of Wood-PVC Composites (Freq = 1 Hz)

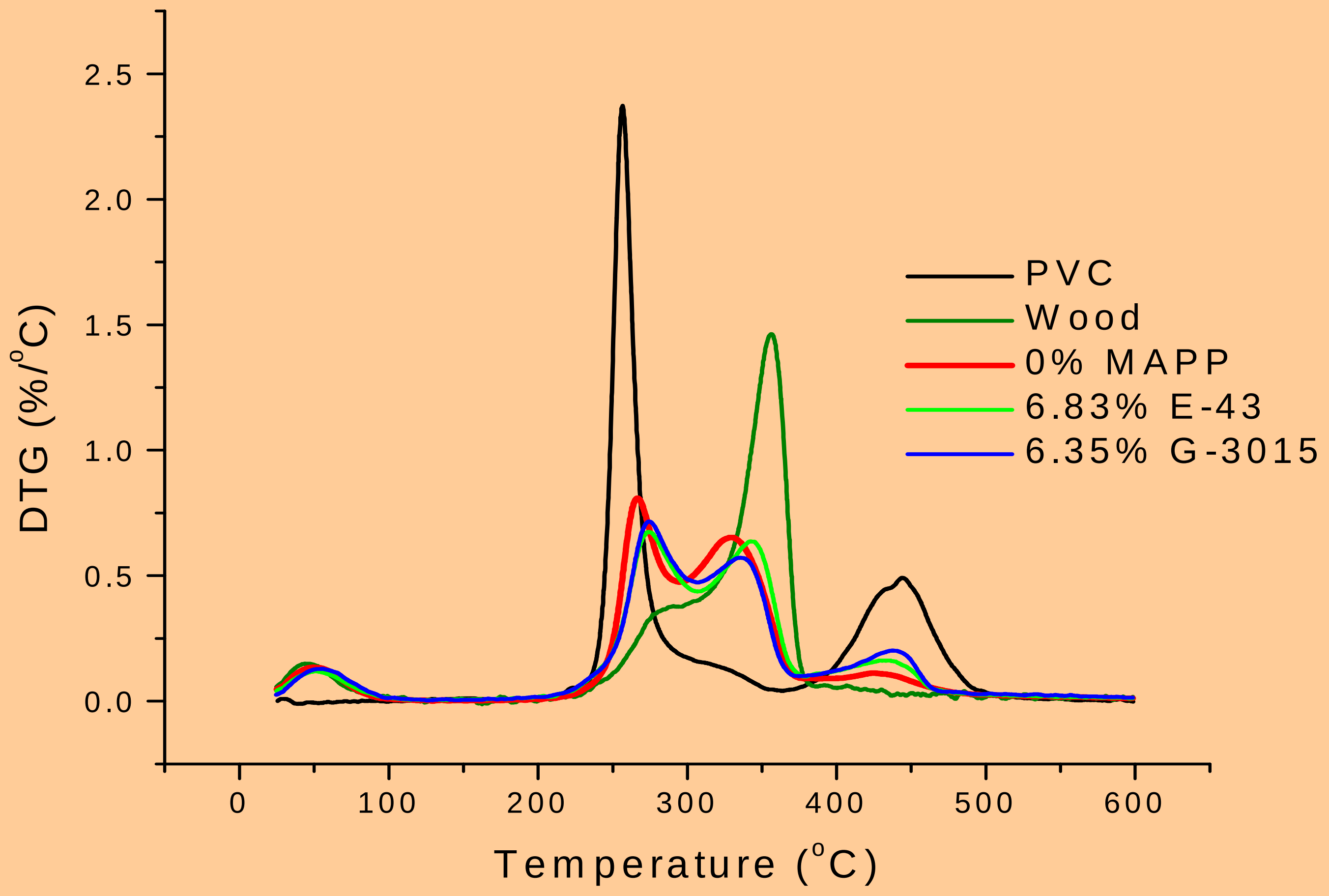


TGA Results

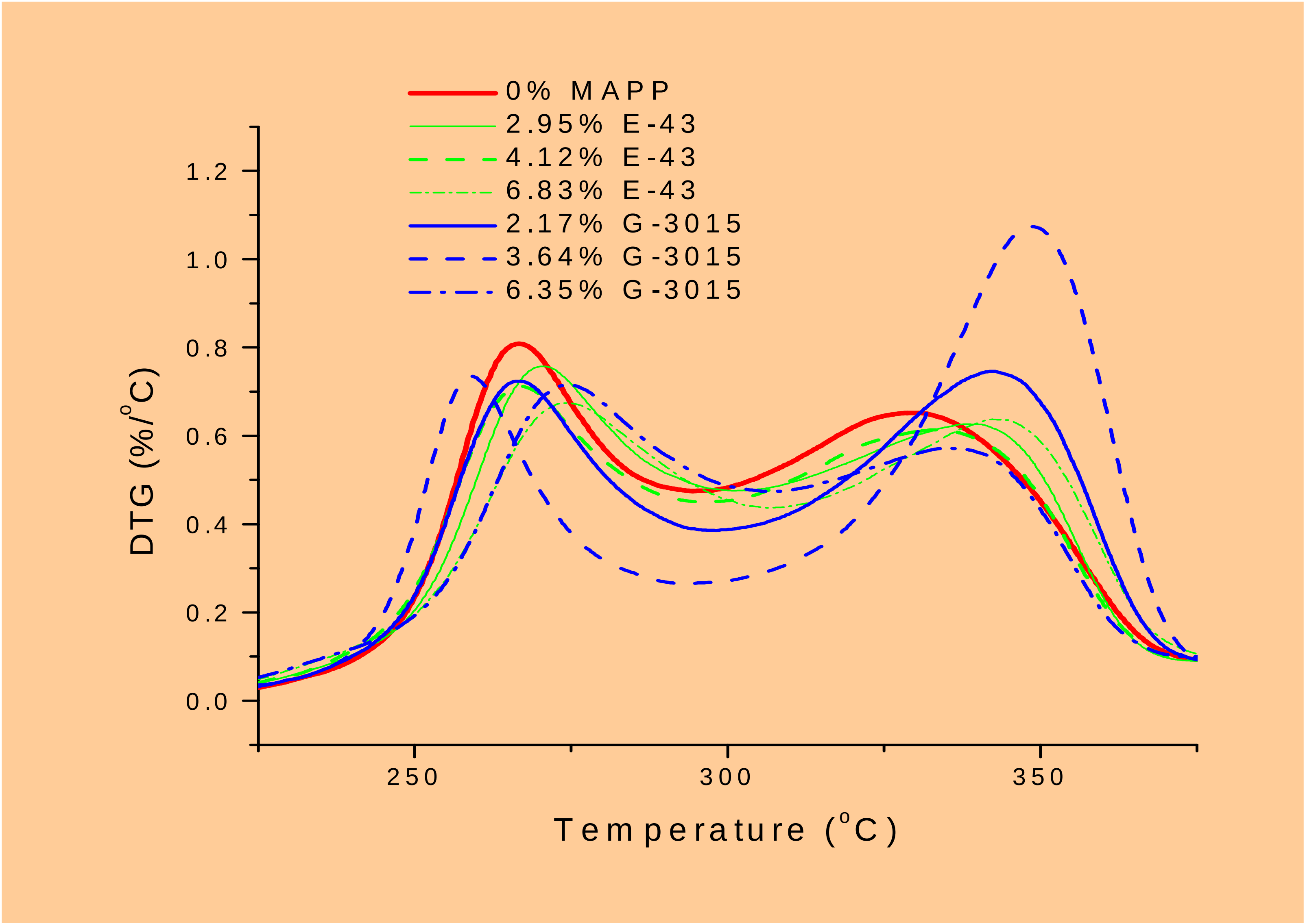
Influence of Maleation on Decomposition of Wood-PVC Composites by TG



Influence of Maleation on Decomposition of Wood-PVC Composites by DTG

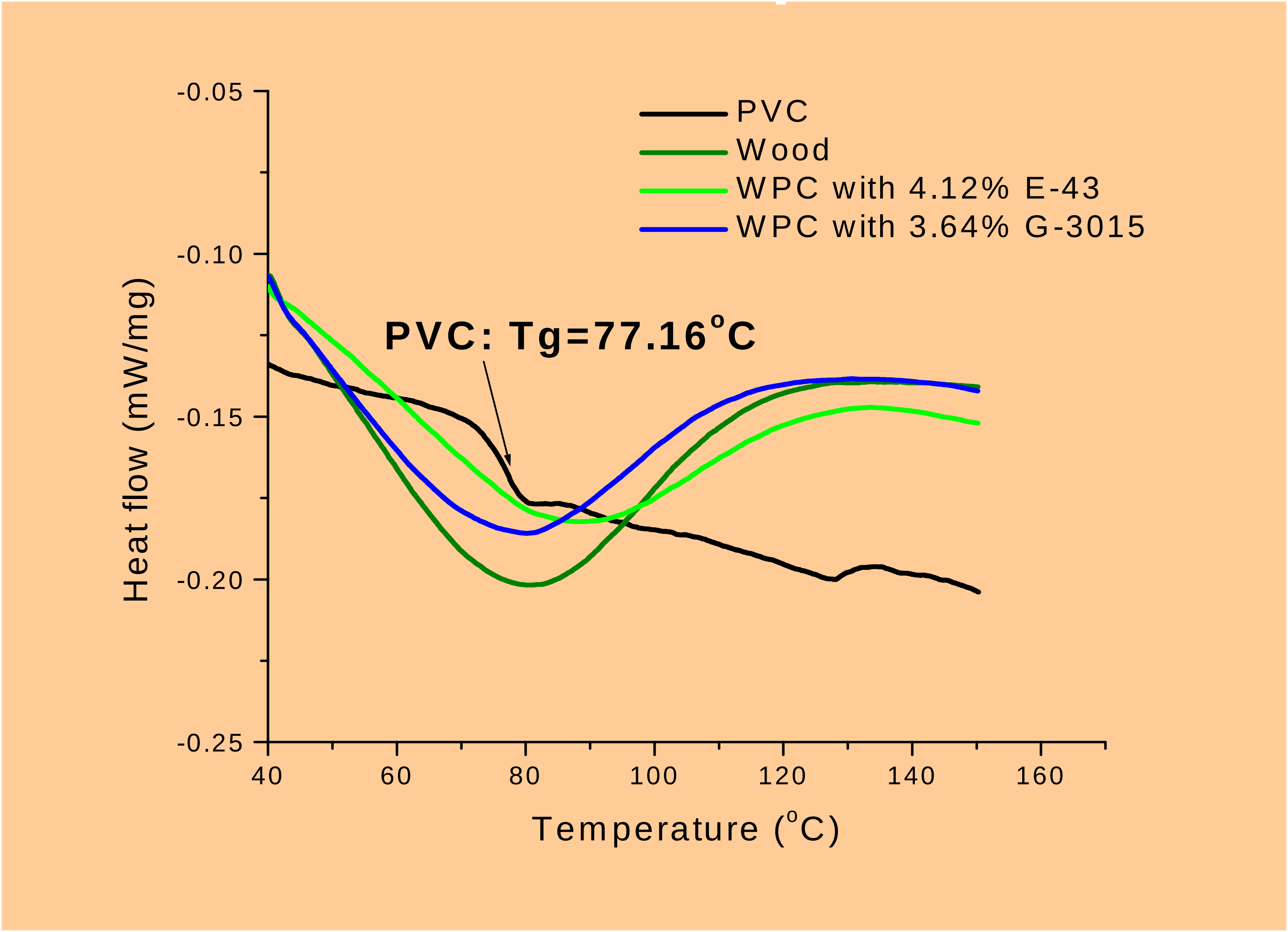


Comparisons on DTG Decomposition of Wood-PVC Composites with and without Maleation

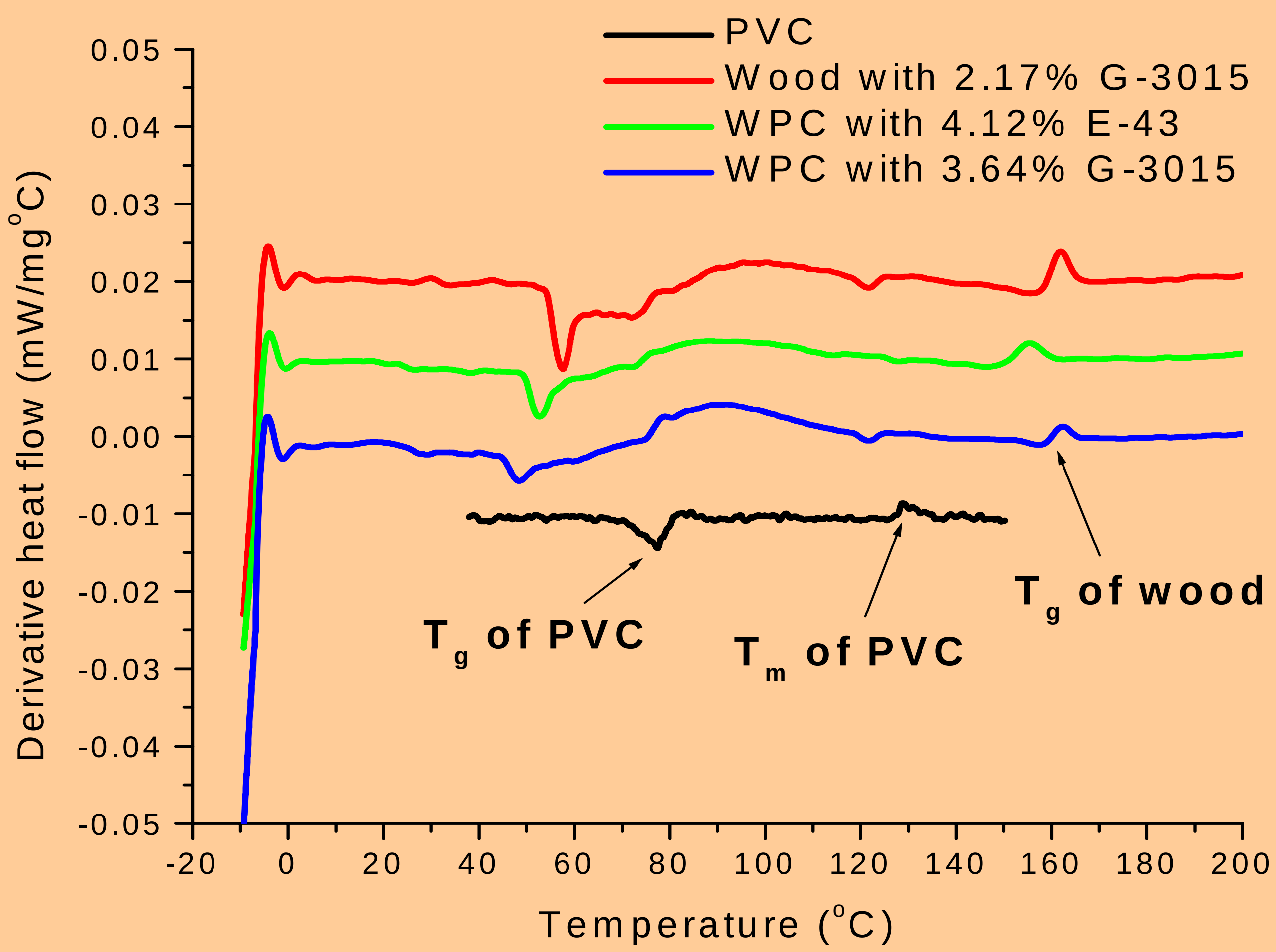


DSC Results

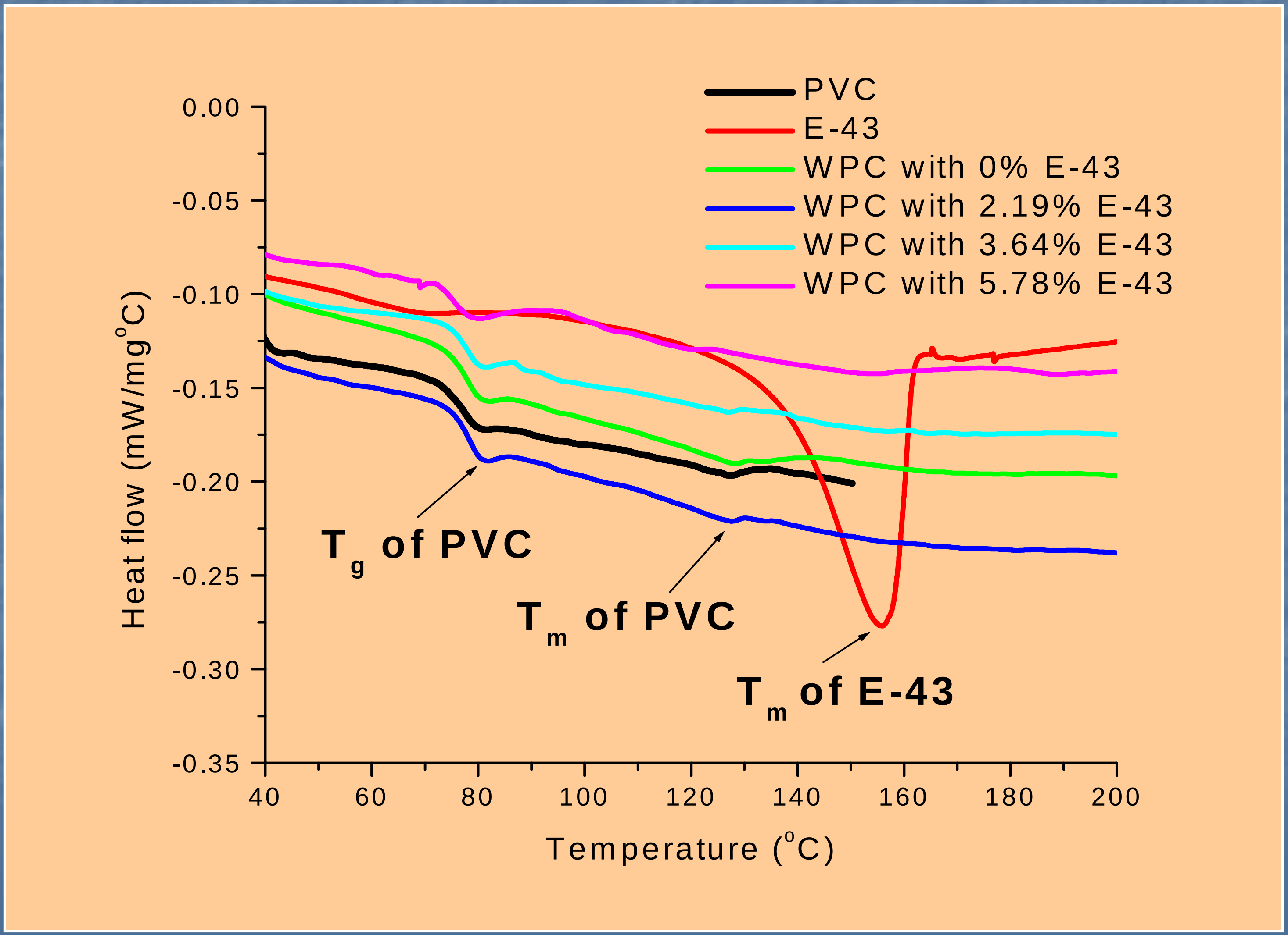
Heat Flow (dQ/dt) *vs.* Temperature For Wood-PVC Composites



Derivative DSC spectra for PVC, modified wood veneer, and wood-PVC composites



DSC Spectra of PVC-MAPP Interphases



Conclusions

- Maleation significantly influenced the thermal behavior of wood-PVC composites.
- E' and E^* increased with MAPP retention and graft rate. However, tanδ was independent of retention and graft rate.
- Wood-PVC composites with MAPP had significant shifts in DMA, DSC, and TG/DTG spectra compared with those without MAPP.