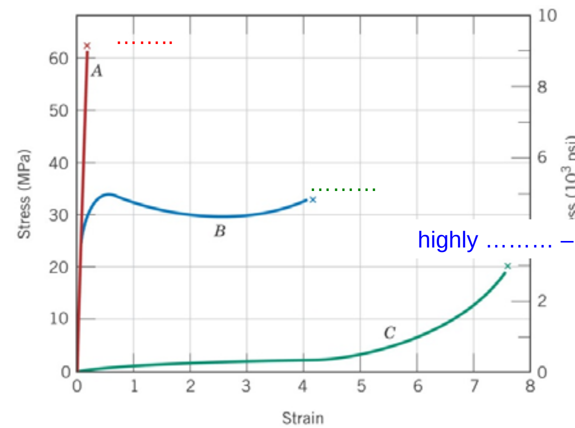
Outline

- Mechanical Properties of Polymers
- Melting and glass transition temperature
- Polymer Additives
- Forming of Polymers

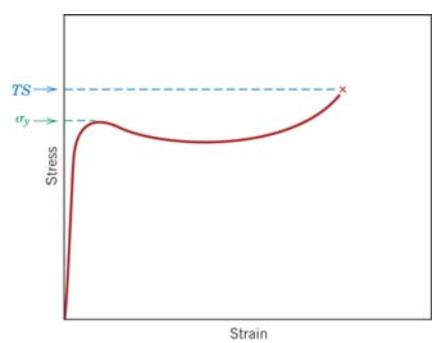
Mechanical Properties of Polymers

- There are three typical classes of polymer stress-strain characteristic



Mechanical Properties of Polymers

- Elastic modulus is very much lower than for metals or ceramics
- Beyond the yield point sample deforms plastically.
- Tensile stress (TS) is the stress at fracture
- TS may be less or greater than the yield strength.



Schematic stress–strain curve for a plastic polymer showing how yield and tensile strengths are determined.

Mechanical Properties of Polymers

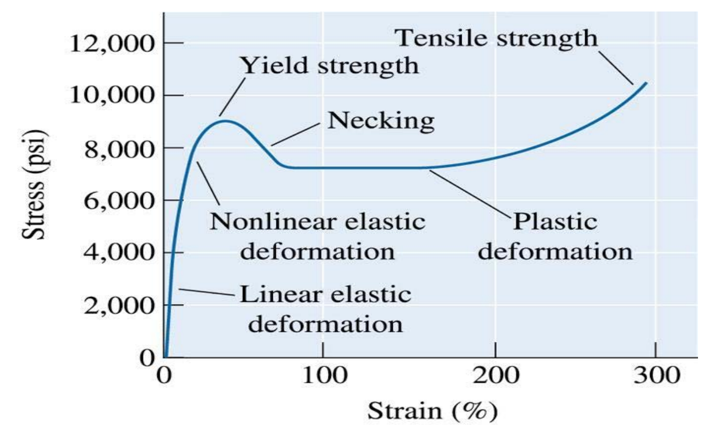
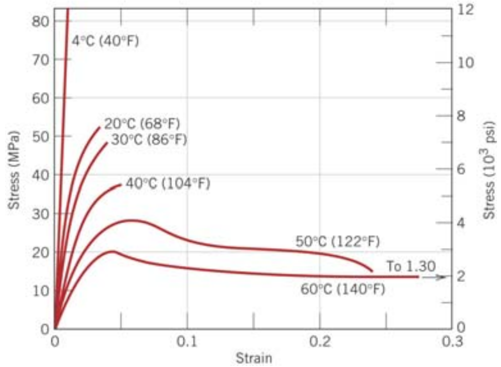


Figure 15.17 The stress-strain curve for 6,6-nylon, a typical thermoplastic polymer.
(The Science and Engineering of Materials – by D.R. Askeland and P.P. Phule)

Mechanical Properties of Polymers

- Decreasing Temp.
  - ……….. E
  - ………. TS
  - ……….. %EL



Effect of temperature on stress-strain behavior of PMMA (left).

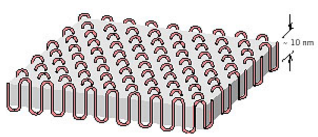
*Increasing strain rate causes the SAME effects as **decreasing T**.*

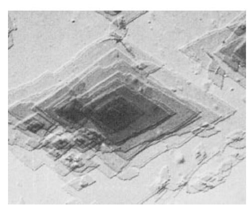
Mechanical Properties of Polymers

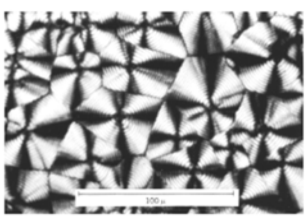
- **Modulus of Elasticity**
  - may be as low as **…. MPa** or as high as **…….. MPa** (*compared to **48 - 410 x 10^3 MPa** for metals*)
  - TS polymers **……. MPa** (*metals up to **4100 MPa***)
- **Elongation**
  - Often elongate plastically as much as **…….%** (*compared to metals - rarely over **100%***)
- **Temperature Dependence**
  - Mechanical properties are …… temperature dependent - even close to room temperature.
- **Strain Rate Dependence**
  - Decreasing strain rate has ……. effect as *raising* temperature

Molecular Structure: *Polymer Crystal Models*

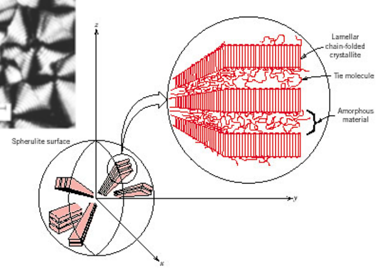
Chain folded model: **crystals are actually small platelets of interwoven polymer chains**





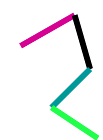


In many bulk polymers crystallized from the melt, these platelets often arrange themselves in radiating patterns to form **spherulites**.



Mechanisms of Elastic Deformation, in Amorphous & Semicrystalline Polymers

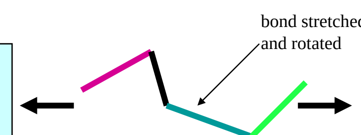
- Elastic deformation takes place due to the elongation of chain molecules by **bond stretching** *(all regions)* and bond **rotation** *(amorphous region)*, along the direction of the applied stress.



stable conformation

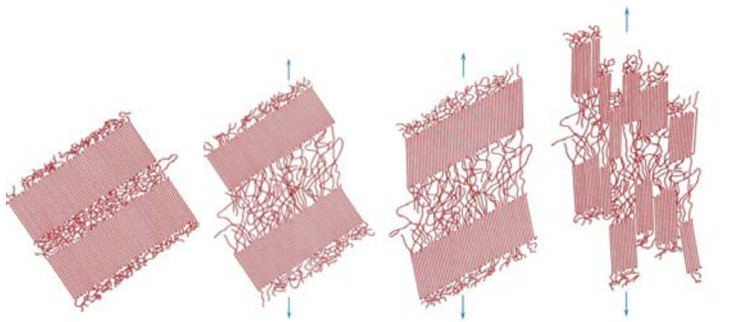
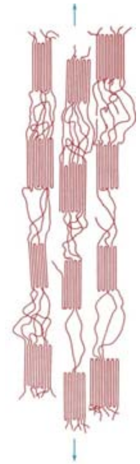
Bonds do not break and chains do not slip past each other.

Inter-molecular bonding (**……………..**) is much weaker than other types, hence **yield strength** of polymers is low compared to metals or ceramics.



"stressed" conformation

Mechanisms of Plastic Deformation - *Semicrystalline Polymers*

Two adjacent chain folded lamellae and interlamellar amorphous material before deformation

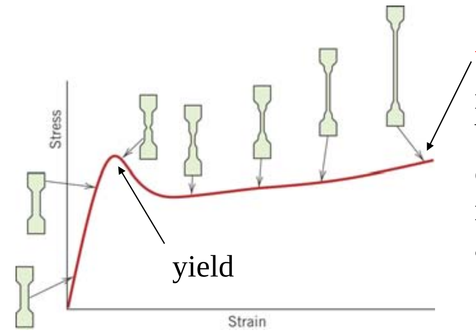
Elongation of amorphous tie chains

Tilting of lamellar chain folds

Separation of crystalline block segments

Orientation of block segments and tie chains with tensile axis

Plastic Deformation - *Semicrystalline Polymers*



Unlike metals, TS is not where neck forms, because deformation continues outside of neck. Neck region is actually strengthened

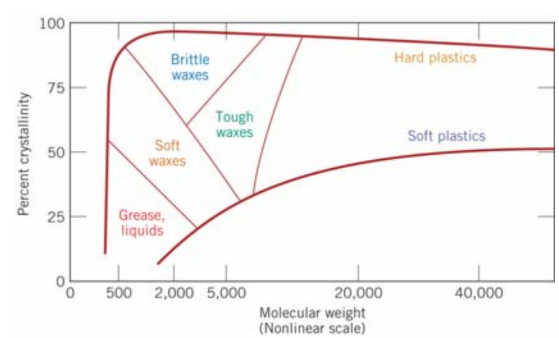
Mechanism - chains slip past each other (bonds rotate to allow this), some inter-molecular bond breaking.

- *Result is a highly oriented structure in the neck region of the tensile specimen*

Strength in Polymers

- Major factors affecting strength are temperature and strain rate:
  - *In general, decreasing the strain rate has the effect similar to increasing the temperature.*
- **Other factors that influence strength**
  - Tensile strength ………… with **molecular weight** ➔ more entangled (short strings vs long)
    - $TS = TS_{\infty} - A/M_n$
  - Strength can be increased by ………… the degree of cross-linking (*inhibits chain motion - makes it more brittle*)
  - Crystallinity ………… strength by increasing *inter*molecular bonding
  - Deforming a polymer can ……….. its strength - *because chains become oriented.*

Strength in Polymers



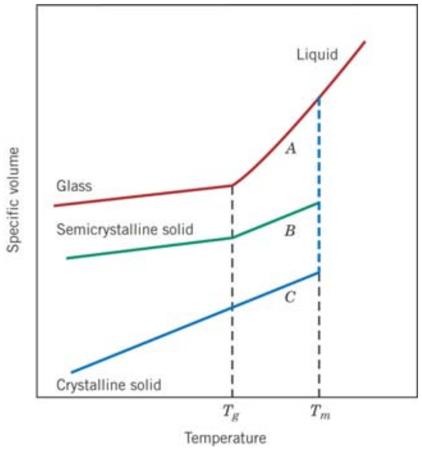
Heat treating (annealing) of semicrystalline polymers can lead to:

- increase in the percent ………………
- increase crystallite …………
- increase crystallite ………………..
- modifications of the spherulite structure

Influence of degree of crystallinity and MW on strength

Melting and Glass Transition Temperature

For amorphous and semicrystalline polymers, this is a critical aspect of designing with polymers.



- Crystalline polymers: there is a discontinuous change in specific volume at T_m
- Amorphous polymer: continuous, no T_m - but there is an increase in slope at T_g, the glass transition temperature,
- Semicrystalline polymer: intermediate to crystalline and amorphous, show both transitions.

Melting and Glass Transition Temperature

- **Melting of a crystalline polymer**
  - transforming solid with an ordered structure to a viscous liquid with a highly ………… structure
- **Amorphous glass transitions**
  - transformation from a rigid material to one that has rubber-like characteristics
  - temperature has large effect on chain flexibility
- Below glass transition temperature, T_g, polymers are usually …….. and …….-like in mechanical behavior.
- Above glass transition, T_g, polymers are usually more elastic.

Why is That?

Below T_g bond are frozen which means chains can't rotate polymer becomes brittle, (no plastic deformation)

Polymers and Spaghetti

- Amorphous polymers → hot, fresh spaghetti with no "clumps"
- Semicrystalline polymers → hot fresh spaghetti with some "clumps"
- Crystalline polymers → spaghetti mostly "clumps" with some free strands
- Polymeric crystals (e.g. spherulite) → looks like "lasagna"
- Polymer below T_g → three day old spaghetti - left in the sun!

T_g is low for simple linear polymers (Polyethylene (low density) to Polypropylene)

T_g and T_m increase with mer complexity (Nylon 6,6 and Poly(ethylene terephthalate) (PET))

Table 15.2 Melting and Glass Transition Temperatures for Some of the More Common Polymeric Materials

Material	*Glass Transition Temperature [°C (°F)]*	*Melting Temperature [°C (°F)]*
Polyethylene (low density)	−110 (−165)	115 (240)
Polytetrafluoroethylene	−97 (−140)	327 (620)
Polyethylene (high density)	−90 (−130)	137 (279)
Polypropylene	−18 (0)	175 (347)
Nylon 6,6	57 (135)	265 (510)
Poly(ethylene terephthalate) (PET)	69 (155)	265 (510)
Poly(vinyl chloride)	87 (190)	212 (415)
Polystyrene	100 (212)	240 (465)
Polycarbonate	150 (300)	265 (510)

Polymer Additives

- **Mechanical, chemical, physical Properties can be modified by additives:**
- Fillers
  - Improve tensile and compressive strengths, abrasion resistance, toughness, and thermal stability
    - Wood, sand, glass, clay, talc (eg. carbon in tires)
  - Particle sizes range from very small (10 nm) to large (mm)
- **Plasticizers**: small molecules which occupy positions between polymer chains *(increase distance and interactions between chains)*
  - increase flexibility, ductility, and toughness
  - reduce hardness and stiffness
- **Stabilizers**
  - UV resistance of C-C bonds
  - Oxidation resistance
- **Colorants and Flame Retardants**

Forming of Polymers

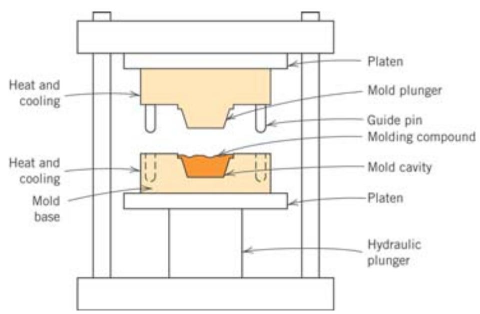
- Polymeric materials are normally fabricated at elevated temperatures and often by application of ……….
- The technique used to form a particular polymer depends on
  – whether it is thermoplastic or thermosetting
  – the atmospheric stability of the material at which forming takes place
  – the geometry and size of the final product
- If the polymer is thermoplastic the temperature at which it ………. will also dictate the process.

Thermosets

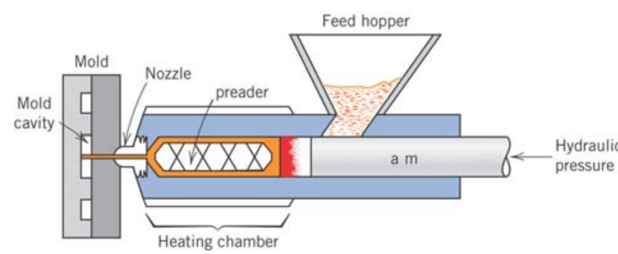
- Crosslinking prevents ………. and viscous flow
- Hot working, such as extrusion is not possible
- At high temperatures they decompose rather than melt
  – *although they can be used at higher temperatures than thermoplastics and are more chemically inert*
- Fabrication of thermosetting polymers is usually a two stage process
  – *In the first stage a linear polymer, with a* ***low molecular weight*** *is prepared*
  – *The second "****curing****" stage is carried out in a mould having the desired shape during the addition of:*
    - heat and/or catalysts
    - pressure
- During the cure, chemical and structural changes take place at a molecular level
  – *crosslinked or network polymer forme*
  – *this is dimensionally …….. and can be removed from the mould while hot*

Compression Moulding

- **Both** thermoplastics and thermosets can be formed by compression moulding
- The polymer, or mixture of resin and hardener is heated and compressed between dies
- This method is well suited for forming of:
  – *thermoset casings for appliances*
  – *thermoplastic car bumpers*
- Since a **thermoset** can be removed when hot, cycle times can be as low as:
  – *10 seconds for small components*
  – *10 minutes for large thick walled mouldings*

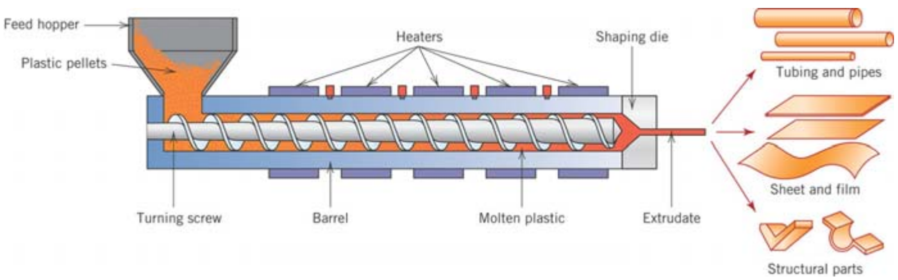


Injection Moulding



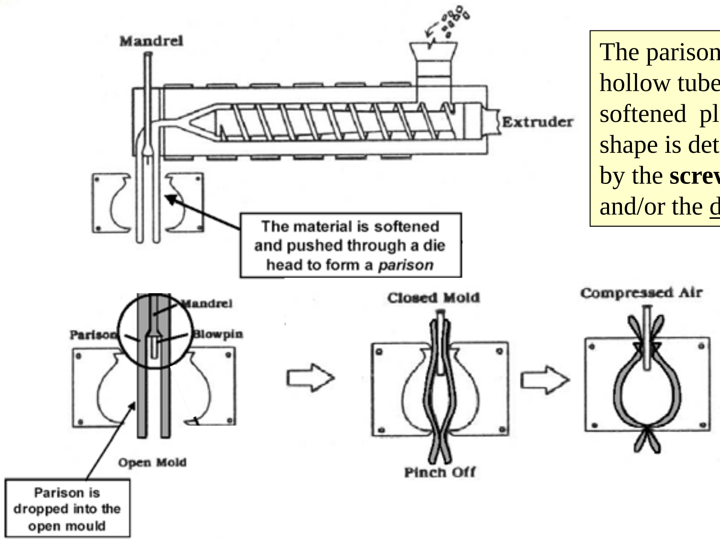
- In injection moulding, polymer granules are
  – *compressed by a ram or a screw*
  – *heated until* ***molten***
  – *injected into a cold, split mould under pressure*
- The moulded polymer is cooled below T_g
  – *the mould opens and the product is ejected*
- This process gives ………………. mouldings because the polymer cools under pressure
- **Cycle time** is typically between 1 – 5 minutes

Thermoplastic Extrusion



It is a cheap **…………..** *process for producing shapes of constant section*

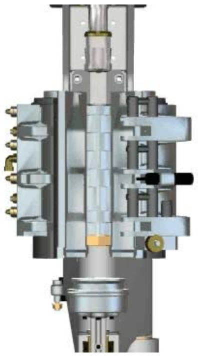
Blow Molding



The parison is a hollow tube of softened plastic It's shape is determined by the **screw speed** and/or the <u>die opening</u>

Eg. Container fabrication similar to glass bottle production

Blow Molding



Next time

Polymers to be continued