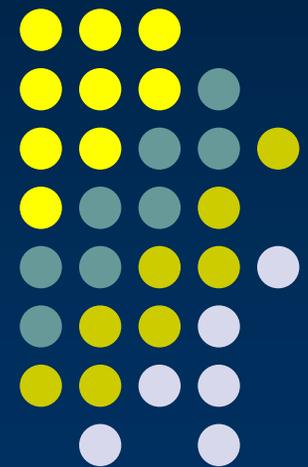


Extruded Bagasse Fiber Plastic Composites: - Creep Performance

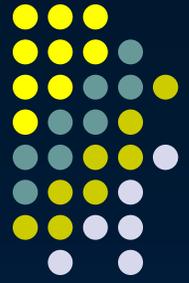
Wu, Q.¹, Y. Xu¹, Y. Lei¹, C. M. Clemons²

¹ School of Renewable Natural Resources, Louisiana State University AgCenter, Baton Rouge, LA 70803

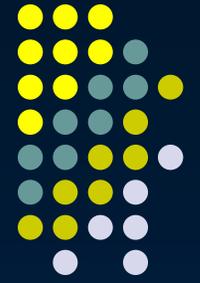
² Performance Engineered Composites, USDA Forest Service, Forest Products Laboratory, One Gifford Pinchot Drive Madison, WI 53705-2398



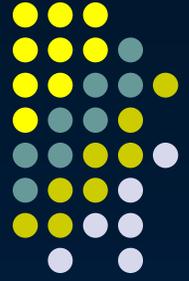
Background



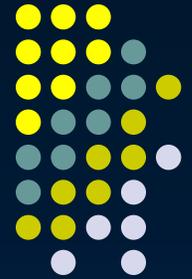
- Use of natural fibers as reinforcers and fillers for polymer composites is commonplace
- Baggase is one of the major fiber resources – 4.5 million tons dry fiber/year in US and 85% burnt for energy
- Time-dependent properties – a major challenge



Objectives



- To develop production technology for manufacturing bagasse polymer composites through profile extrusion.
- To compare basic strength and biological resistance properties of manufactured composites with commercial wood-plastic composites.
- To measure/predict creep performance using time-temperature superposition.

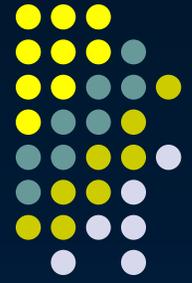


Raw Material

Plastics:	Virgin HDPE & recycled HDPE Virgin PVC & recycled PVC
Bagasse fiber:	Hammermilled bagasse
Coupling agent:	MAPE and SEBS
Heat stabilizer:	MARK 1900 (for PVC)
Lubricant:	TPW-012

Formulations

HDPE-bagasse: HDPE/Fiber/MAPE/lubricant = 42%/50%/2%/6%
PVC-bagasse: PVC/Fiber/SEBS/lubricant/heat stabilizer =
41.2%/50%/2%/6%/0.8%



Compounding

Plastic, bagasse fiber, and additives were fed separately to a single upstream port of a 27-mm twin-screw extruder. The blend was extruded through a strand die, cooled with a water bath, and then pelletized.

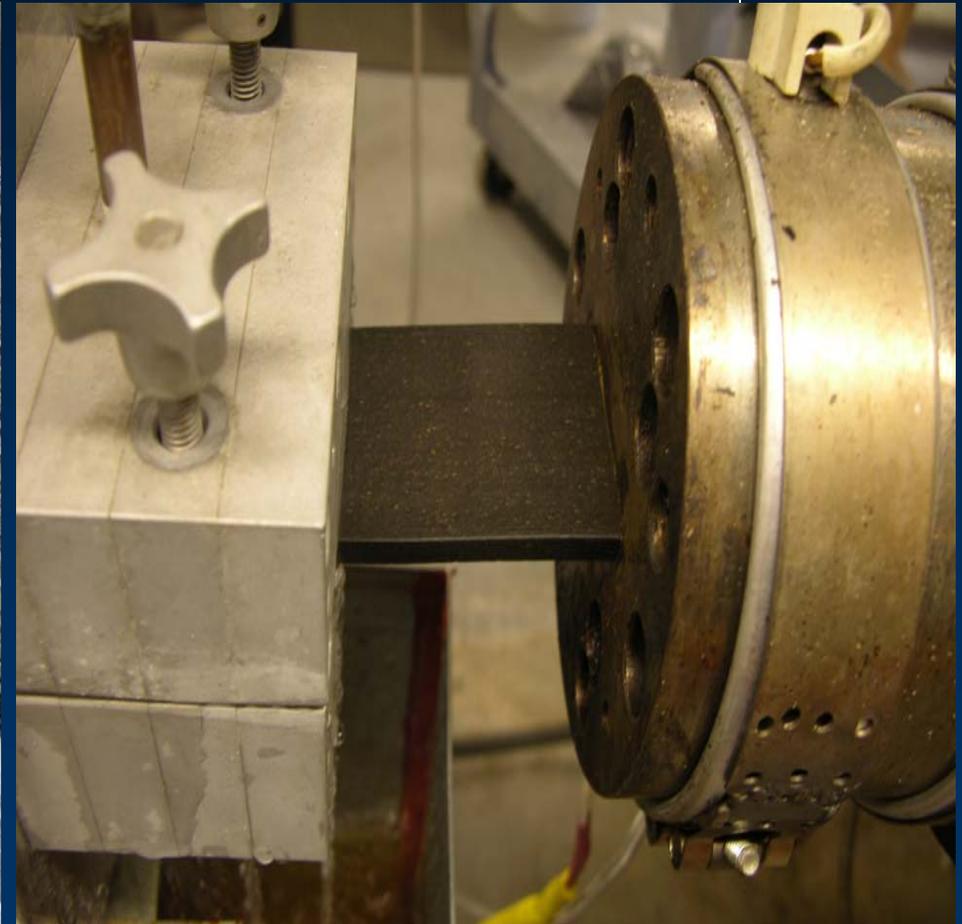
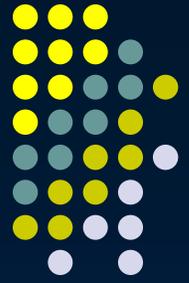
HDPE: 182 (hopper) -182-177-177- 154- 154-154-146°C (die) at 200 rpm
PVC: 182 (hopper)-182-177-177-177-177-177°C (die) at 80 rpm.

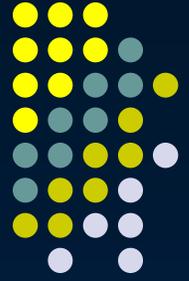
Profile Extrusion

Profile extrusion was done with a different screw design using the pellets to produce a 65 (wide) x 6.5-mm (thick) composites.

182(hopper)-182-199-199-143- 143-149-149-160 (Die) at 150 rpm for HDPE
182 (hopper)-182-199-199-143-143-149-149-160 (Die) at 80 rpm for virgin PVC and
40 rpm for recycled PVC.

Profile Extrusion





Product Testing

- Density profile through sample thickness
- Water absorption and swelling (VPS process)
- Bending modulus and strength (ASTM D790-03)
- Impact strength (ASTM D256-02)
- Composite morphology (SEM)
- Termites (AWPA E1)
- Decay (AWPA E10)
- **Creep (TTS)**

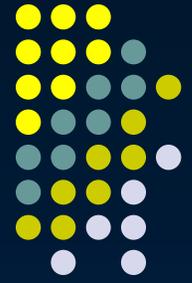
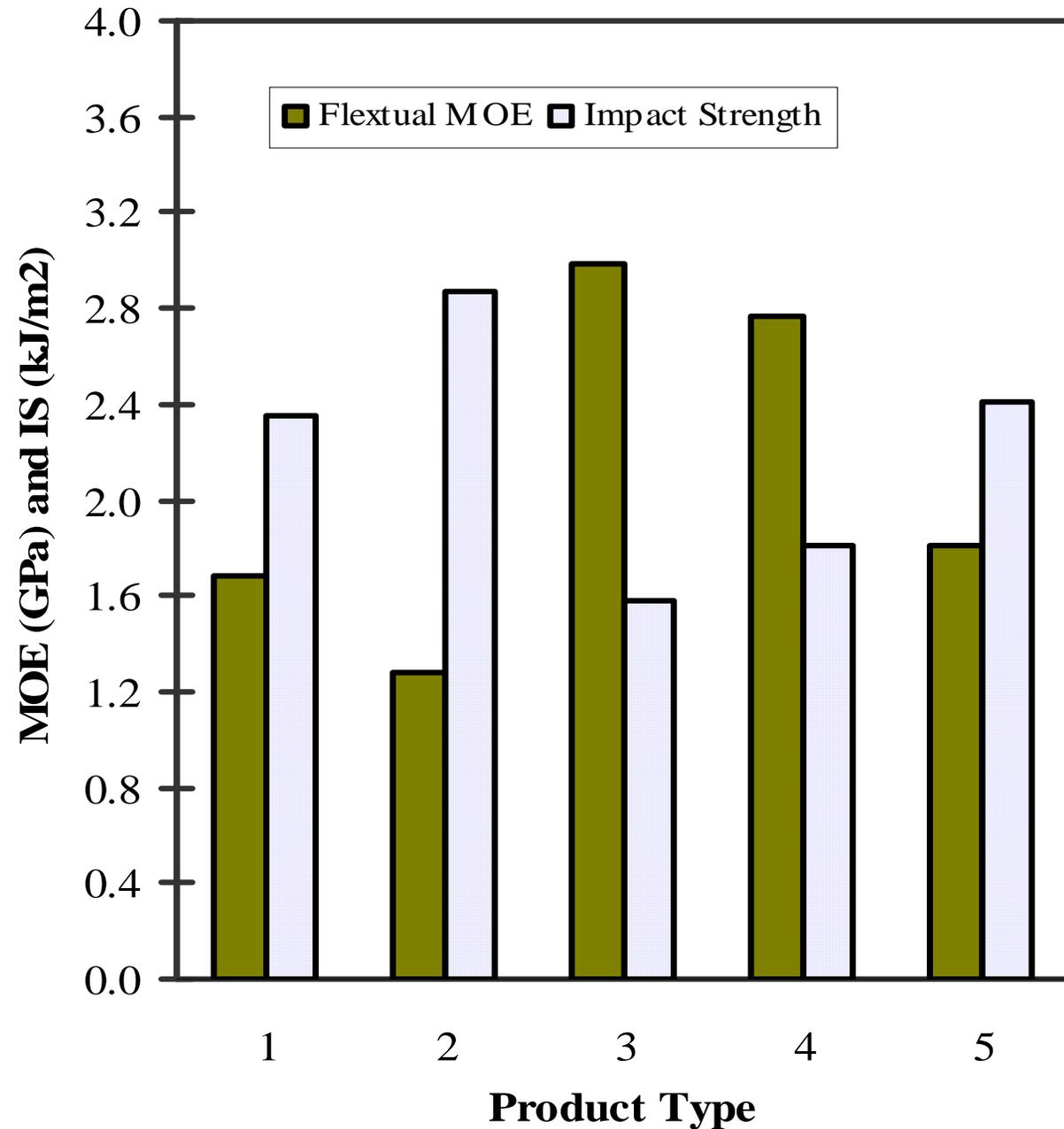
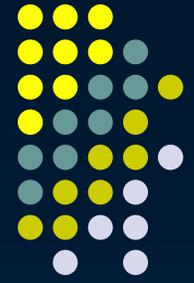


Table 1. Summary of physical and mechanical properties of the profile extruded composites.

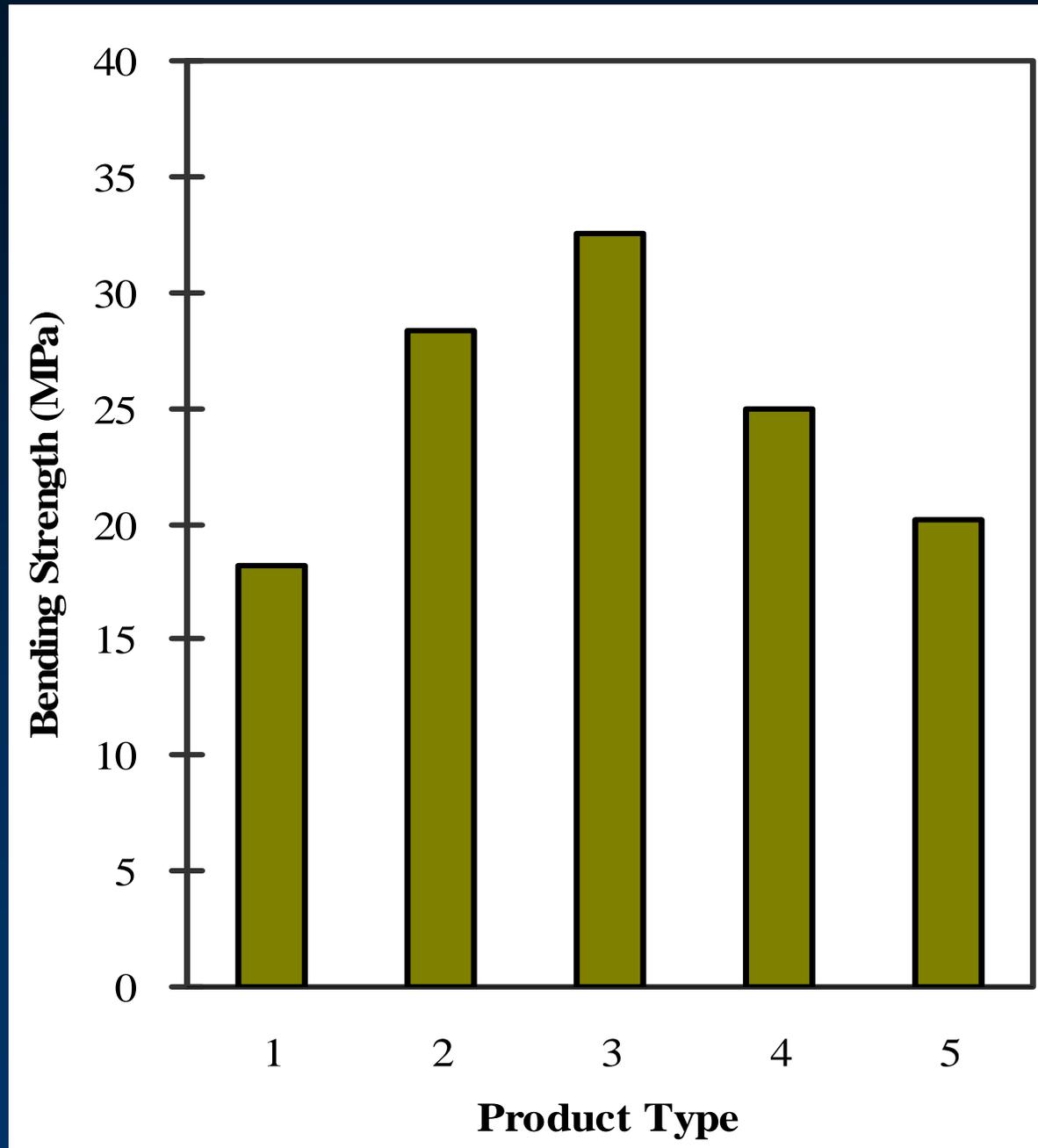
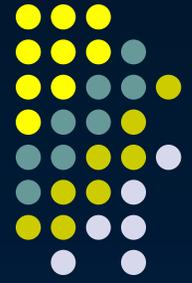
Product Type¹	Density (kg/m³)	Water Absorption² (%)	Thickness Swelling² (%)	Bending Strength (MPa)	Bending Modulus (GPa)	Impact Strength (kJ/m²)
B-V-HDPE	994	1.04 (0.09) C	0.50 (0.27) B	20.17 (2.33) C	1.68 (0.11) B	2.35 (0.19) B
B-R-HDPE	1130	0.40 (0.08) D	0.87 (0.34) B	28.31 (0.92) AB	1.28 (0.15) C	2.87 (0.11) A
B-V-PVC	1244	3.67 (0.45) A	3.30 (1.34) A	32.49 (0.35) A	2.98 (0.18) A	1.58 (0.09) D
B-R-PVC	1322	1.33 (0.06) C	3.04 (1.10) A	24.95 (1.45) B	2.77 (0.13) A	1.81 (0.11) C
W-V-HDPE	1050	1.91 (0.14) B	1.15 (0.66) B	20.15 (3.45) C	1.81 (0.43) B	2.41 (0.22) B

¹ B-V-HDPE: bagasse virgin HDPE; B-R-HDPE: bagasse recycled HDPE; B-V-PVC: bagasse virgin PVC; B-R-PVC: bagasse recycled PVC; and W-V-HDPE: wood virgin HDPE (commercial docking material).

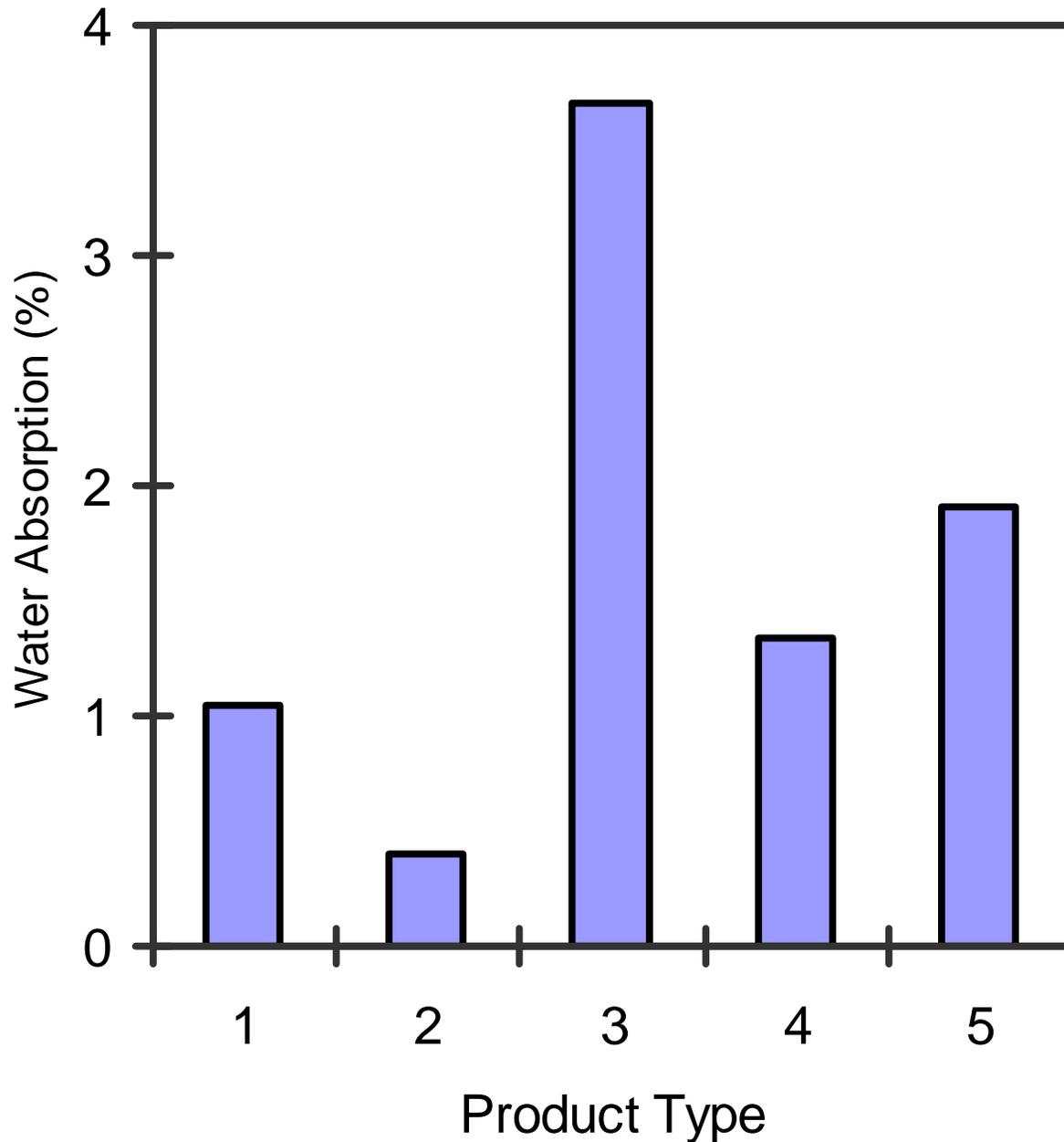
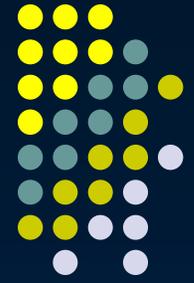
² Water absorption cycle: 30 minutes vacuum at 30 inch Hg -> 3-hour pressuring at 100 PSI.



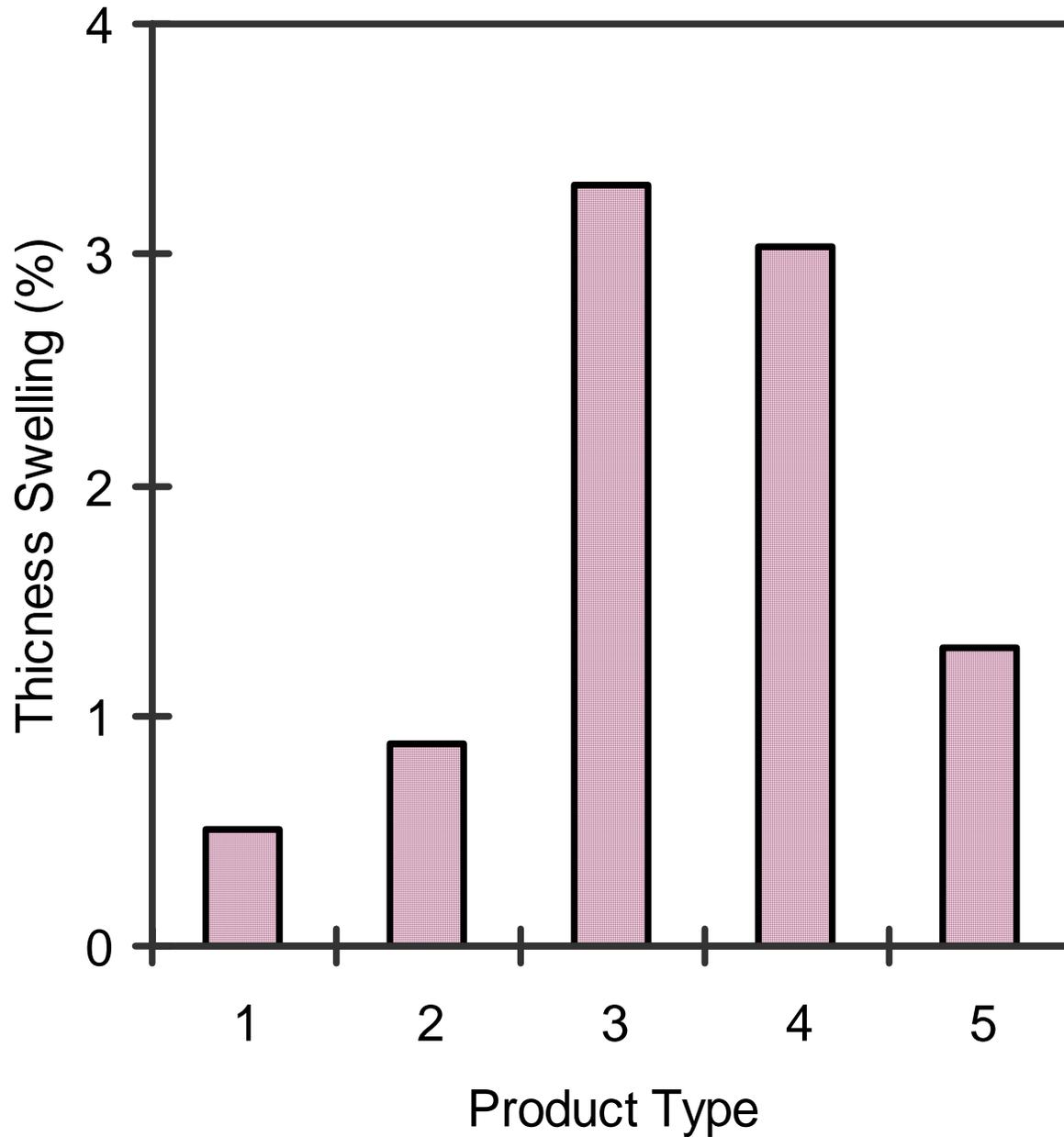
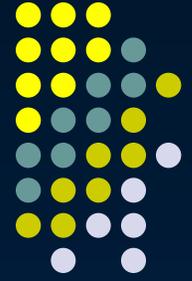
- 1: B-V-HDPE: bagasse virgin HDPE;
- 2: B-R-HDPE: bagasse recycled HDPE;
- 3: B-V-PVC: bagasse virgin PVC;
- 4: B-R-PVC: bagasse recycled PVC;
- 5: W-V-HDPE: wood virgin HDPE (commercial decking material).



- 1: B-V-HDPE: bagasse virgin HDPE;
- 2: B-R-HDPE: bagasse recycled HDPE;
- 3: B-V-PVC: bagasse virgin PVC;
- 4: B-R-PVC: bagasse recycled PVC;
- 5: W-V-HDPE: wood virgin HDPE (commercial decking material).

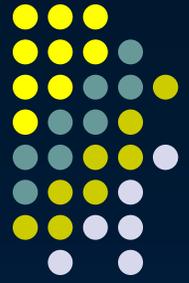


- 1: B-V-HDPE: bagasse virgin HDPE;
- 2: B-R-HDPE: bagasse recycled HDPE;
- 3: B-V-PVC: bagasse virgin PVC;
- 4: B-R-PVC: bagasse recycled PVC;
- 5: W-V-HDPE: wood virgin HDPE (commercial decking material).

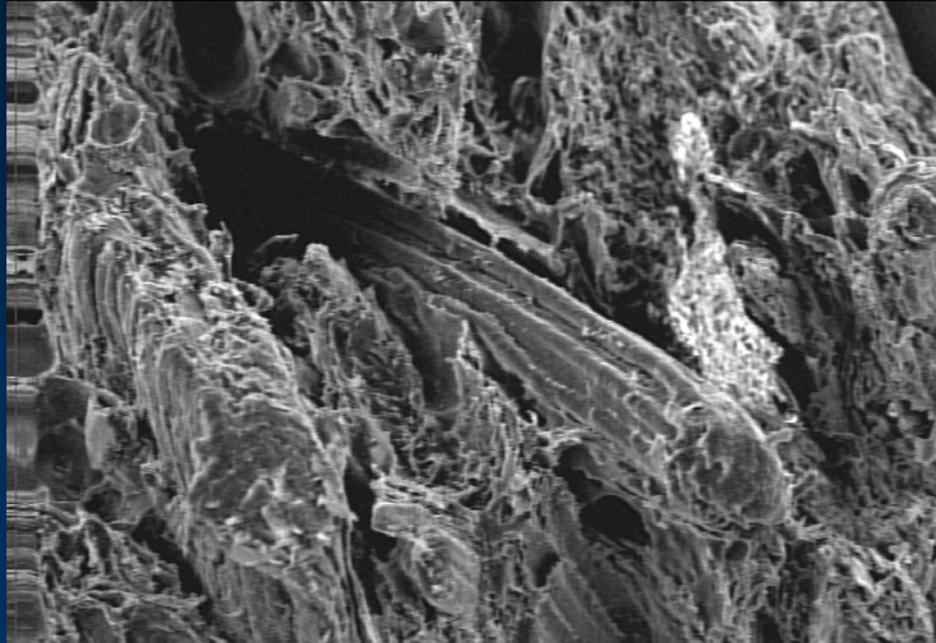


- 1: B-V-HDPE: bagasse virgin HDPE;
- 2: B-R-HDPE: bagasse recycled HDPE;
- 3: B-V-PVC: bagasse virgin PVC;
- 4: B-R-PVC: bagasse recycled PVC;
- 5: W-V-HDPE: wood virgin HDPE (commercial decking material).

Morphology

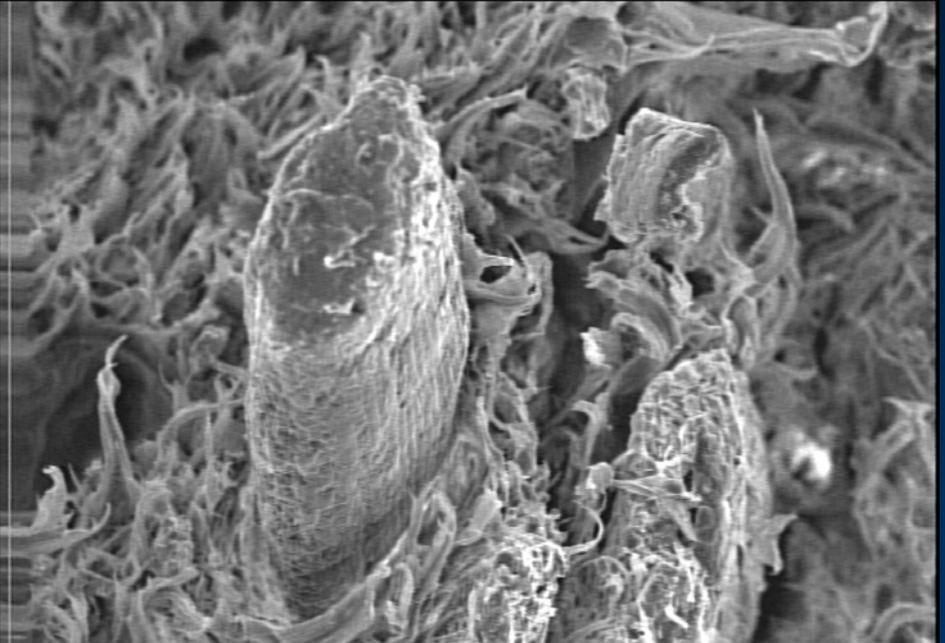


204X 15kV WD:21mm S:46 P: p2
200um



PVC

204X 15kV WD:21mm S:44 P: p4
200um



HDPE

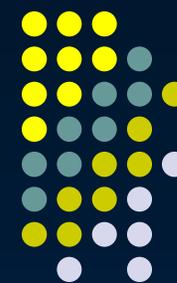
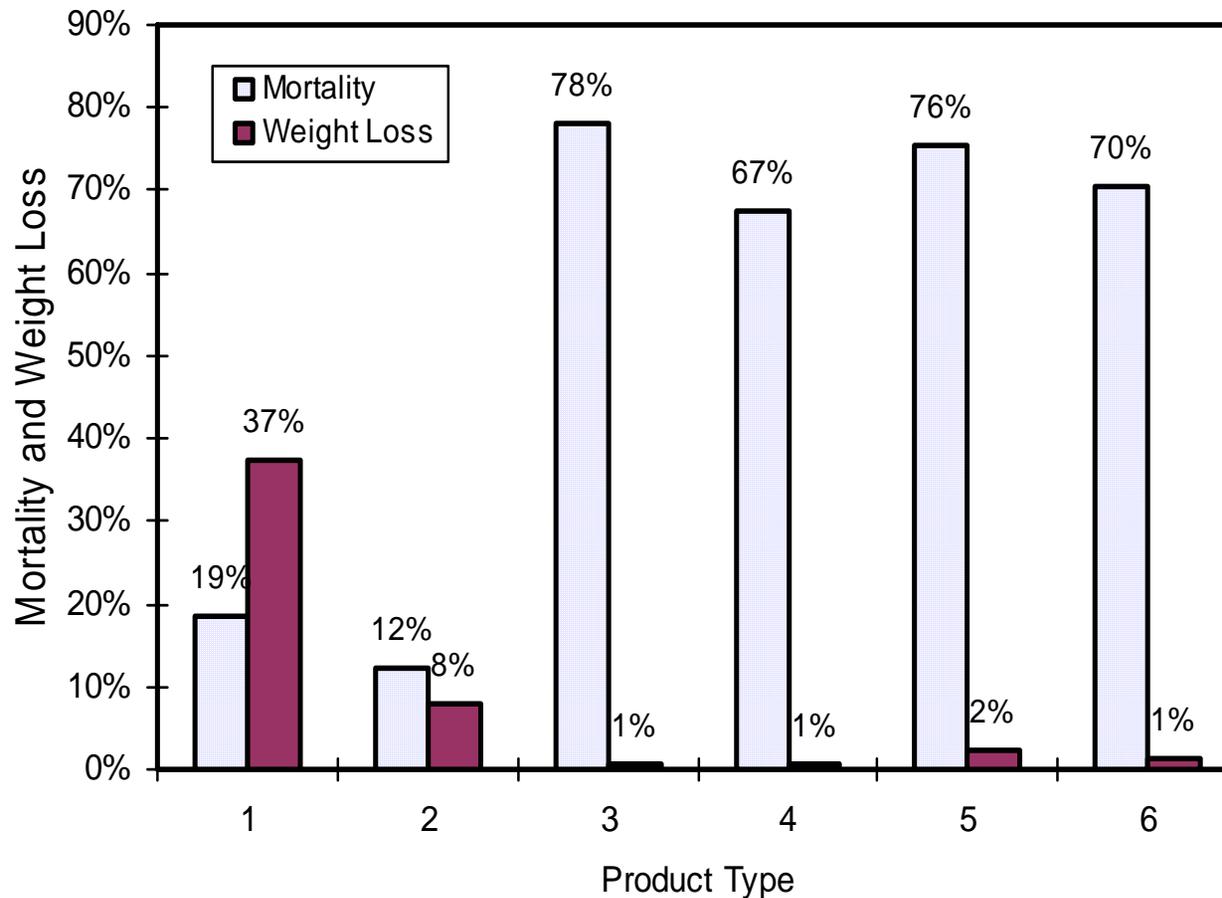
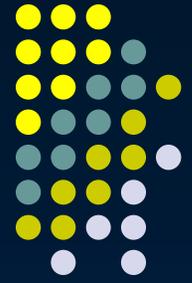


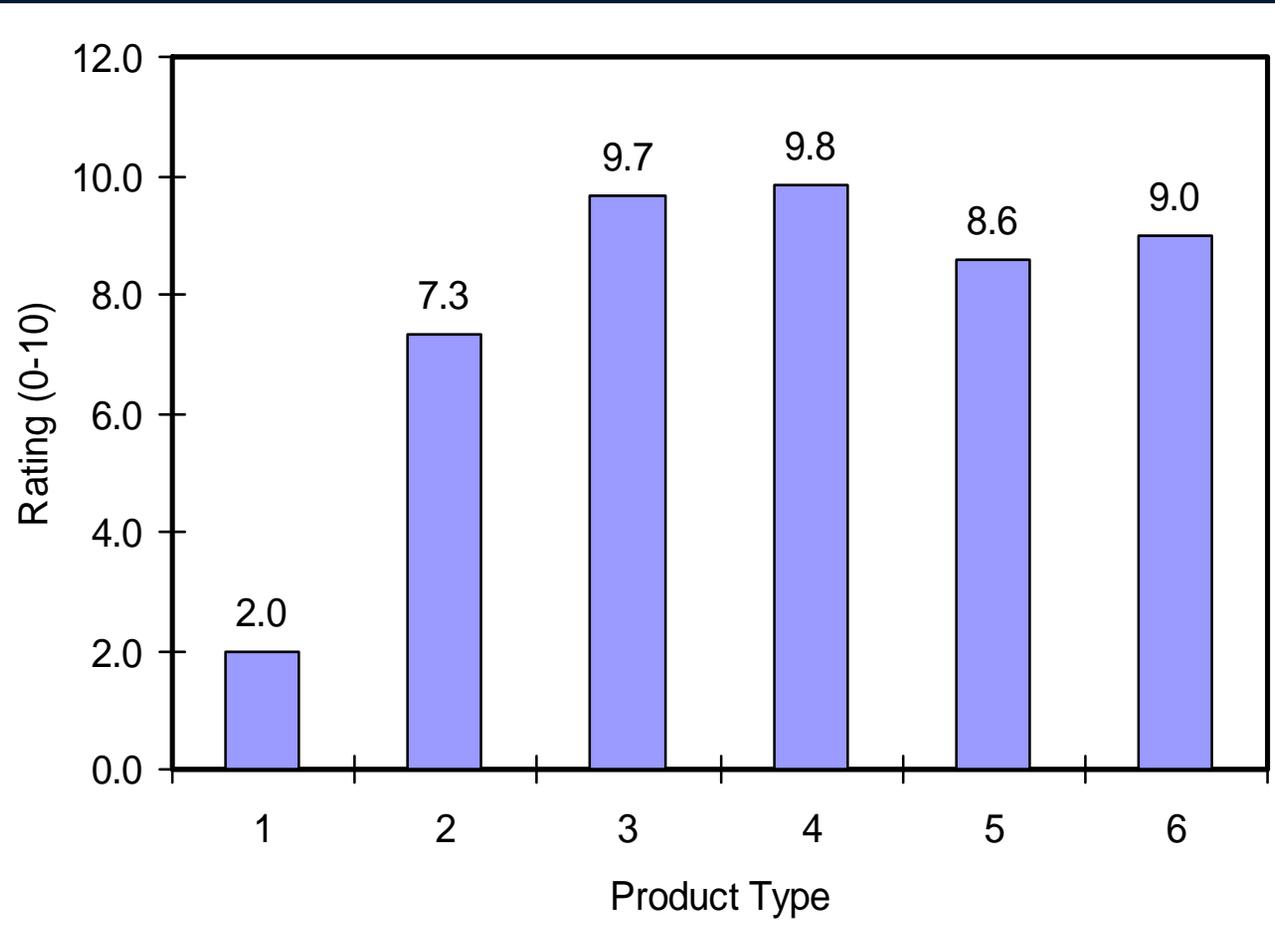
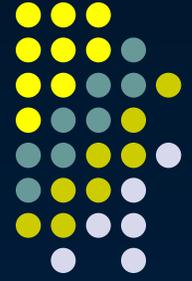
Table 2. Summary of Termite Test.

Sample Type ¹	Mortality (%)	Weight Loss (%)	Average Rating (0-10)
W-Control	18.65% (29.05%) A	37.47% (14.1%) B	2.00 (1.69) A
W-V-HDPE	12.40% (11.82%) A	7.93% (0.33%) A	7.32 (0.23) B
B-V-PVC	78.15% (21.02%) B	0.71% (0.14%) A	9.68 (0.11) D
B-R-PVC	67.35% (23.67%) B	0.60% (0.05%) A	9.84 (0.09) D
B-V-HDPE	75.50% (25.13%) B	2.20% (0.21%) A	8.60 (0.20) C
B-R-HDPE	70.45% (26.87%) B	1.44% (0.04%) A	9.00 (0.00) CD

¹ W-Control: Solid wood control; B-V-HDPE: bagasse virgin HDPE; B-R-HDPE: bagasse recycled HDPE; B-V-PVC: bagasse virgin PVC; B-R-PVC: bagasse recycled PVC; and W-V-HDPE: wood virgin HDPE (commercial docking material).

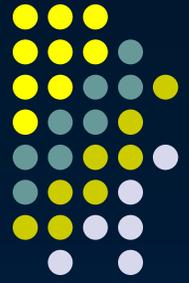


- 1: W-Control: Solid wood control
- 2: B-V-HDPE: bagasse virgin HDPE;
- 3: B-R-HDPE: bagasse recycled HDPE;
- 4: B-V-PVC: bagasse virgin PVC;
- 5: B-R-PVC: bagasse recycled PVC;
- 6: W-V-HDPE: wood virgin HDPE (commercial decking material).



1: W-Control: Solid wood control
2: B-V-HDPE: bagasse virgin HDPE;
3: B-R-HDPE: bagasse recycled HDPE;
4: B-V-PVC: bagasse virgin PVC;
5: B-R-PVC: bagasse recycled PVC;
6: W-V-HDPE: wood virgin HDPE (commercial decking material).

Time-Temperature Superposition

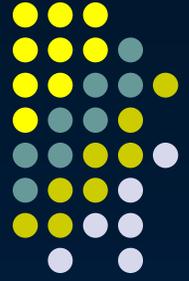


- Temperature effects are described by altering the time scale of the visco-elastic response:

$$t^* = \frac{t}{a_T(T)}$$

a_T is the horizontal (or time) shift factor (temperature dependent)

Creep Properties - TTS



$$\log a_T = \frac{E}{R} \left(\frac{1}{T} - \frac{1}{T_0} \right)$$

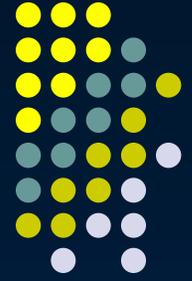
a_T is the horizontal (or time) shift factor

R is the universal gas constant

E is activation energy

T_0 is the reference temperature

T is the temperature at which a_T is desired



Creep Test

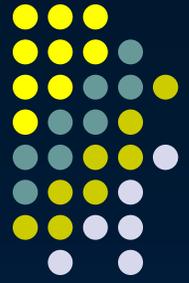
- DMA Q 800 in dual cantilever mode
- Stress level 2 MPa
- Creep temperature range 35° C to the maximum degradation temperature with 5° C increment
- Creep time 17 minutes for TTS data
- Three-day creep with recovery for verification



$$E = \frac{K_s}{F_c} \cdot \frac{L^3}{24 \cdot I} \cdot \left[1 + \frac{12}{5} (1 + \nu) \left(\frac{t}{L} \right)^2 \right]$$

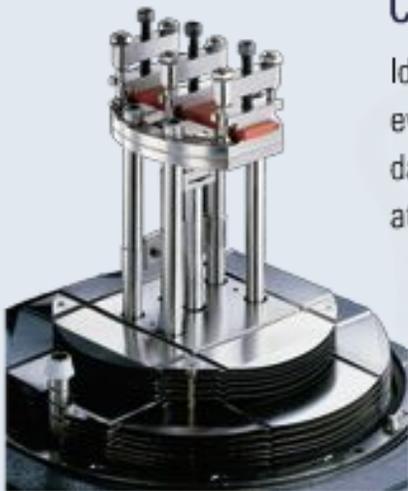
$$F_c = 0.7616 - 0.02713 \sqrt{\frac{L}{t}} + 0.1083 \ln\left(\frac{L}{t}\right)$$

$$K = \frac{24 \cdot E \cdot I}{L^3 \left[1 + \frac{12}{5} (1 + \nu) \left(\frac{t}{L} \right)^2 \right]}$$



CANTILEVER

Ideal for general-purpose mode for evaluating thermoplastics and highly damped materials, the sample is clamped at both ends.



$$\sigma_x = \frac{3 \cdot P \cdot L}{w \cdot t^2}$$

$$\varepsilon_x = \frac{3 \cdot \delta \cdot t \cdot F_c}{L^2 \left[1 + \frac{12}{5} (1 + \nu) \left(\frac{t}{L} \right)^2 \right]}$$

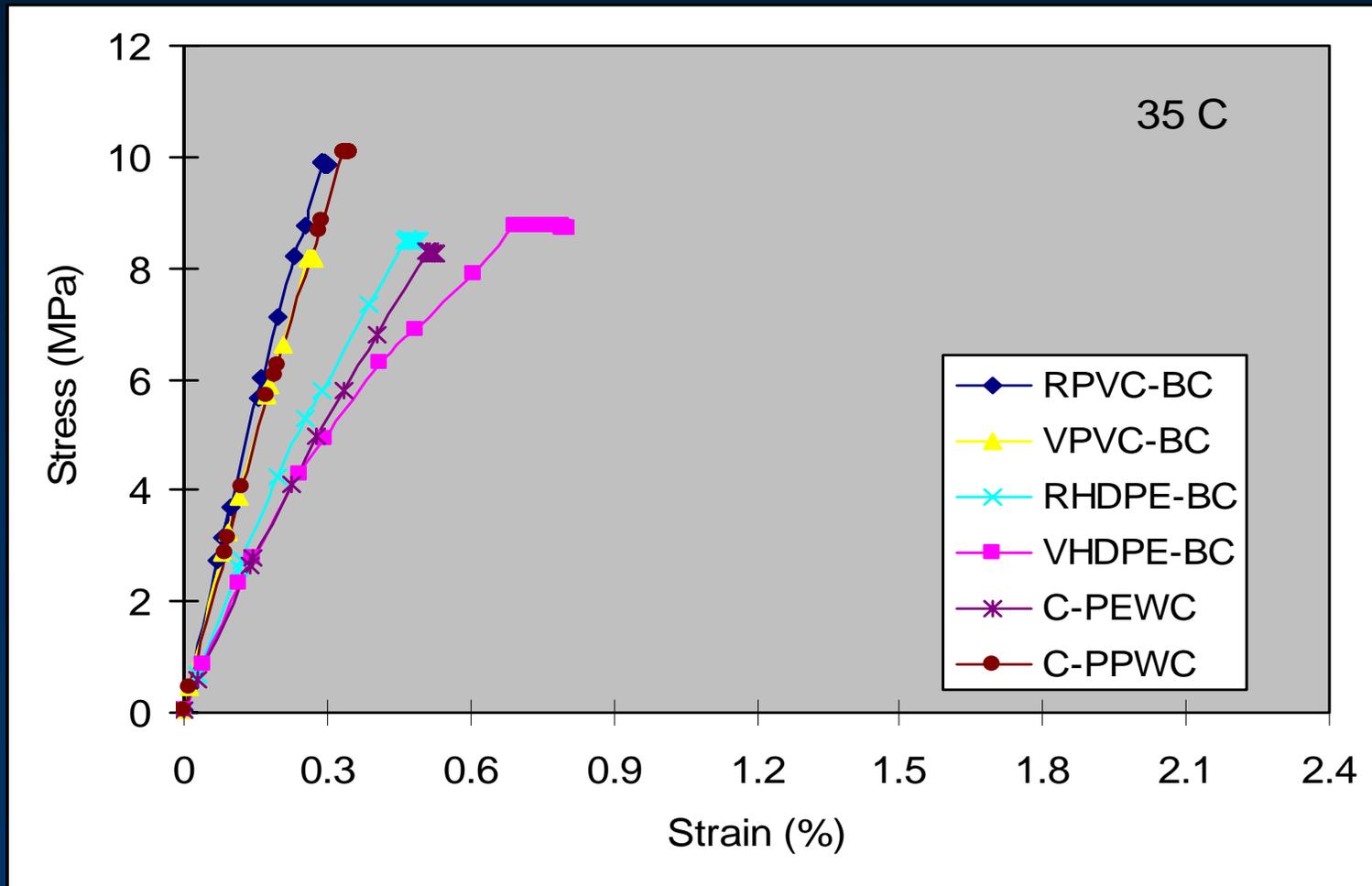
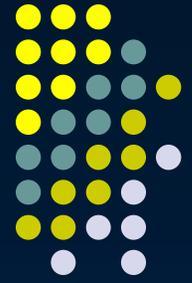
$P = 1/2$ applied force; $\delta =$ amplitude of deformation

$L =$ sample length (one side)

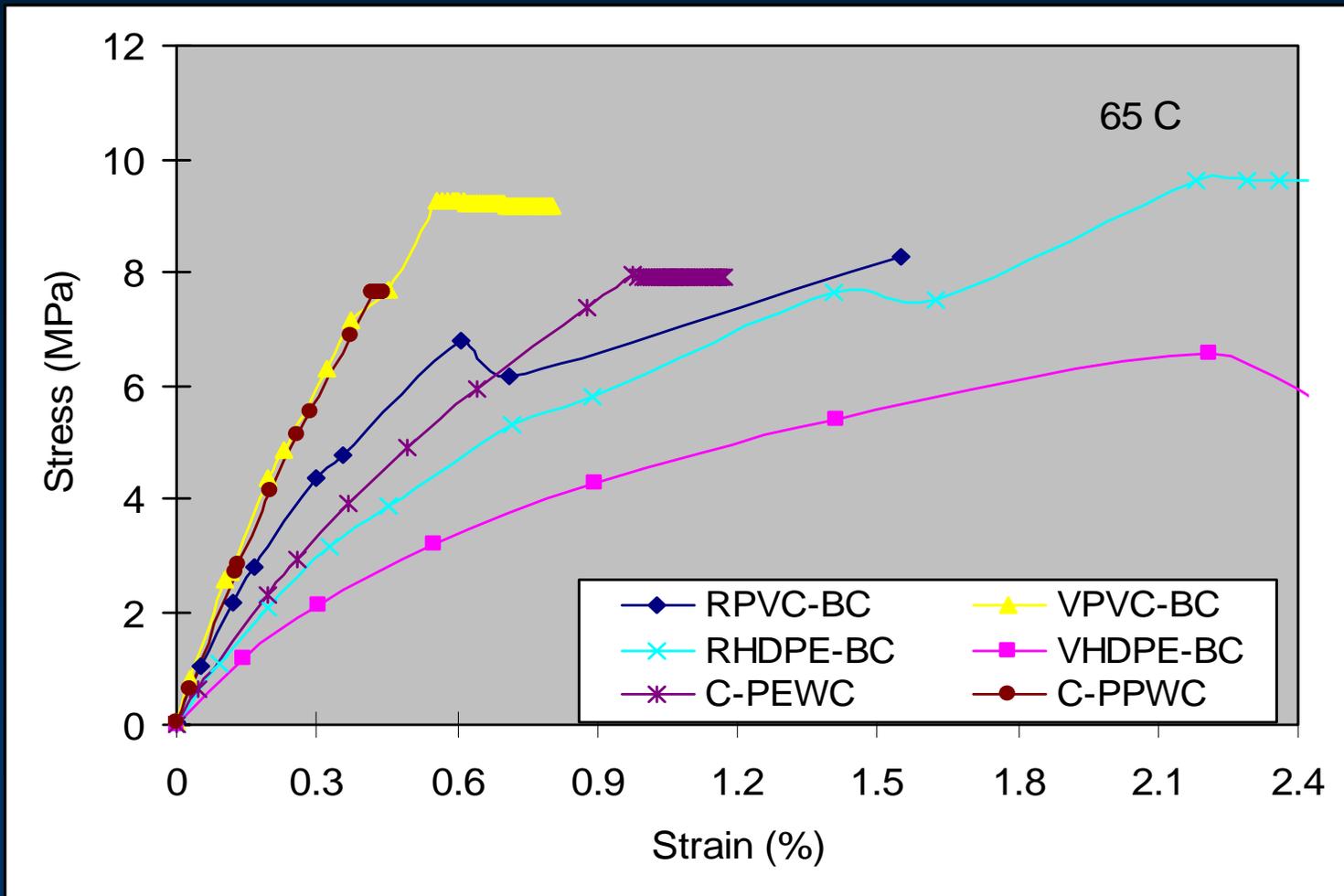
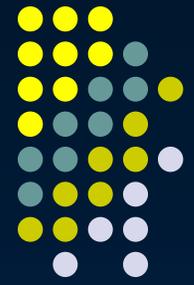
$t =$ sample thickness; $w =$ sample width

$F_c =$ clamping correction factor; $\nu =$ Poisson's ratio

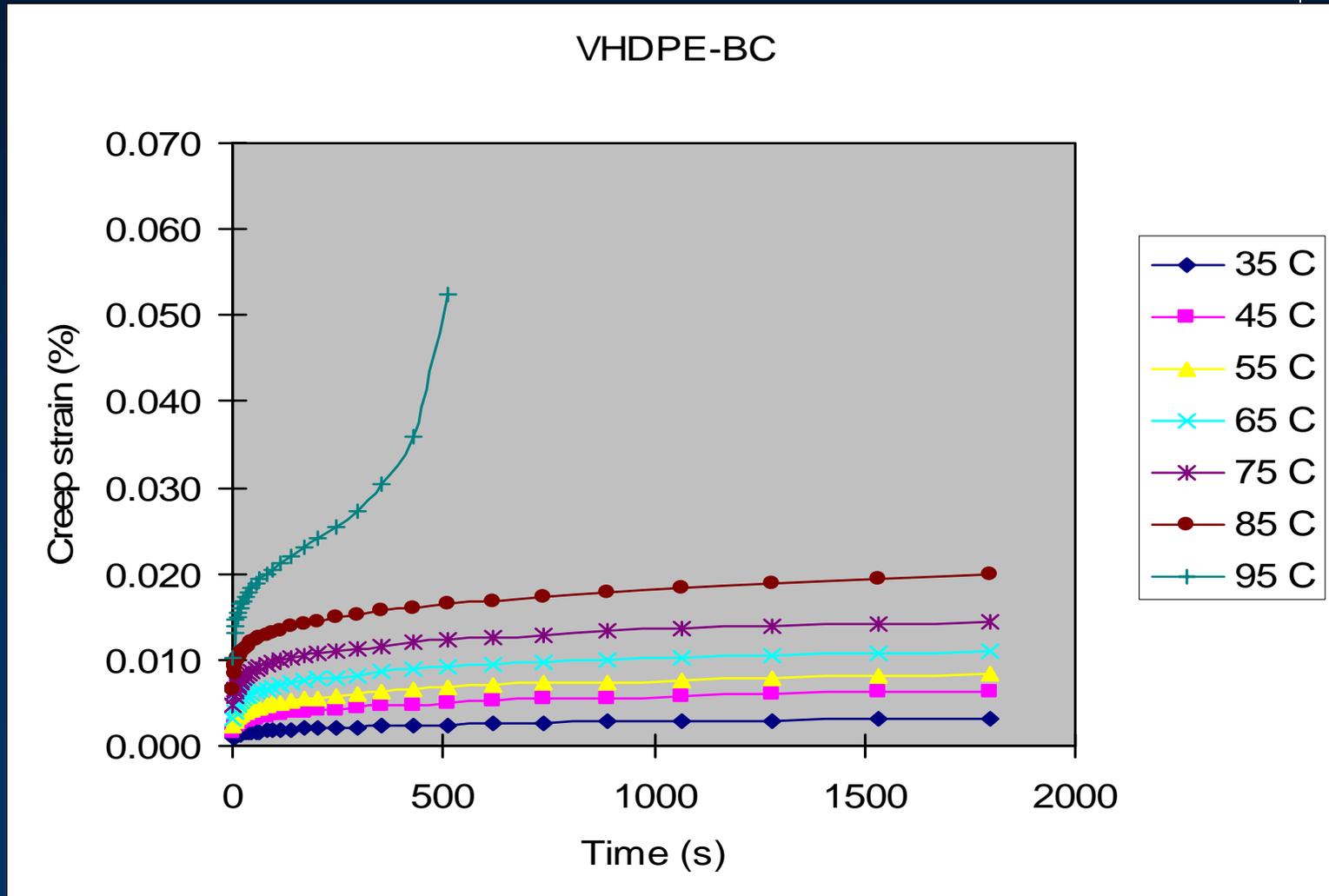
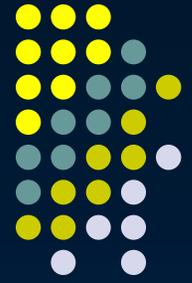
Stress-Strain Relationship



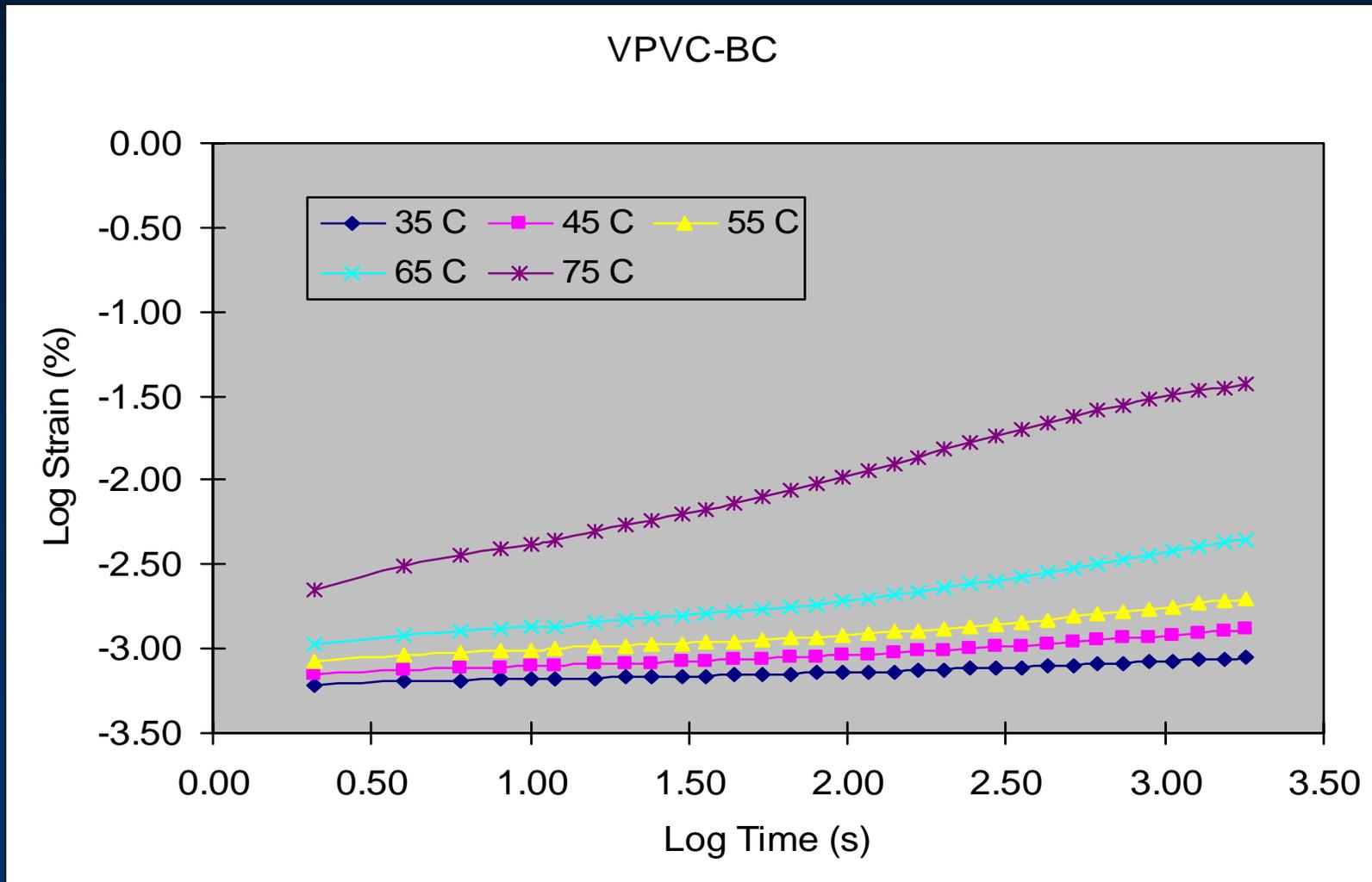
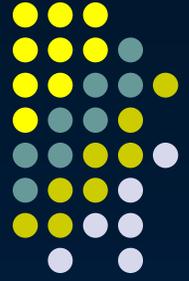
Stress-Strain Relationship



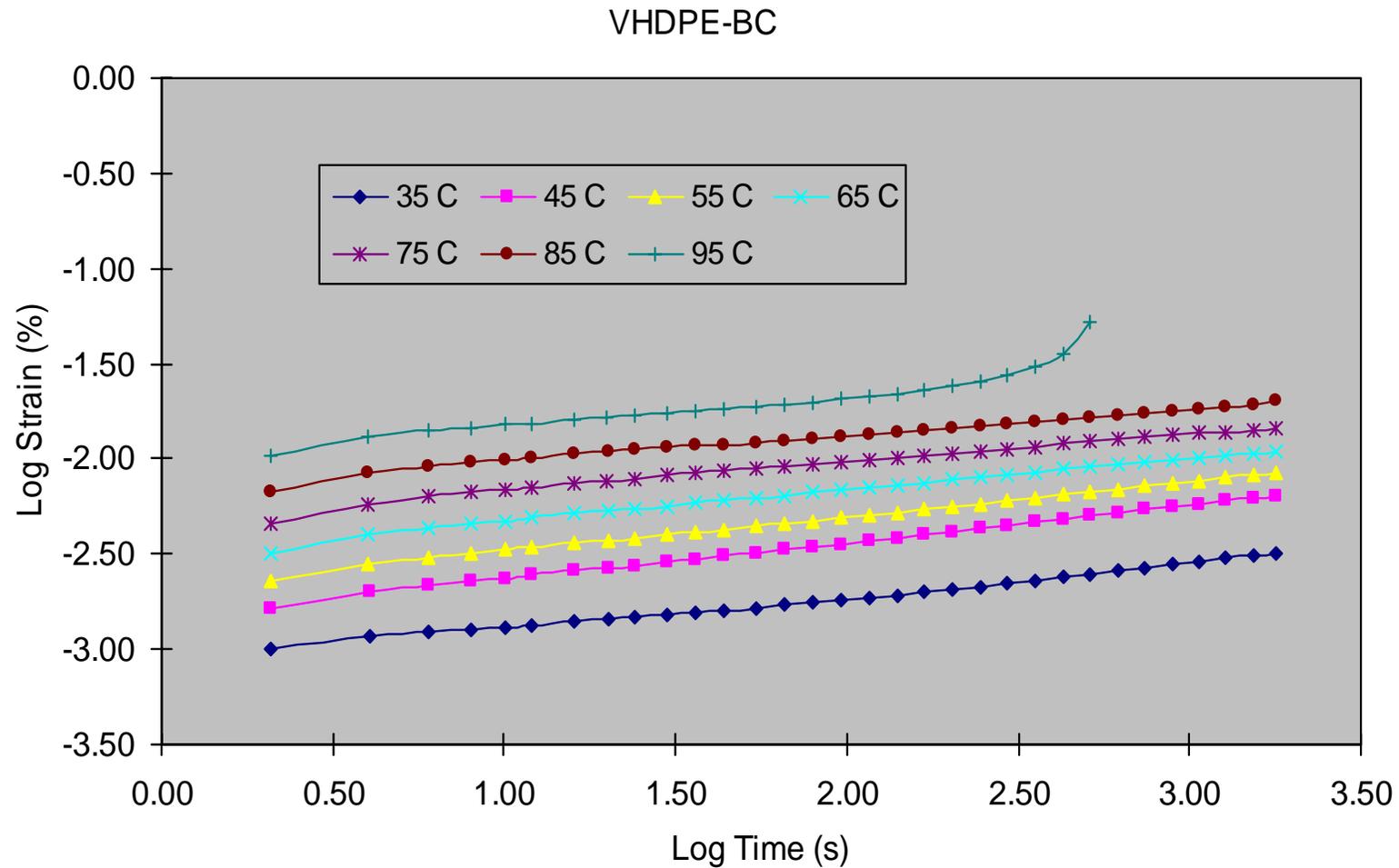
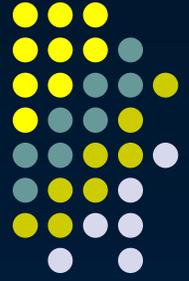
Typical Creep Curves



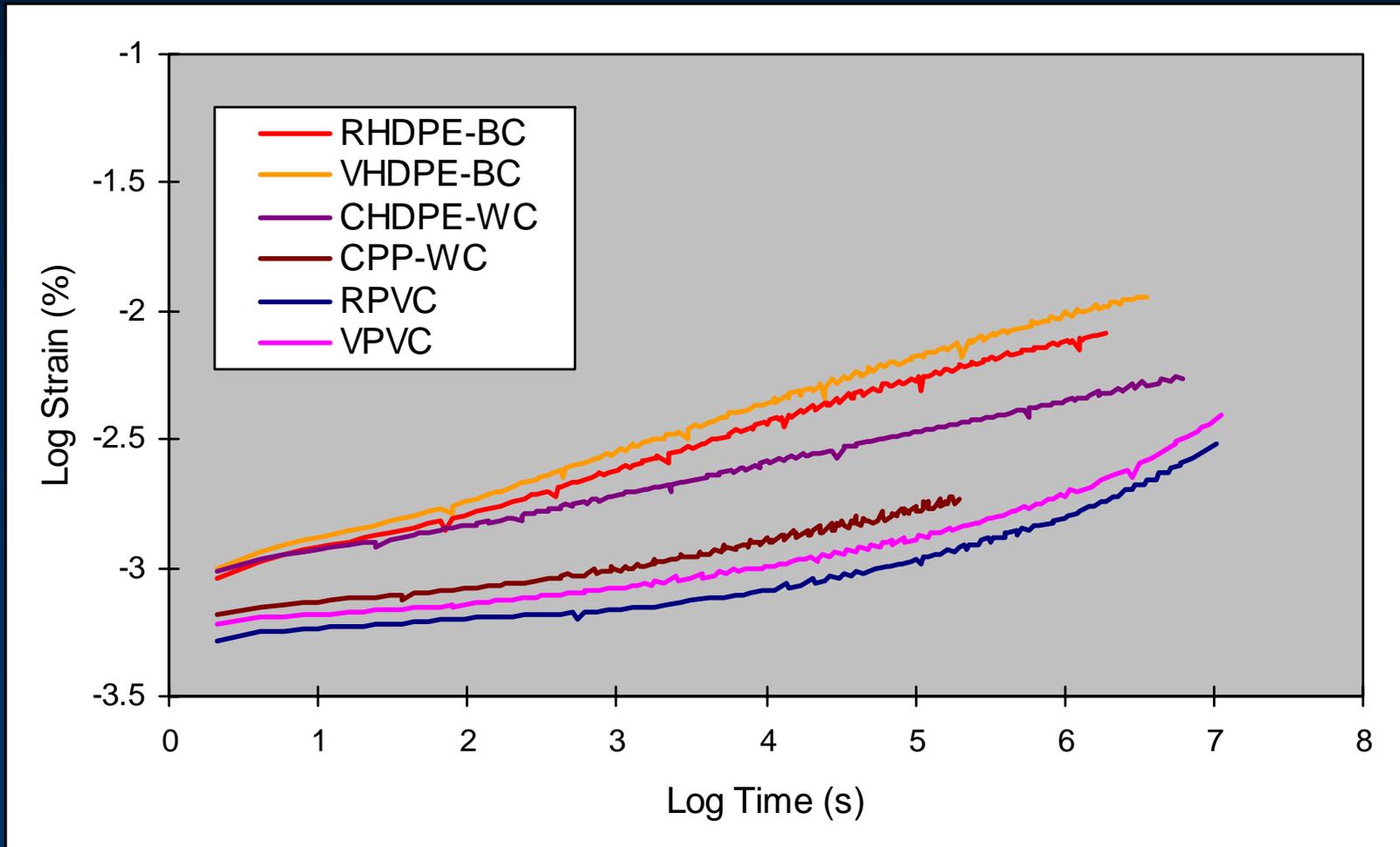
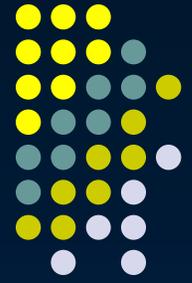
Log(strain)-Log(time) Plots



Log(strain)-Log(time) Plots

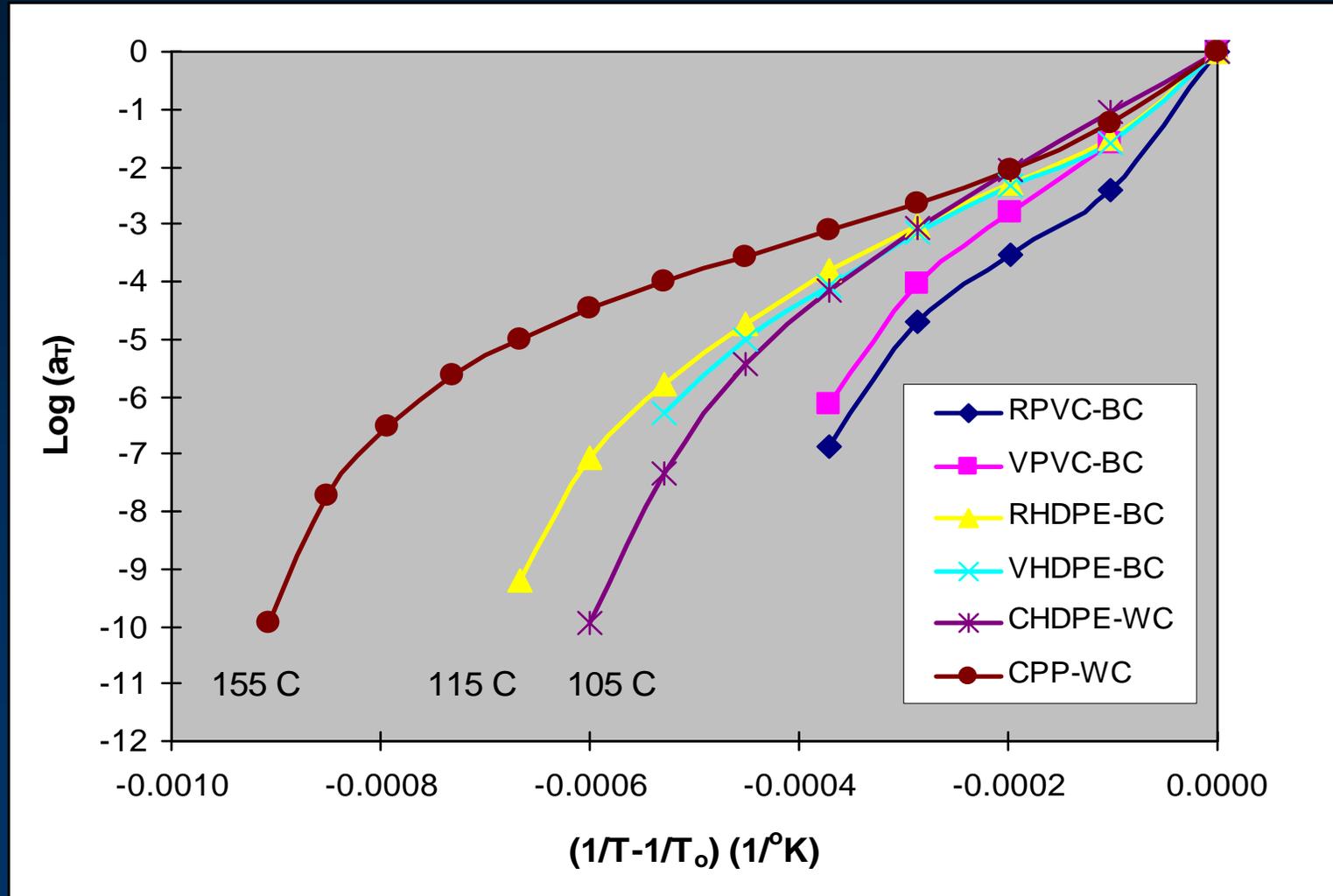
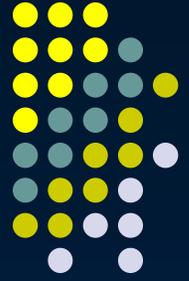


Master Curves at 35 °C

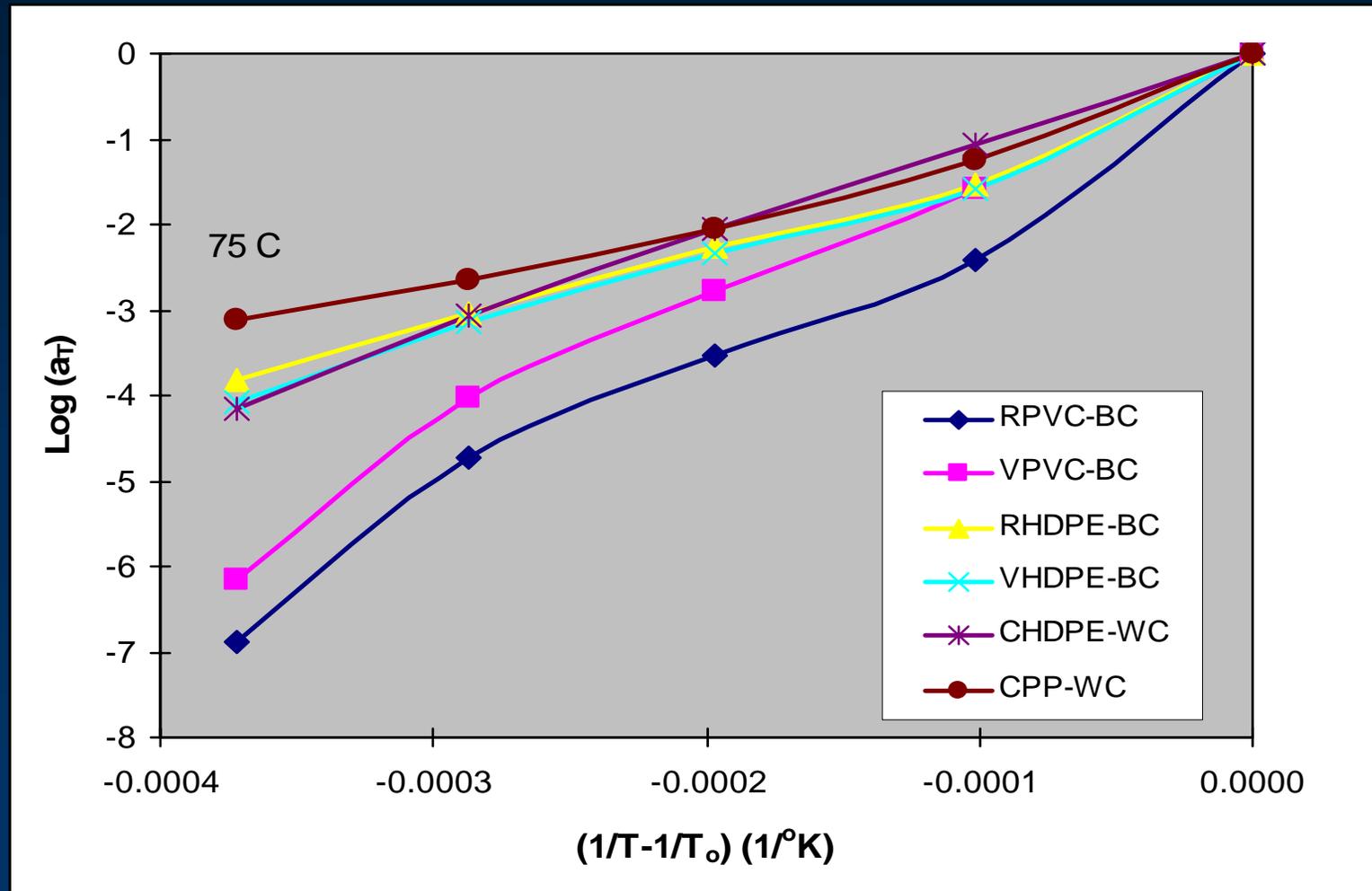
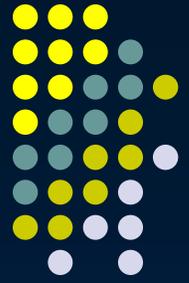


TTS - shifting factor

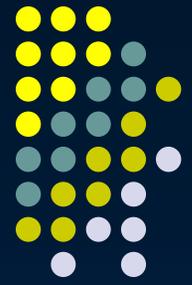
$\text{Log}(a_T)$ vs $f(1/T)$



TTS - shifting factor $\text{Log}(a_T)$ vs $f(1/T)$

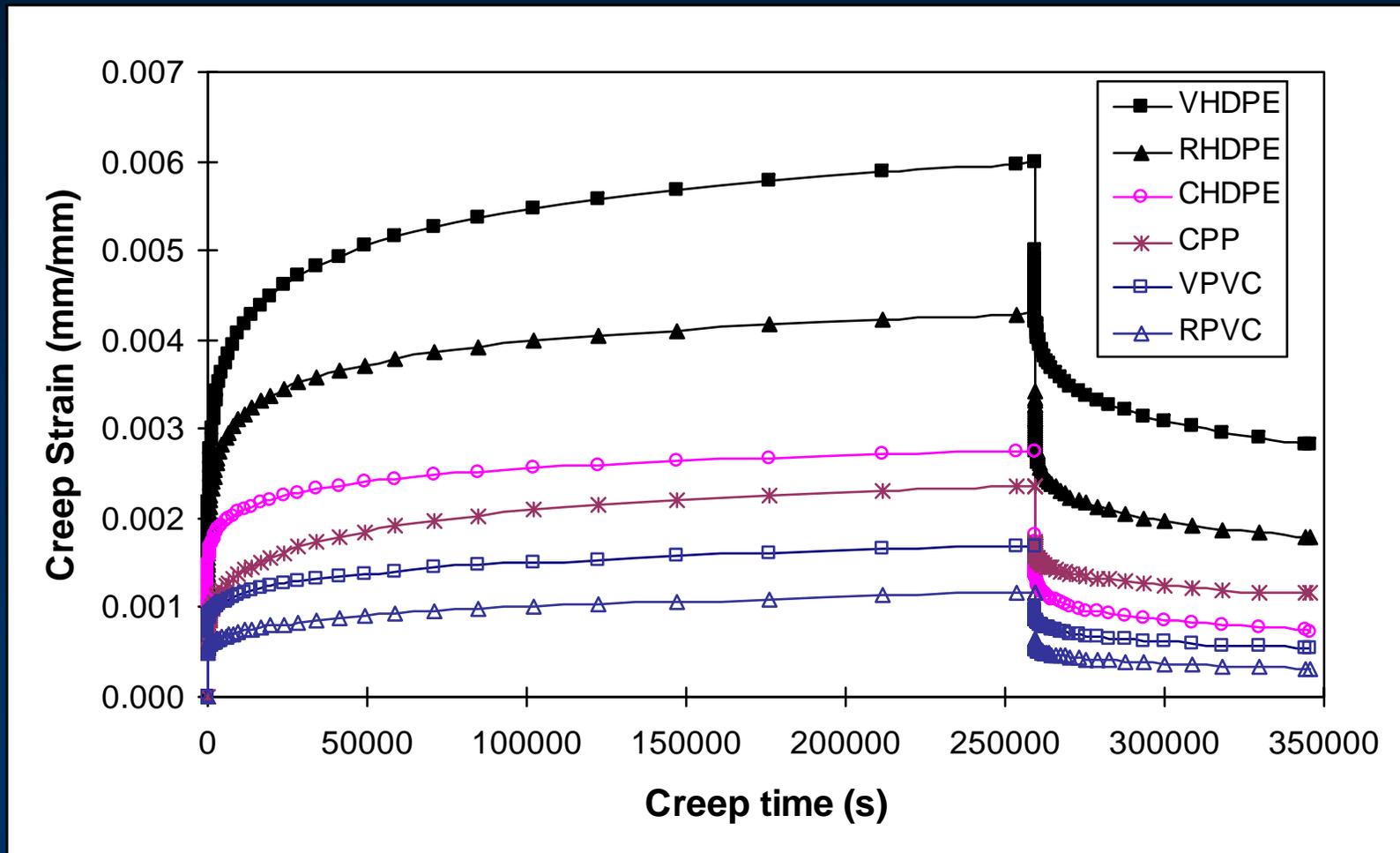
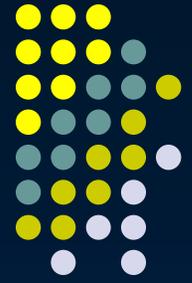


Activation Energy (up to 75 °C)

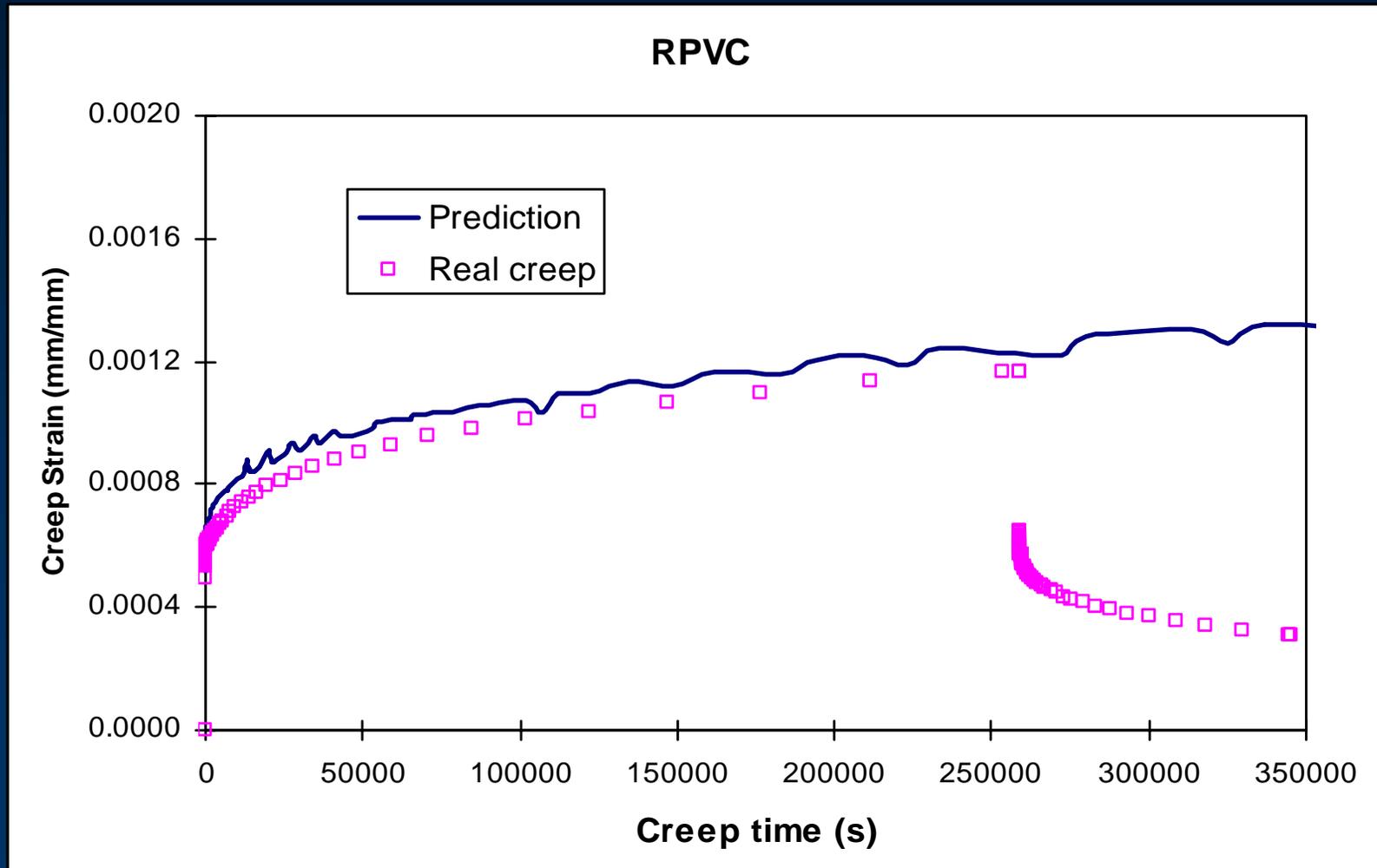
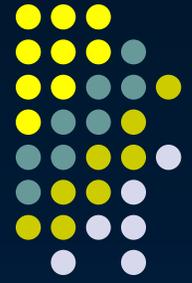


Composites	Regression Analysis		E_{act} (KJ/mol)
	$\text{Log}(a_T) \sim f(1/T)$	r^2	
CHDPE	$Y = 11089 X + 0.0598$	0.998	92.199
VHDPE	$Y = 10486 X - 0.2171$	0.985	87.185
RHDPE	$Y = 9851.3 X - 0.2394$	0.982	81.908
CPP	$Y = 8240.4 X - 0.2340$	0.972	68.515
RPVC	$Y = 17291 X - 0.1968$	0.979	143.765
VPVC	$Y = 15792 X + 0.1178$	0.983	131.302

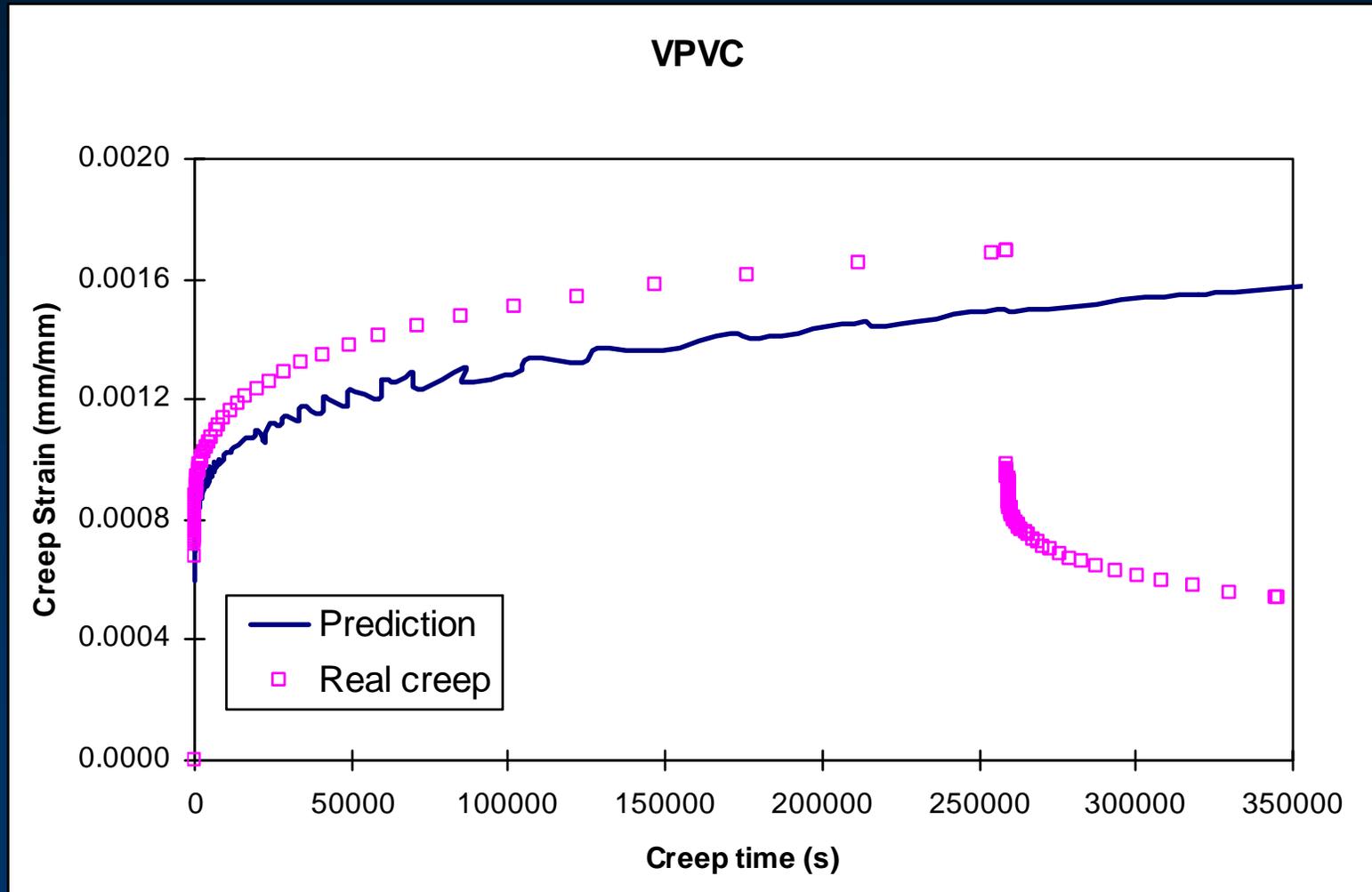
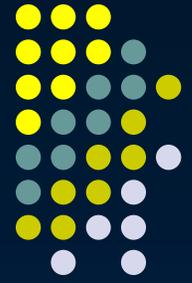
Creep Data (72-hour creep)



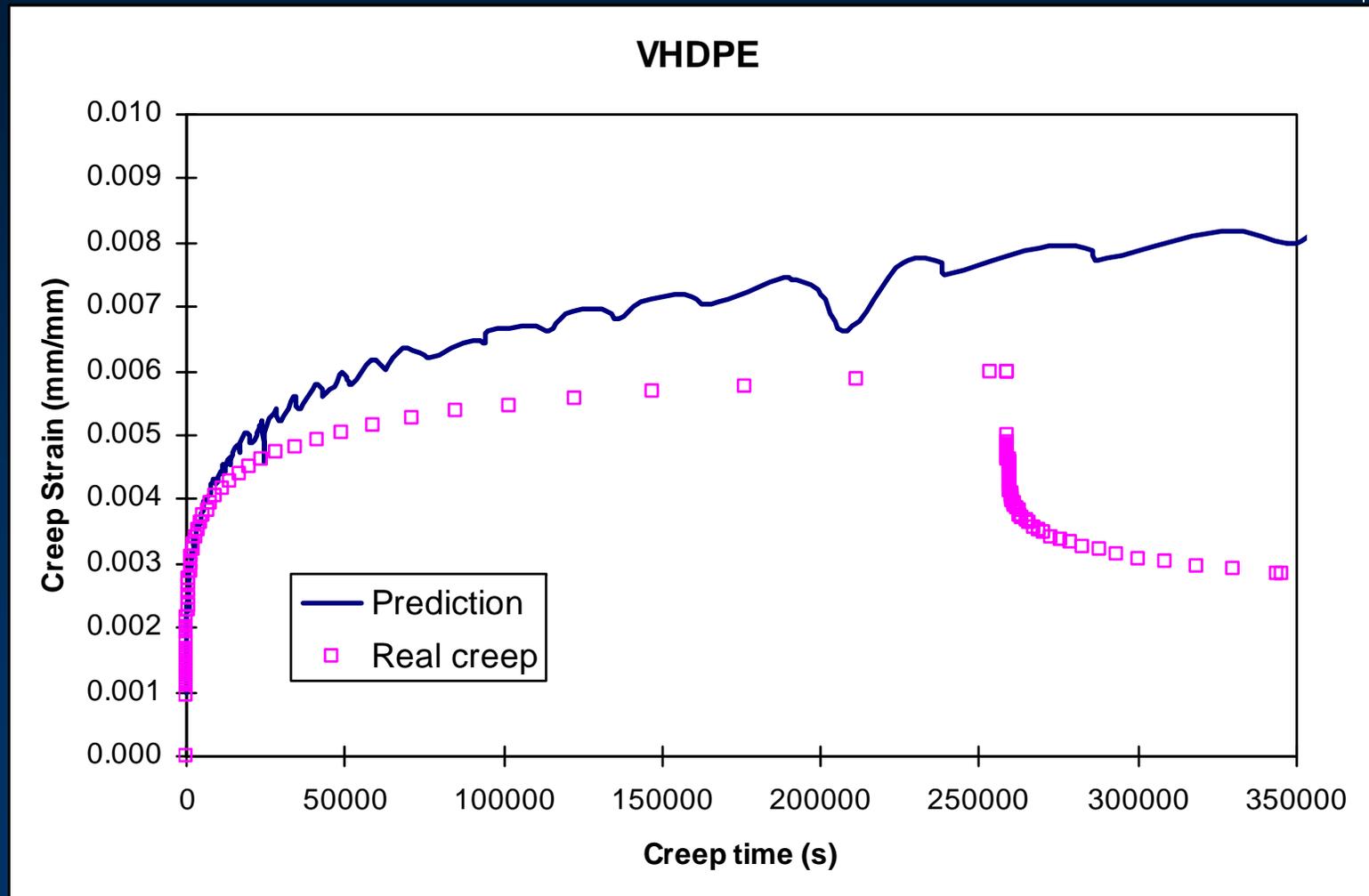
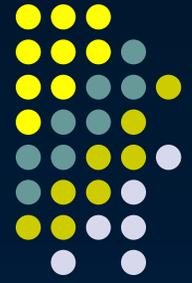
Comparison with TTS data



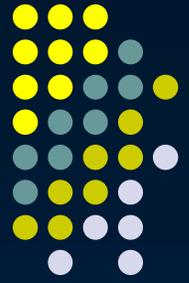
Comparison with TTS data



Comparison with TTS data



Summary



- Bagasse fiber can be successfully used to make profile extruded products with both virgin and recycled plastics including HDPE and PVC.
- Creep varied with plastic matrix type.
- HDPE composite creep more compared with PVC and PP products.
- TTS with H-shift worked well for certain composites, but V-shift is necessary for good correlation with experimental data.