Structure-Property Relationships in Polymer Systems: Part 2

Updated 26 November, 2011

Parameters

Structure and environmental factors	Properties	
polymer class/structure	strength/hardness	viscoelasticity
loading	elastic modulus (stiffness)	T_g, T_m
temperature	ductility	fatigue
crystallinity	toughness	
molecular weight		

General "Useful" Properties of Different Polymer Classes

Thermoplasts	Thermosets	Elastomers
can range from soft to hard recyclable often flexible (E), ductile, tough	high strength thermal stability (properties do not change with T)	huge elastic capacity tunable stiffness (crosslinks)

lightweight, low cost, chemically inert, electrically insulating

Outline of Structure-Property Relationships Considered

	polymer class
loading	stress-strain as f(T) viscoelastic behavior as f(T)

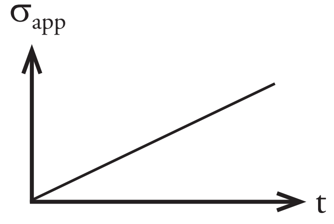
- effect of crystallinity on mechanical properties
- effect of molecular weight on mechanical properties
- factors affecting T_g, T_m
- fatigue characteristics
- design examples given in class

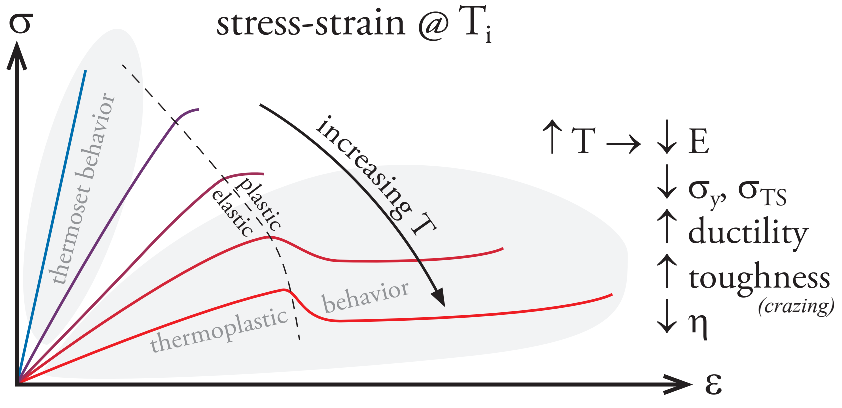
polymer class

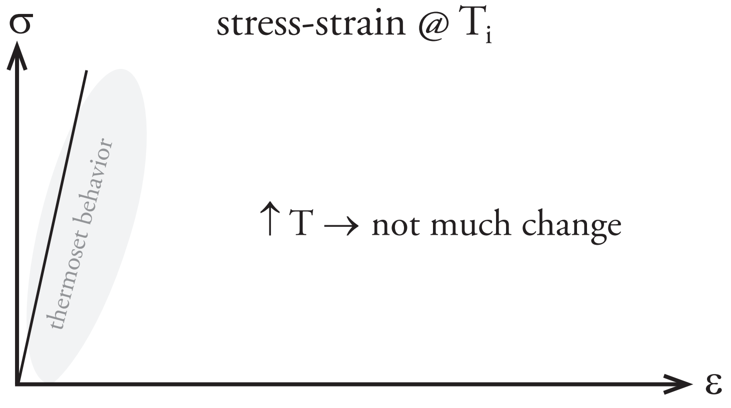
thermoplasts | thermosets | elastomers

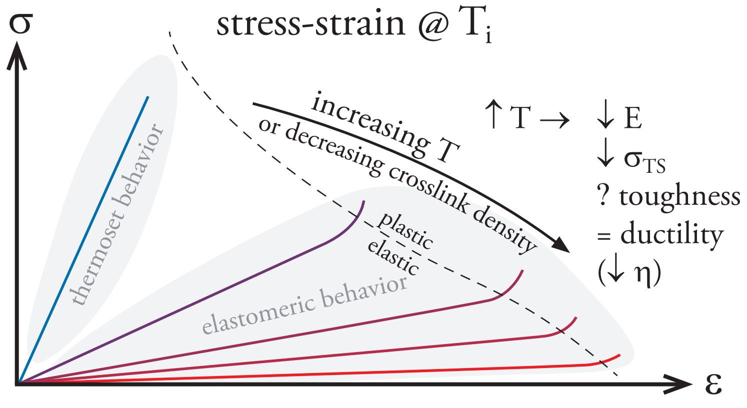
loading

gradual loading (tensile testing; low $\dot{\varepsilon}$)



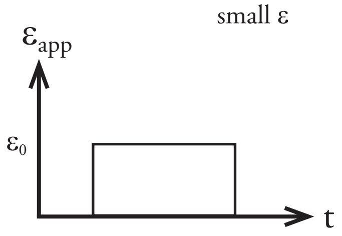


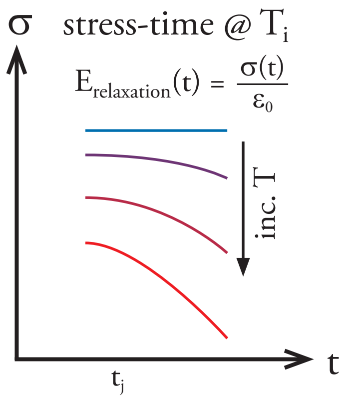


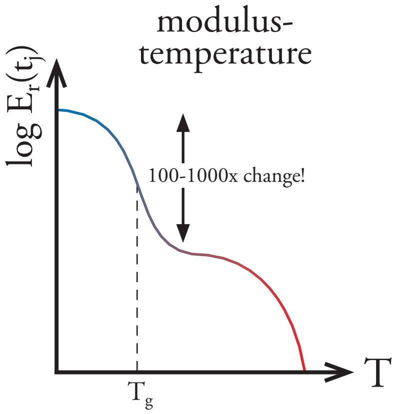


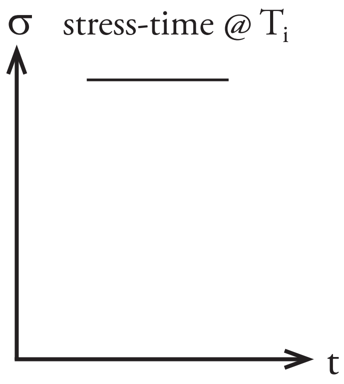
constant strain

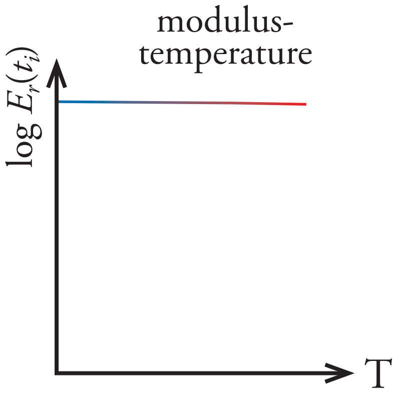
small ε

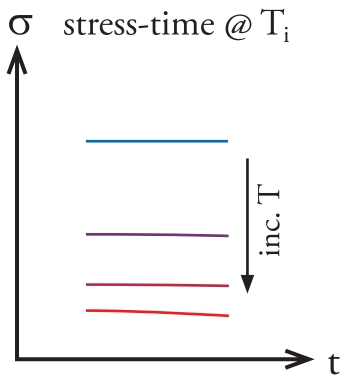


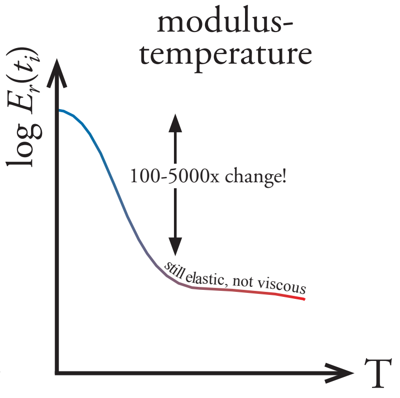






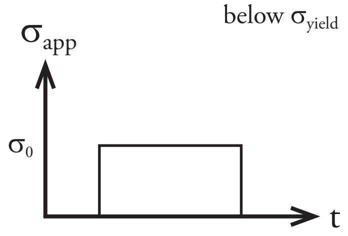


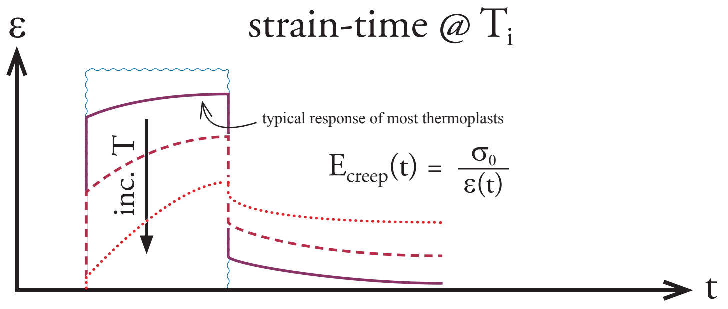


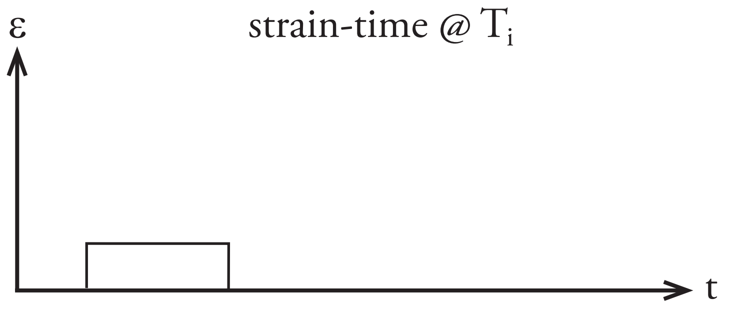


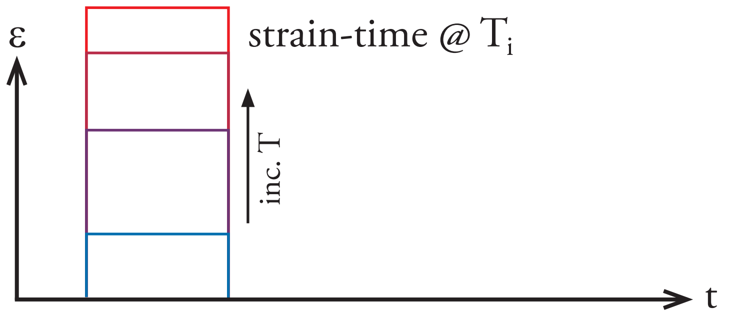
constant stress

below σ_{yield}



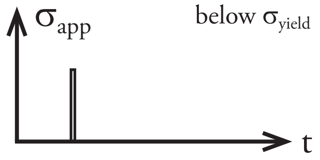






impulse (high $\dot{\varepsilon}$)

below σ_{yield}



elastic (non-viscous, non-plastic)

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Effect of Crystallinity on Mechanical Properties

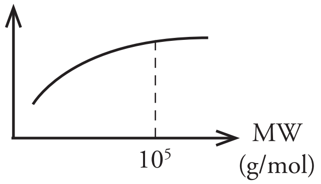
Crystalline polymer regions have increased chain packing and alignment, thus resulting in significantly higher interchain secondary bonding forces compared to those existent in amorphous regions.

↑ % crystallinity → ↑ E
↑ σ_y, σ_{TS}
↓ ductility
↓ toughness
↑ η
↑ T_g, T_m

Effect of Molecular Weight on Mechanical Properties

As polymer chains become longer and longer, there is increased chain entanglement. This causes some reduction in interchain mobility up to a chain weight of about 10^5 to 10^6 g/mol, where effects level off.

↑ molecular weight → ↑ E
↑ σ_y, σ_{TS}
↓ ductility
? toughness
↑ η
↑ T_g, T_m



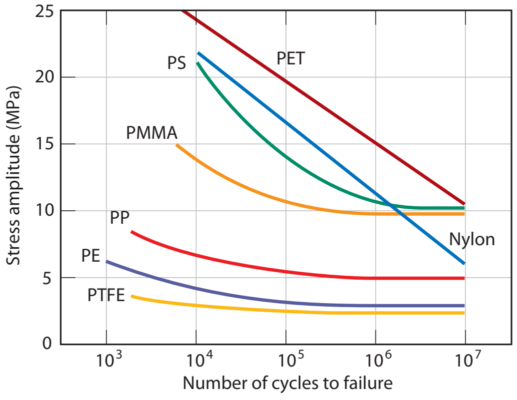
Factors Affecting T_g, T_m

Similar to factors affecting crystallinity of a polymer, structural features that affect interchain mobility will also affect the polymer's glass transition (amorphous regions) and melting (crystalline regions) temperature. Features that hinder interchain mobility will raise the value of these properties:

• crosslinking	
• side groups	small H atoms vs. polar or bulky side groups
• branching	small branching "spaces" chains apart, ↓ interchain forces, ↑ chain mobility, thus ↓ T_g, T_m (LDPE melts before HDPE); longer branching hinders mobility
• repeating unit	simple backbone vs. double-bonds or aromatic groups
• molecular weight	

Fatigue Characteristics

Most thermoplastic polymers can survive a large number of cyclic loads before failure. However, the failure stresses (1-10 MPa) are orders of magnitude lower than those of metals (100's of MPa).



Design examples given in class

plastic bag	extremely ductile thermoplast (huge amount of necking); T_g is far below room temperature
ice cube tray	choose thermoplast with T_g far below room temperature to allow for flexibility (low E) and toughness
billiard ball	use a network polymer (Bakelite) to maintain high strength and hardness but have good toughness (so it won't shatter)
coffee cup	choose a thermoplast with T_g above hot-water temperature to keep it from "flowing" (being viscoelastic) when in contact with hot liquid
picnic knife	flexible thermoplast with viscoelastic response
silly putty	extremely viscoelastic thermoplast; loading rate affects properties (e.g. modulus) immensely