Microstructure Mechanics
Polymers: Structure and Properties

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Class 2011
New materials for key technologies: Aero-space

- Titanium
- Aluminium
- Magnesium
- Nickel
- Steels
- Intermetallics
Technology Status A380 – Material Distribution

- 62% Aluminum
- 20% Composite
- 10% Titanium / Steel
- 4% Glare
- 2% Surface protections
- 2% Miscellaneous
Advanced Alloys
- New initiative of metal industry
- Improved DT, density, stiffness

Premium Casting
- Industrial attractive
- Competition (High Speed Milling, etc.)

Advanced Welding
- Laser Beam Welding
- Friction Stir Welding
- Damage tolerance

Fiber Metal Laminates

Metal Laminates
- Improved Stiffness
- Improved hot-wet shear
- Material Optimised Hybrid
- Cost reduction
- Design rules
  - Fiber dominated
  - Bonded Metal laminate
Status A380

Status: A380 – Advanced
Advanced Metal-Technologies in Fuselage and Wing

Status: Composite Wing
Advanced Metal-Technologies in Fuselage

Status: Full Composite
Car Body Structure.
High Strength Steel.
BMW 1 Series.

- Other steel: 340 MPa
- DX 54: 380 MPa
- DX 56: 400 MPa
- 180 MPa: 420 MPa
- 220 MPa: 500 MPa
- 260 MPa: 680 MPa
- 300 MPa: 950 MPa

Others 3%

- Multiphase steel: 16%
- Deep drawing quality: 19%
- Standard high-strength steel: 63%
New materials for key technologies: automotive mobility

Car Body Structure.
Aluminium Front End / Steel passenger Cab.
BMW 5 Series.
New materials for key technologies: automotive mobility

**Car Body Shell.**
Materials for the BMW 6 Series.
Weight savings compared to Steel

- Aluminium Bonnet: -10 kg
- Sheet moulded Compound Deck Lid (SMC): -2 kg
- Thermoplastic Fenders (PPE+PA): -4 kg
- Aluminium Doors: -10 kg
New materials for key technologies: automotive mobility

Car Body Shell.
Aluminium and Steel.
Car Body Shell.
Aluminium and Thermoplastic.

BMW 5 Series
(Aluminium)

BMW 6 Series
(Thermoplastics)
New materials for key technologies: automotive mobility

Car Body Shell.
Cast Magnesium.
BMW 3 Series Convertible.

- Lightweight design
- Optimised stiffness
- Reduced number of parts
- Integrated fastenings

AM50 HP, pressure diecasting
Car Body Shell.
Sheet Moulded Compound (SMC).
Deck Lid BMW 6 Series.

• Lightweight design
• Complex shape
• Integrated antennas
  AM, FM, Diversity,
  TV, Tel, GPS,
  SDARS, digital Tuner
New materials for key technologies: automotive mobility
New materials for key technologies: automotive mobility
New materials for key technologies: automotive mobility
New materials for key technologies: Green energy

Steels
Cu(In,Ga)Se$_2$
CdTe
New materials for key technologies: Health

TITANIUM
MAGNESIUM
POYLMERS
BONE
Polycarbonate (PC) and the PC/Ni interface

Grooves and address pits of a die cast sample of polycarbonate for a high storage density (blue laser) optical disc

Bayer Materials
Self-healing materials, polymer batteries, flexible electronics, electronic polymers, organic light emitting diodes (OLED), regenerative biomaterials, organic solar cells, drug delivery materials, materials science of food (organics), soft matter in medicine......
Natural materials
- Polymers
- Biological Materials
Soft Matter Theory: Comprehensive Understanding of Physical and Chemical Properties

Time
Length

Local Chemical Properties ↔ Scaling Behavior of Nanostructures
Energy Dominance ↔ Entropy Dominance of Properties

Analytic Theory
Numerical Methods
Molecular
Atomistic
Soft Fluid
Finite Elements, Macrosc. Theory
• Macromolecule that is formed by linking of repeating units through covalent bonds in the main backbone
• Properties are determined by
  – molecular weight
  – length
  – backbone structure
  – side chains
  – crystallinity
• Resulting macromolecules have huge molecular weights
### Types of polymers

<table>
<thead>
<tr>
<th>Structure</th>
<th>Source-Based Name</th>
<th>Application</th>
</tr>
</thead>
<tbody>
<tr>
<td>R = -H</td>
<td>Polyethylene</td>
<td>Plastic</td>
</tr>
<tr>
<td>R = -CH₃</td>
<td>Polypropylene</td>
<td>Rope</td>
</tr>
<tr>
<td>R = -Cl</td>
<td>Poly(vinyl chloride)</td>
<td>&quot;Vinyl&quot;</td>
</tr>
<tr>
<td>X = -H, R = -C₂H₅</td>
<td>Poly(ethyl acrylate)</td>
<td>Latex paints</td>
</tr>
<tr>
<td>X = -CH₃, R = -CH₃</td>
<td>Poly(methyl methacrylate)</td>
<td>Plastic</td>
</tr>
<tr>
<td>R = -H</td>
<td>Polybutadiene</td>
<td>Tires</td>
</tr>
<tr>
<td>R = -CH₃</td>
<td>Polyisoprene</td>
<td>Tires</td>
</tr>
<tr>
<td>X = -F, R = -F</td>
<td>Polytetrafluoroethylene</td>
<td>Teflon®</td>
</tr>
</tbody>
</table>
Monomer arrangement in copolymers

Monomers within a copolymer may be organized along the backbone in a variety of ways.

- **Alternating copolymers** possess regularly alternating monomer residues.

- **Periodic copolymers** have monomer residue types arranged in a repeating sequence: $[A_n B_m...]$ $m$ being different from $n$.

- **Statistical copolymers** have monomer residues arranged according to a known statistical rule. A statistical copolymer in which the probability of finding a particular type of monomer residue at a particular point in the chain is independent of the types of surrounding monomer residue may be referred to as a truly **random copolymer**.

- **Block copolymers** have two or more homopolymer subunits linked by covalent bonds (4). Polymers with two or three blocks of two distinct chemical species (e.g., A and B) are called diblock copolymers and triblock copolymers, respectively. Polymers with three blocks, each of a different chemical species (e.g., A, B, and C) are termed triblock terpolymers.
Durability of polymer composites

Polymer composites change with time and most significant factors are

• Elevated temperatures
• Fire
• Moisture
• Adverse chemical environments
• Natural weathering when exposed to sun’s ultra-violet radiation
### Polymer composites: mechanical properties

<table>
<thead>
<tr>
<th>MATERIAL</th>
<th>Relative density</th>
<th>Diameter thickness ratio (microns)</th>
<th>Length (mm)</th>
<th>E (GPa)</th>
<th>Tens. Str. (MPa)</th>
<th>Failure strain (%)</th>
<th>Volume in composite (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortar matrix</td>
<td>1.8-2.0</td>
<td>300-5000</td>
<td>-</td>
<td>10-30</td>
<td>1-10</td>
<td>0.01-0.05</td>
<td>85-97</td>
</tr>
<tr>
<td>Concrete matrix</td>
<td>1.8-2.4</td>
<td>10000-20000</td>
<td>-</td>
<td>20-40</td>
<td>1-4</td>
<td>0.01-0.02</td>
<td>97-99.5</td>
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<tr>
<td>Asbestos</td>
<td>2.55</td>
<td>0.02-30</td>
<td>5-40</td>
<td>164</td>
<td>200-1800</td>
<td>2-3</td>
<td>5-15</td>
</tr>
<tr>
<td>Carbon</td>
<td>1.16-1.95</td>
<td>7-18</td>
<td>3-cont.</td>
<td>30-390</td>
<td>600-2700</td>
<td>0.5-2.4</td>
<td>3-5</td>
</tr>
<tr>
<td>Glass</td>
<td>2.7</td>
<td>12.5</td>
<td>10-50</td>
<td>70</td>
<td>600-2500</td>
<td>3.6</td>
<td>3-7</td>
</tr>
<tr>
<td>Polyethylene</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HDPE filament</td>
<td>0.96</td>
<td>900</td>
<td>3-5</td>
<td>5</td>
<td>200</td>
<td>-</td>
<td>2-4</td>
</tr>
<tr>
<td>High modulus</td>
<td>0.96</td>
<td>20-50</td>
<td>Cont.</td>
<td>10-30</td>
<td>&gt; 400</td>
<td>&gt; 4</td>
<td>5-10</td>
</tr>
<tr>
<td>Polypropylene</td>
<td>0.91</td>
<td>20-100</td>
<td>5-20</td>
<td>4</td>
<td>-</td>
<td>-</td>
<td>0.1-0.2</td>
</tr>
<tr>
<td>(Monofilament)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Polyvinyl alcohol</td>
<td>1-3</td>
<td>3-8</td>
<td>2-6</td>
<td>12-40</td>
<td>700-1500</td>
<td>-</td>
<td>2-3</td>
</tr>
<tr>
<td>(PVA)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Steel</td>
<td>7.86</td>
<td>100-600</td>
<td>10-60</td>
<td>200</td>
<td>700-2000</td>
<td>3-5</td>
<td>0.3-2.0</td>
</tr>
</tbody>
</table>

Performance is controlled by
- vol. fraction of fibers
- properties of fibers and matrix
- bond between the two
Structure, scales, partially crystalline polymers
Structure, scales, partially crystalline polymers
The crystalline unit cell for PET ($a = 4.56 \text{ Å}$, $b = 5.94 \text{ Å}$, $c = 10.75 \text{ Å}$; $\alpha = 98.5^\circ$, $\beta = 118^\circ$, $\gamma = 112^\circ$),

M Durell (2002)
Polymer structure: spherulite growth

Polymer structure: spherulite growth

Fig. 2 AFM contact mode images. Cellulose molecules in micro-fibril crystal: (a) topographic image; and (b) error-signal image. Polybutene-1 molecules: (c) topographic image; and (d) simulated AFM image based on crystallographic data.

M. Miles, M. Antognozzi, H. Haschke, J. Hobbs, A. Humphris, I. McMaster
H.H. Wills Physics Laboratory, University of Bristol, Materials Today, Feb. 2003
Polymer structure: spherulite growth

Bamford, Nature 173 (1954) p. 27; Astbury, Endeavor 1(1942) p. 70
Polymer structure: PET: XRD

Polyethylen-Terephtalate (PET), Cr-Kα₁, 40KV 40mA

(hkl)                  (hkl)                     2theta
(Cr)                  (Cr)                     2theta

(001) 15.12
(0-11) 24.52
(010) 26.2
(-111) 31.92
(101) 32.2
(-110) 33.8
(011) 35.36
(100) 38.64
(111) 41.94
(101) 49.68
(11-1) 50.36
(110) 58.38
(111) 69.84
Polypropylen (PP), Cr-Kα1, 40KV 40mA
Reorientation: deformation

Polymer structure: deformation
Polymer structure: deformation and decrystallization

orientation-dependence of decrystallization

tensorial nature of polymer deformation

$-\sigma_{11}$