POLYMER MATERIALS

Plastics
Rubbers

... Hugely diverse group

- **Solid materials**
- **Cellular materials**
- **Fibres/textiles**
- **Adhesives**
- **Coatings**
- **Composites**

POLYMER MATERIALS

Applied across the whole of engineering:

consumer markets
packaging

heavy engineering

advanced engineering

POLYMER MATERIALS

Applied across the whole of engineering:

consumer markets
packaging

heavy engineering
civil engineering, pipeline technology

advanced engineering

POLYMER MATERIALS

Applied across the whole of engineering:

consumer markets
packaging

heavy engineering

advanced engineering
aerospace, automobile and sports engineering

Large Diameter Polyethylene Pipe

Storm water drainage system

60 in dia
HDPE

POLYMER MATERIALS

Callister: Chapters 14, 15 [6th edn]

Hall: Polymer Materials 2nd edn

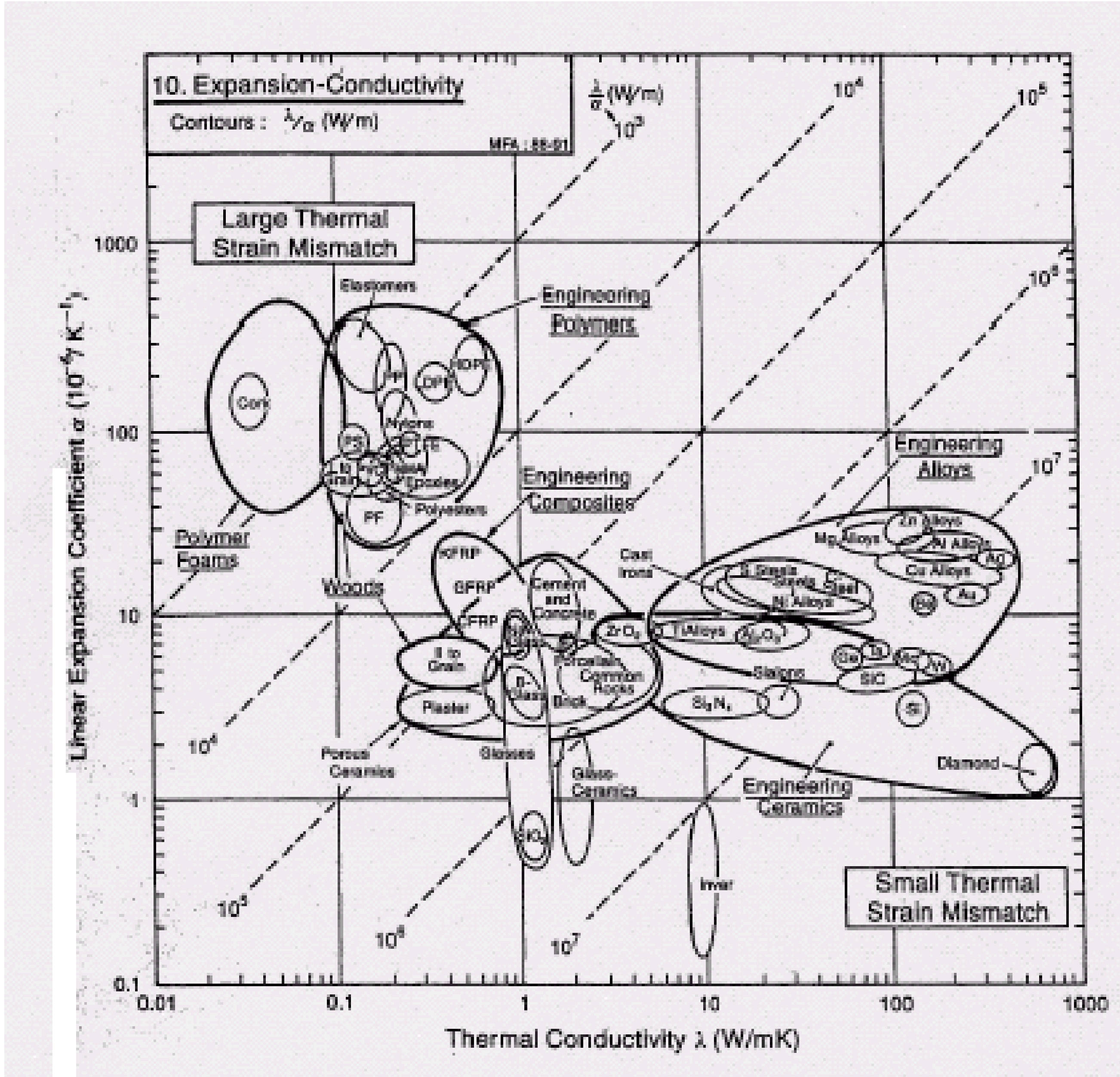
Hall: *Polymers* in Jackson & Dhir, Civil Engineering Materials 5th edn

Thermal expansivity

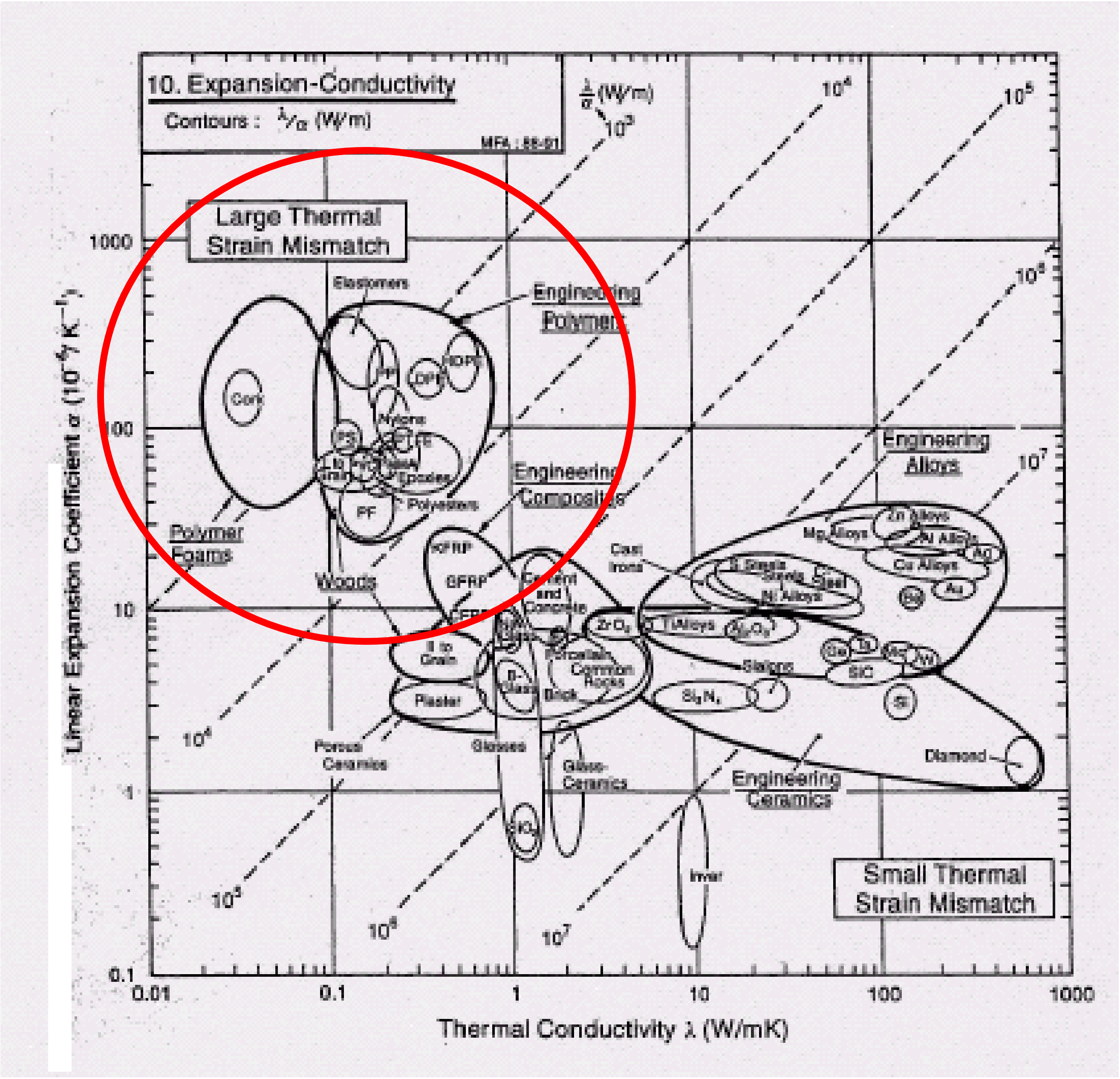
- What are typical values of α ?
- and what is the range?

- *Metals* 10 -- 20 $\times$ 10^{-6} / K
- *Ceramics* 1 -- 10 $\times$ 10^{-6} / K
- *Polymers* 30 -- 300 $\times$ 10^{-6} / K

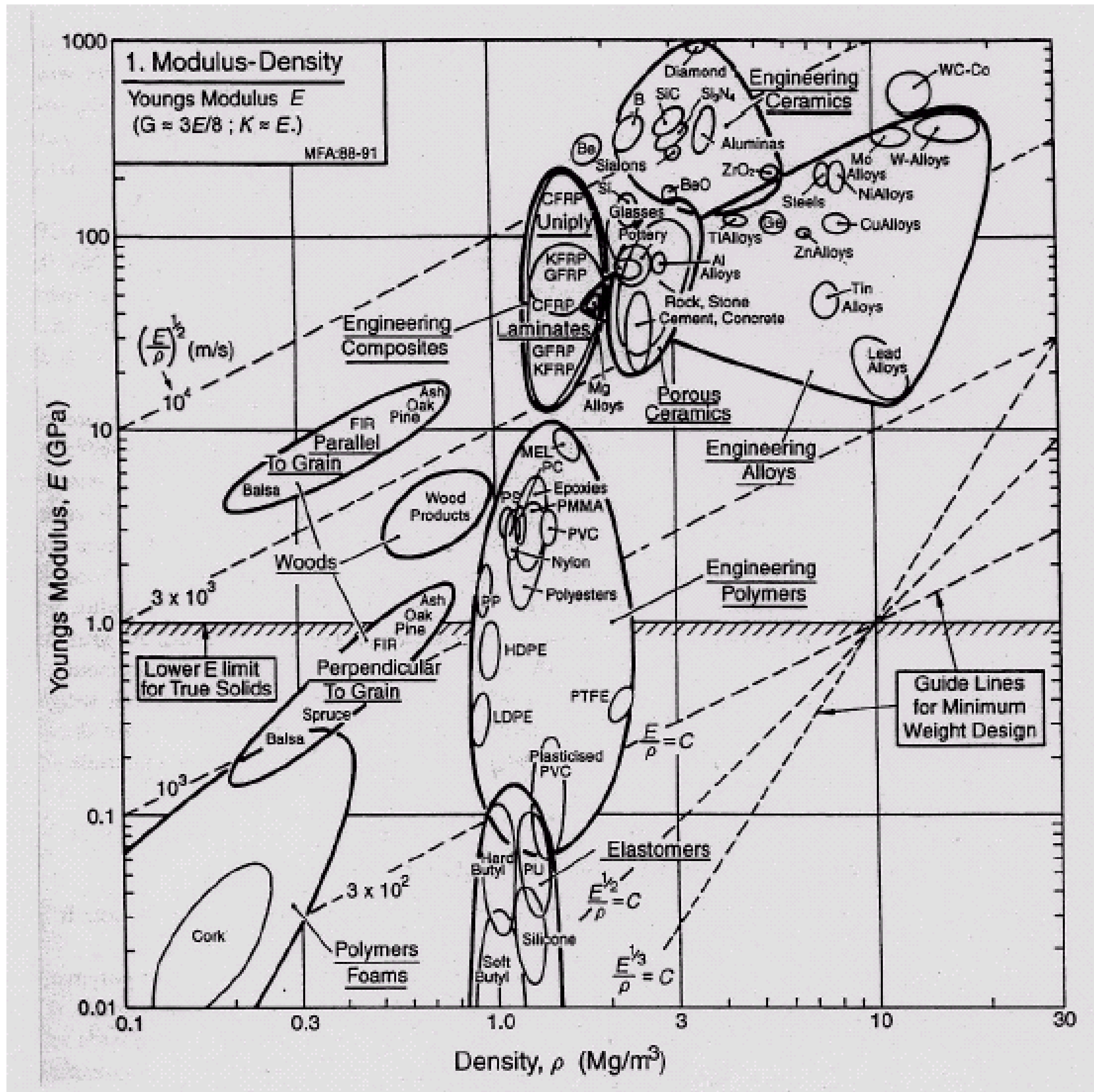
Ashby diagram: Thermal expansivity–Thermal conductivity from Ashby Materials Selection in Mechanical Design 2nd edn p51



Ashby diagram: Thermal expansivity–Thermal conductivity from Ashby Materials Selection in Mechanical Design 2nd edn p51



Ashby diagram:
Young's modulus–Density
from Ashby
Materials Selection in
Mechanical Design
2nd edn p37



Ashby diagram:
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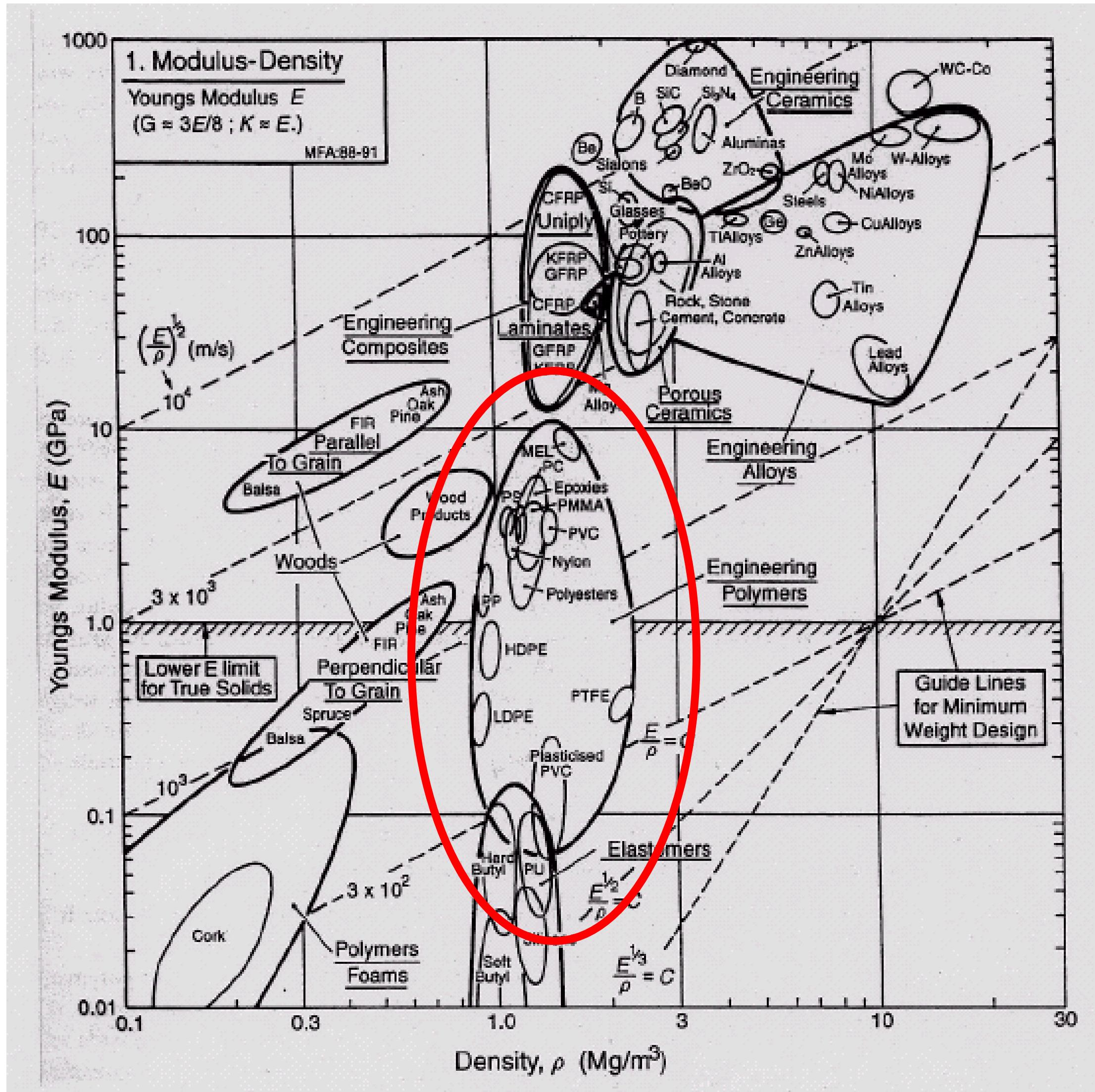
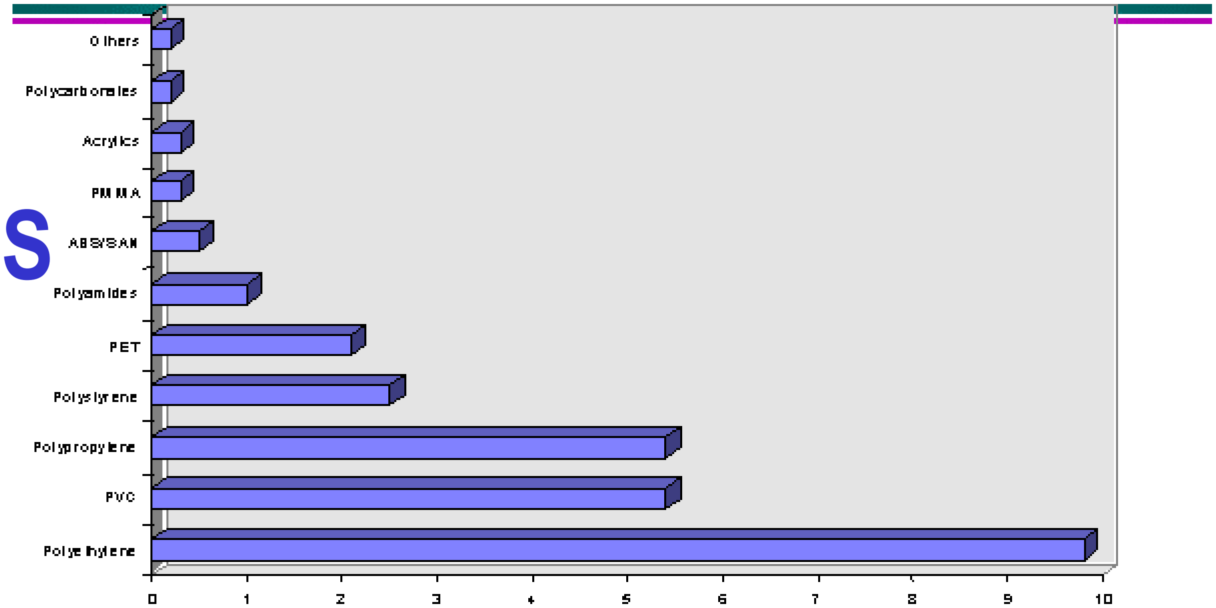
2nd edn p37



Eu Polymer Consumption 1997 - Thermoplastics



PIA/IBEC

ABS
PA
PS
PP
PVC
PE

Million tonnes

POLYMER MATERIALS: Standard abbreviations

PE	polyethylene
PA	polyamide
PS	polystyrene
PP	polypropylene
PVC	poly(vinyl chloride)
ABS	acrylonitrile-butadiene-styrene polymer

POLYMER MATERIALS

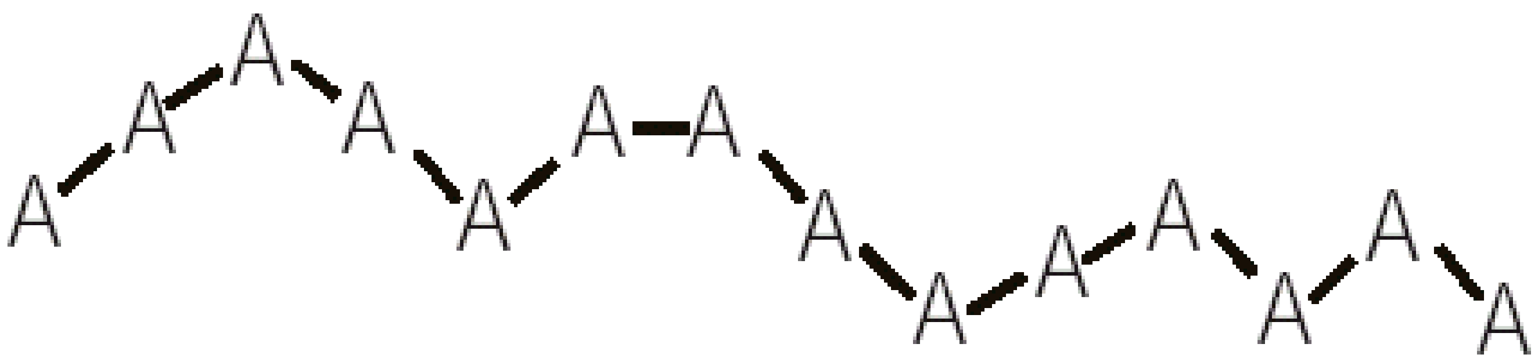
what is a polymer?

A very large molecule comprising hundreds or thousands of atoms formed by successive linking of one or two, occasionally more, types of small molecule in chain or network structures

POLYMER MATERIALS

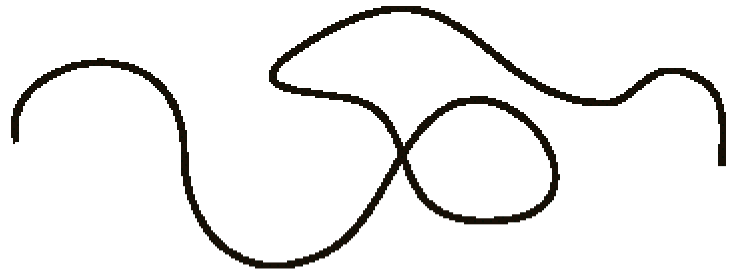
What is a polymer?

A very large molecule comprising hundreds or thousands of atoms formed by successive linking of one or two, occasionally more, types of small molecule in chain or network structures



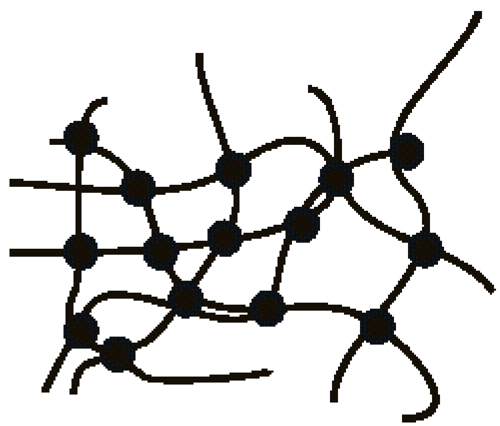
A is a Monomer unit

— represents a covalent bond



(a)

(b)



(c)

Large Diameter Polyethylene Pipe

Storm water drainage system

60 in dia
HDPE

POLYETHYLENE

A
thermoplastic
linear chain
semicrystalline
hydrocarbon
polymer

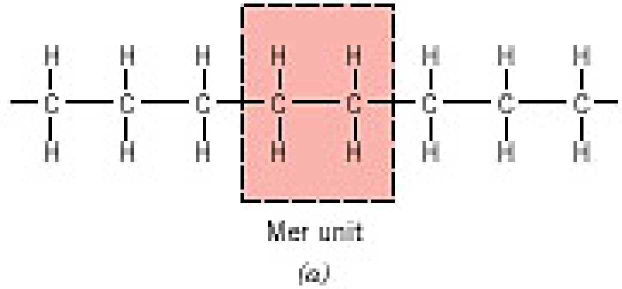
POLYETHYLENE

A
thermoplastic
linear chain
semicrystalline
hydrocarbon
polymer

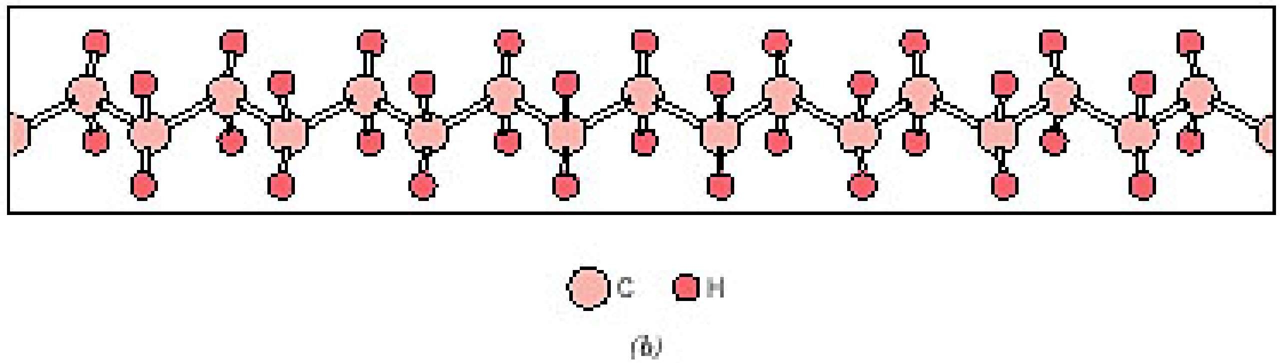
Polyethylene ***systematic name***
PE ***standard abbreviation***

Polythene, Alkathene ***trade names***

POLYETHYLENE



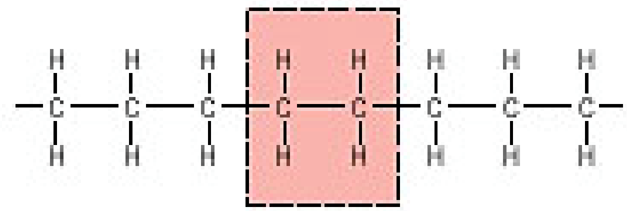
A thermoplastic linear chain semicrystalline hydrocarbon polymer



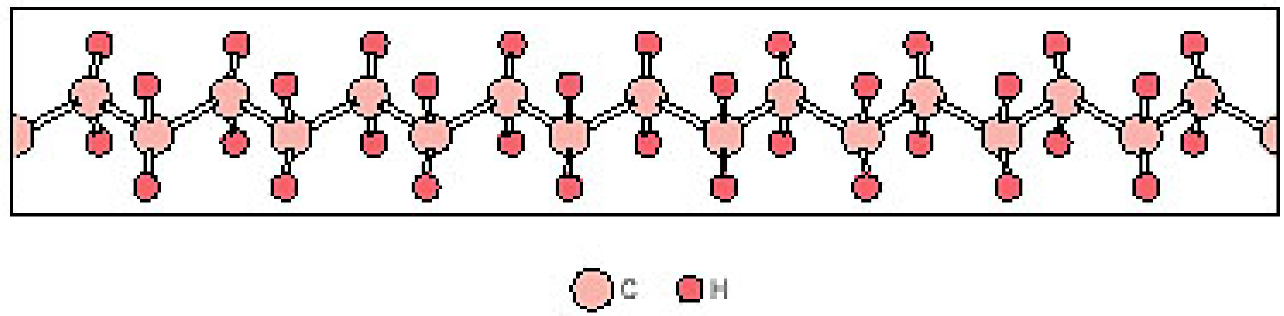
Melting temperature 100-110°C

Density 910-970 kg/m^3

POLYETHYLENE



A thermoplastic linear chain semicrystalline hydrocarbon polymer



Melting temperature 100-110°C

Density 910-970 kg/m^3

Typical chain lengths 10^4 -- 10^5 units

Polymer chain mechanics:
The freely-jointed chain

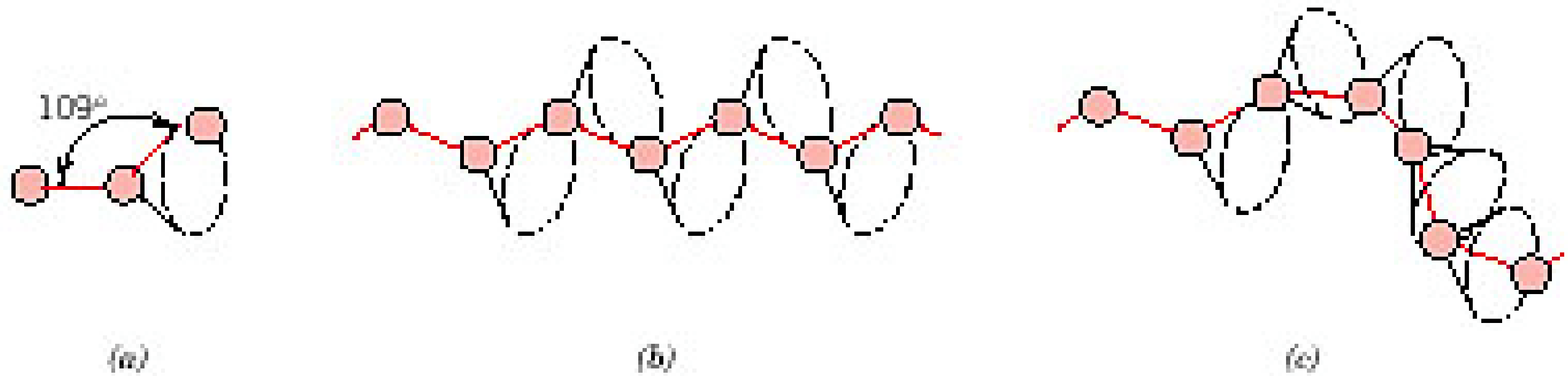


FIGURE 15.5 Schematic representations of how polymer chain shape is influenced by the positioning of backbone carbon atoms (solid circles). For (*a*), the rightmost atom may lie anywhere on the dashed circle and still subtend a 109° angle with the bond between the other two atoms. Straight and twisted chain segments are generated when the backbone atoms are situated as in (*b*) and (*c*), respectively. (Reprinted with permission of Brooks/Cole Publishing Company, a division of International Thomson Publishing Inc.; fax (800) 730-2215. From *The Science and Engineering of Materials*, 3/e by D. Askeland. © 1994.)

Polymer chain: typical configuration in melt or solution

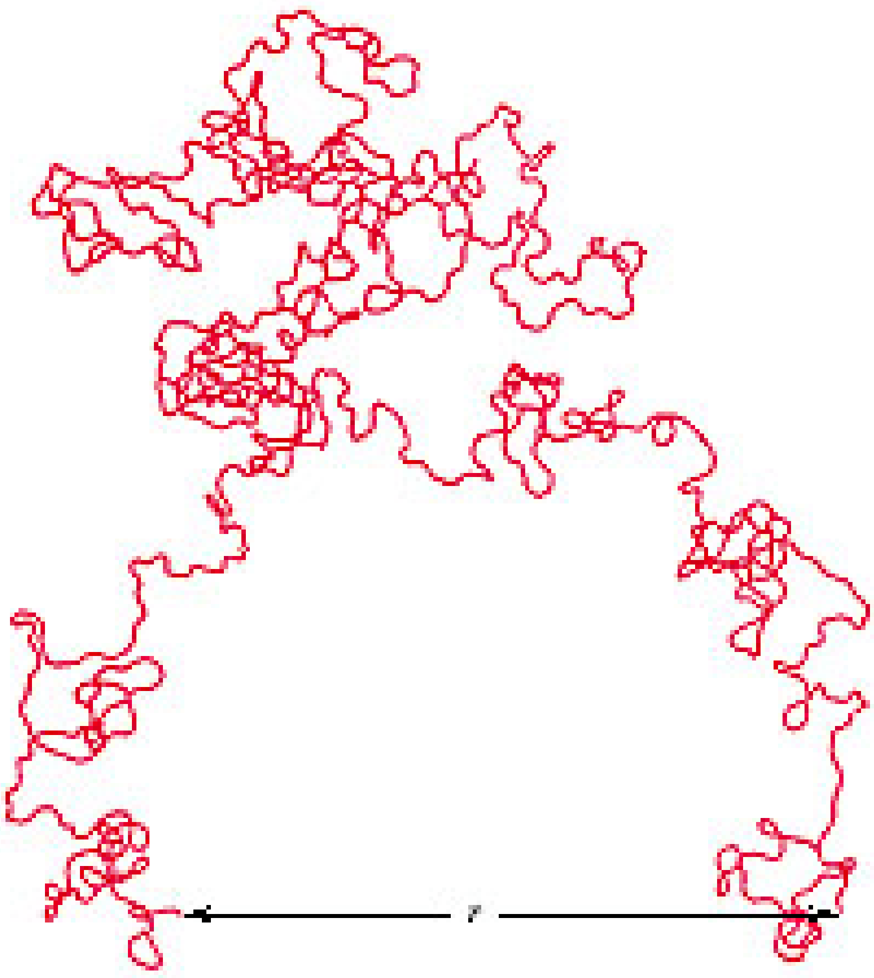


FIGURE 15.6 Schematic representation of a single polymer chain molecule that has numerous random kinks and coils produced by chain bond rotations. (From L. R. G. Treloar, *The Physics of Rubber Elasticity*, 2nd edition, Oxford University Press, Oxford, 1958, p. 47.)

Polyethylene single crystal
AFM image
Lin

Polyethylene single crystal

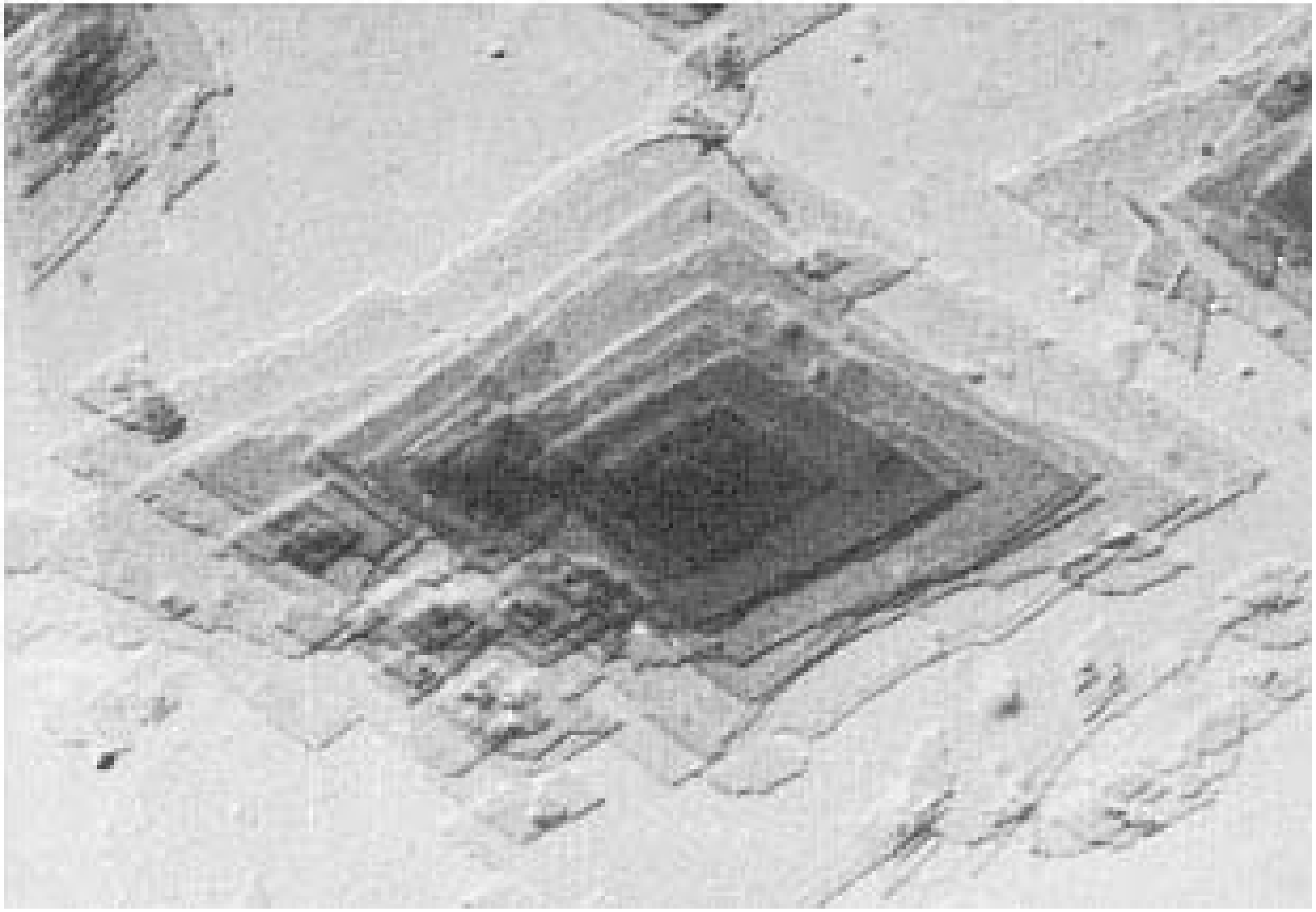


FIGURE 15.12 Electron micrograph of a polyethylene single crystal. 20,000×. (From A. Keller, R. H. Doremus, B. W. Roberts, and D. Turnbull, Editors, *Growth and Perfection of Crystals*. General Electric Company and John Wiley & Sons, Inc., 1958, p. 498.)

Polyethylene: arrangement of chains in crystalline domains

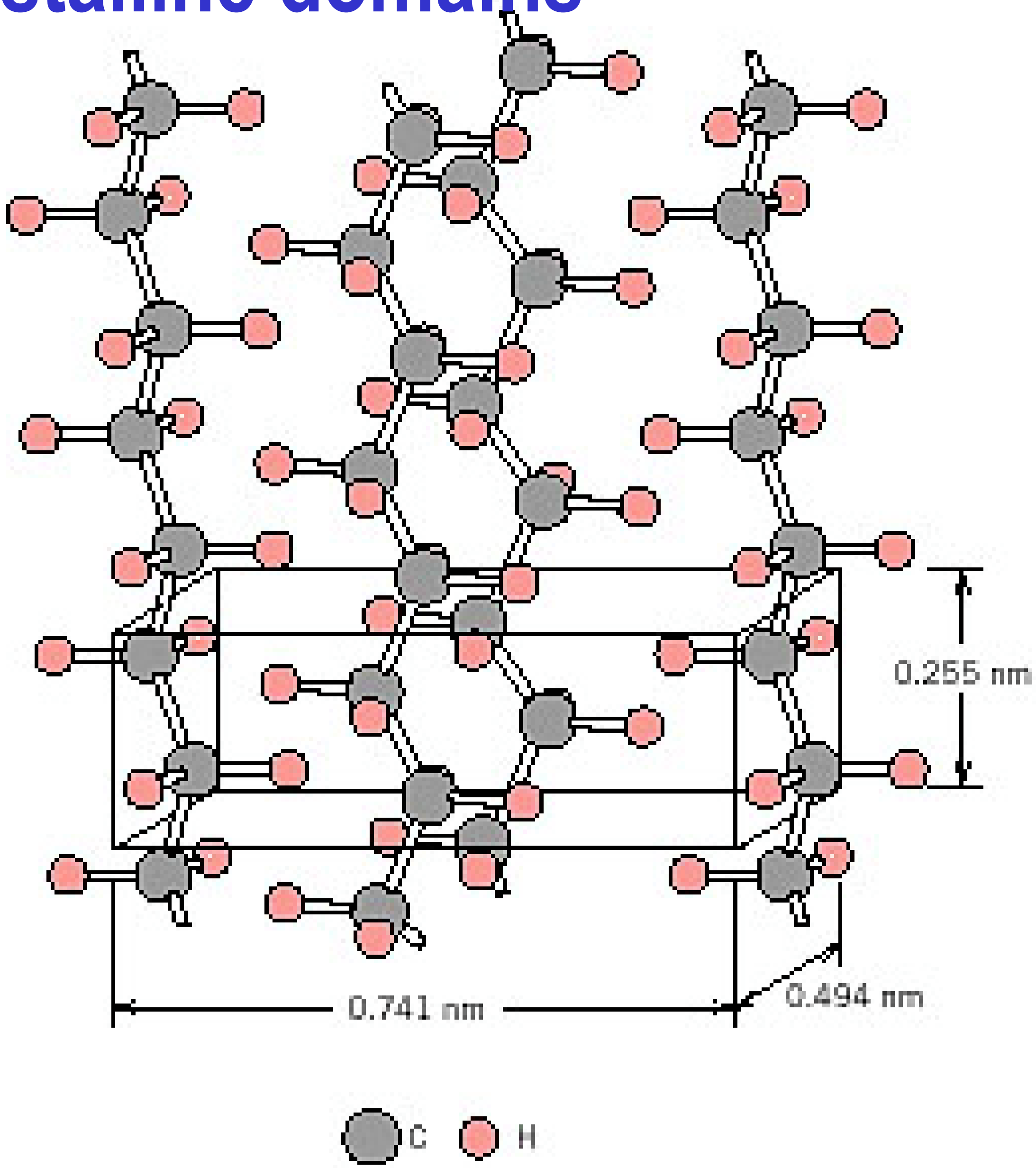


FIGURE 15.10
Arrangement of molecular chains in a unit cell for polyethylene. (Adapted from C. W. Bunn, *Chemical Crystallography*, Oxford University Press, Oxford, 1945, p. 233.)

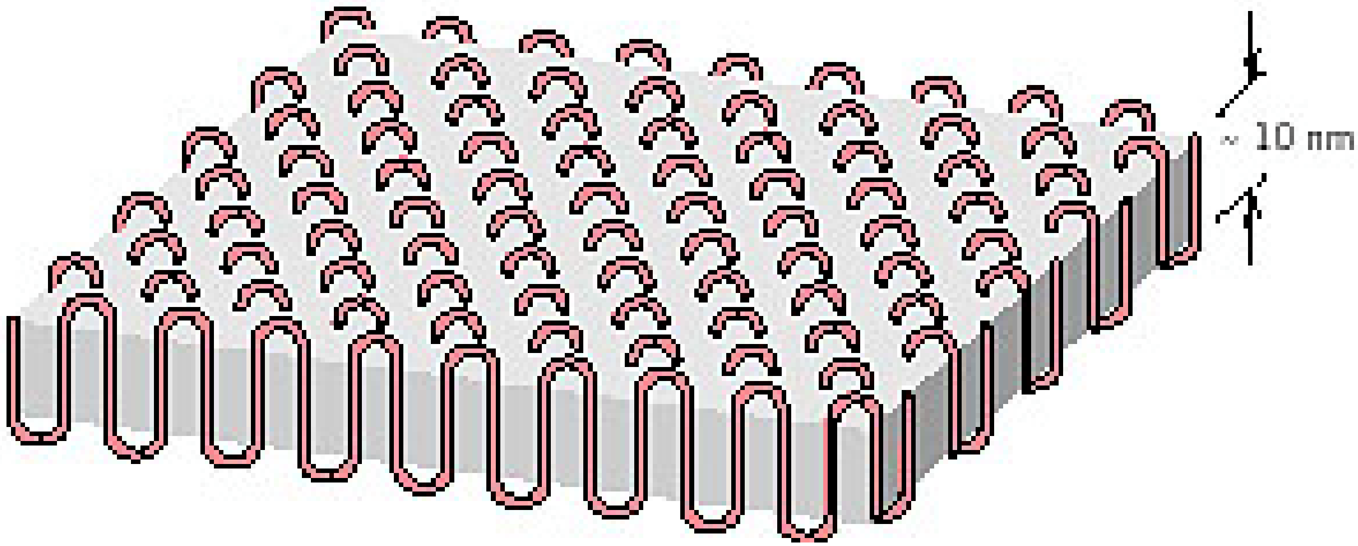


Figure 15.13 The chain-folded structure for a plate-shaped polymer crystallite.

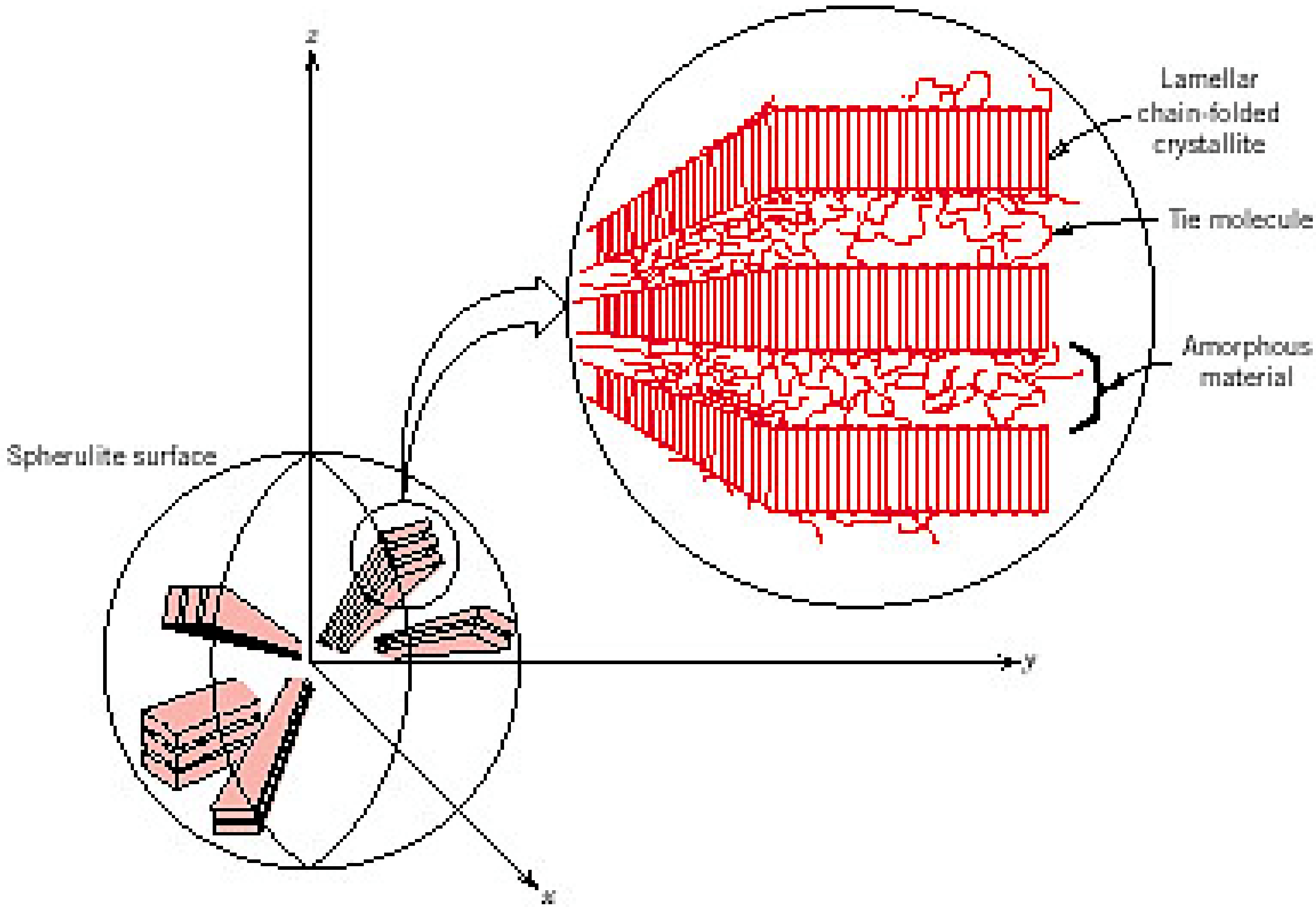
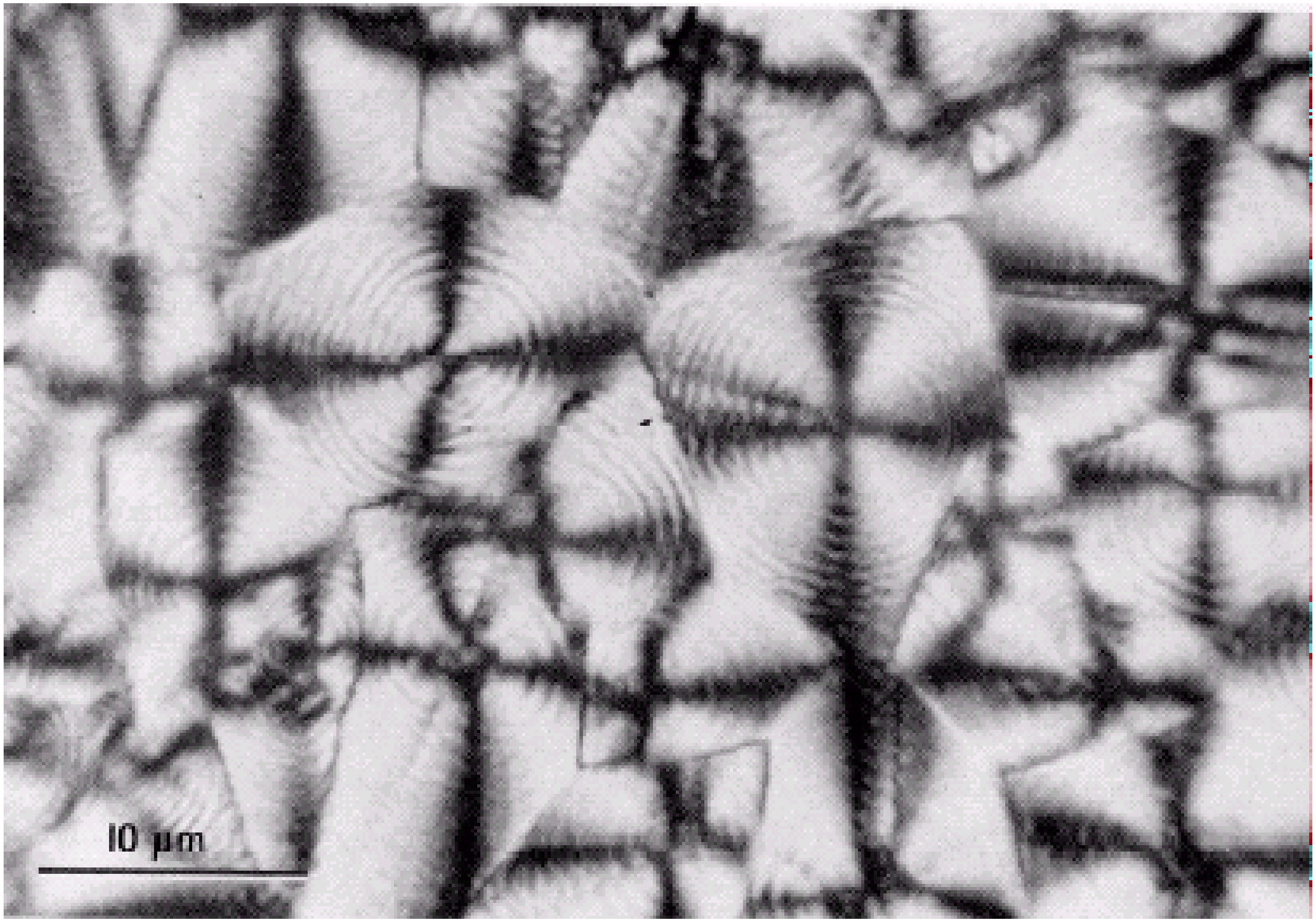
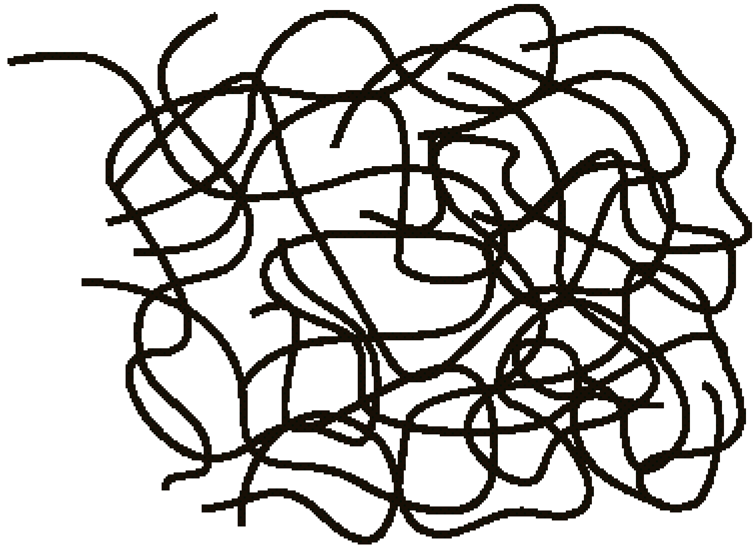


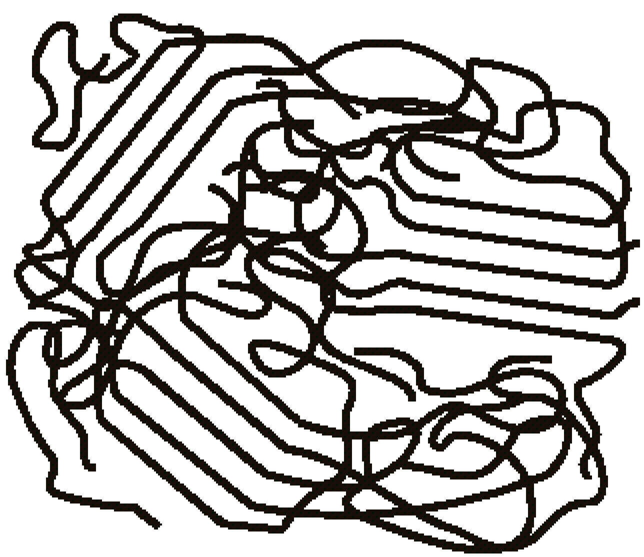
Figure 15.14 Schematic representation of the detailed structure of a spherulite. (From John C. Coburn, *Dielectric Relaxation Processes in Poly(ethylene terephthalate)*, Dissertation, University of Utah, 1984.)

Spherulite structure in polyethylene





(a) **Amorphous**



(b) **Semi-crystalline**

OTHER SIMPLE HYDROCARBON POLYMERS

Engineering the polymer chain:

POLYPROPYLENE

TACTICITY

OTHER SIMPLE HYDROCARBON POLYMERS

Engineering the polymer chain:

POLYSTYRENE

Completely amorphous: glassy

POLYMER MECHANICS

Thermoplastic polymers under normal working conditions do not show simple hookean behaviour

Stress-strain behaviour is TIME DEPENDENT

POLYMER MECHANICS

Thermoplastic polymers under normal working conditions do not show simple hookean behaviour

Stress-strain behaviour is TIME DEPENDENT

... Such materials are described as VISCOELASTIC

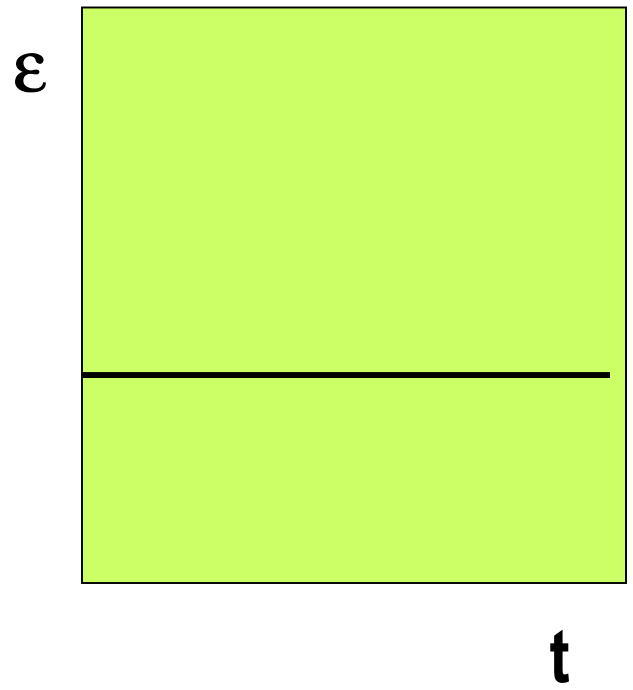
CREEP

For many materials under many conditions, simple elastic behaviour

so that for example at CONSTANT TENSILE STRESS

$\varepsilon = D\sigma$

D tensile compliance
D is CONSTANT



POLYETHYLENE:

Controlling the degree of crystallization

chain branching

thermal processing

CREEP

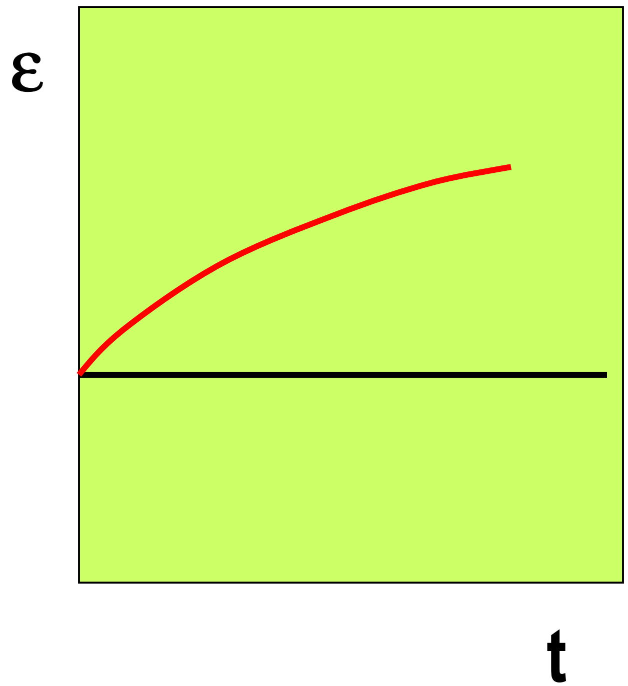
BUT OFTEN
the stress-strain behaviour is not constant <u>with time</u>

At CONSTANT TENSILE STRESS σ_1

$\varepsilon(t) = D\sigma_1$

D is time dependent

We speak of CREEP COMPLIANCE



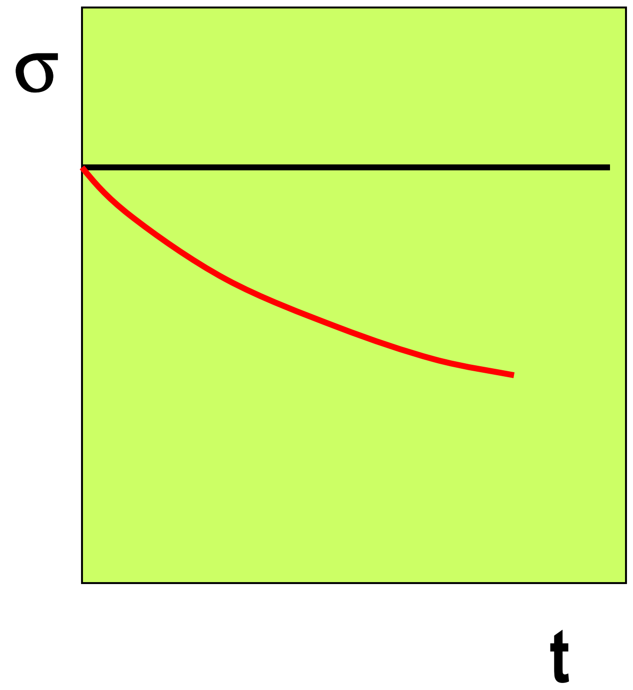
STRESS RELAXATION IN CREEP

In materials which show creep

At CONSTANT TENSILE STRAIN

$\varepsilon_1 = D\sigma(t)$

We speak of
RELAXATION OF STRESS



CREEP

We can of course also define a CREEP MODULUS

$E(t) = 1/D$

GENERAL COMMENTS ABOUT CREEP

Slow, time-dependent deformation under constant load IMPLIES mobility and reorganisation of the lattice

Generally found in materials at absolute $T > 0.6\ T_m$

Most metals at high temperatures
Many polymers at normal use temperatures

CREEP

References

HALL: POLYMER MATERIALS 1989 3.7-3.10

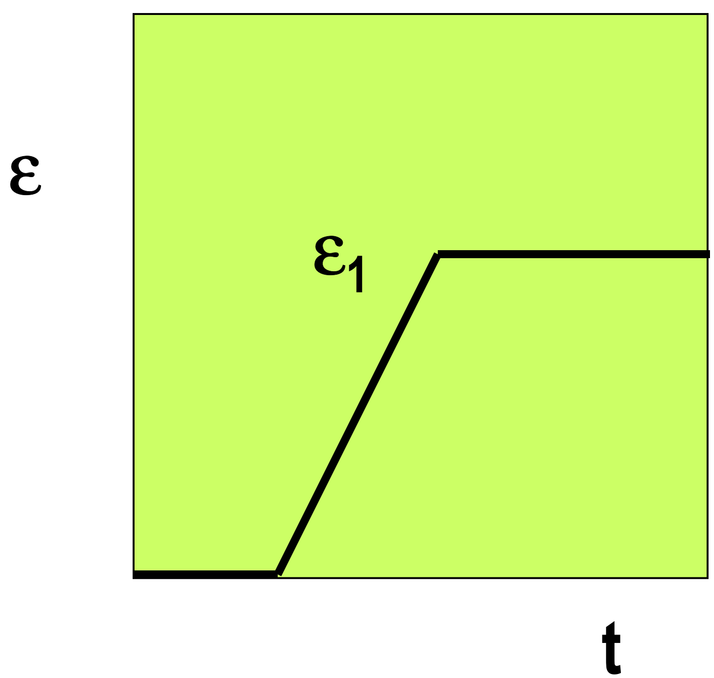
HALL: in JACKSON + DHIR, CIVIL ENGINEERING MATERIALS 5th Edn

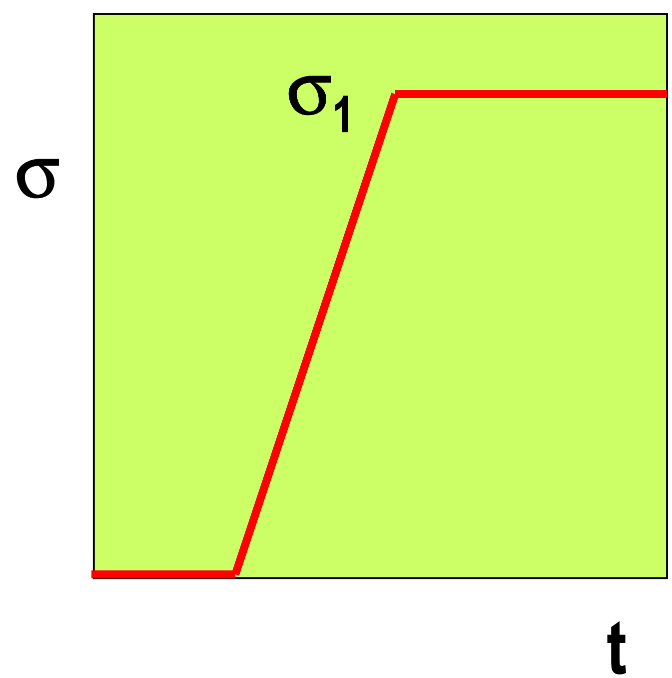
CALLISTER: Metals 8.13; Polymers 16.7

Mechanical properties of materials

Stress-strain relations as input-output functions

SIMPLE ELASTIC

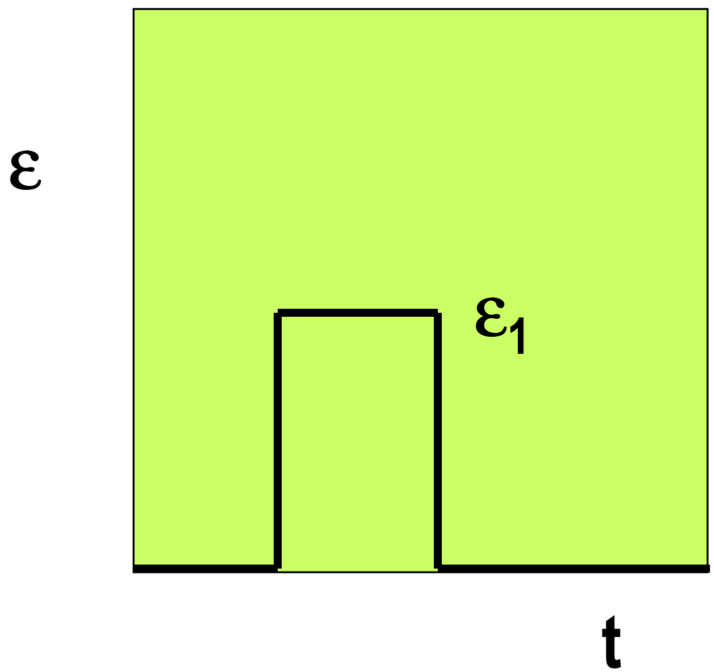


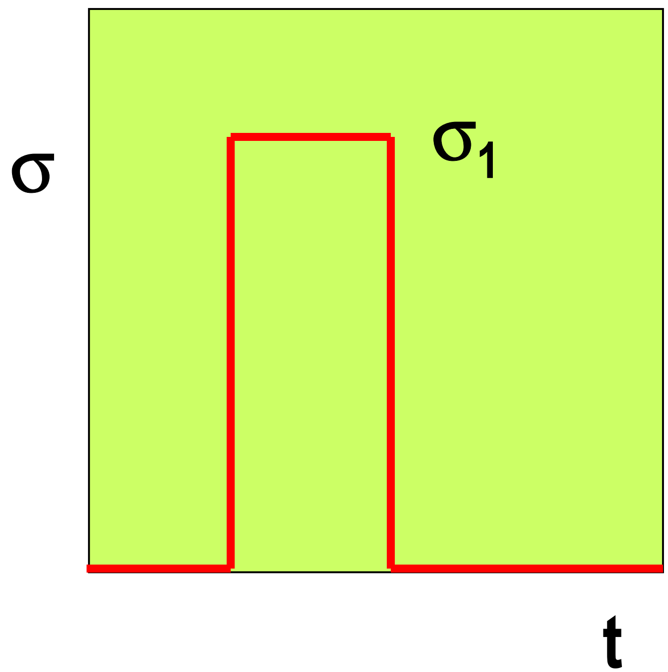


Mechanical properties of materials

Stress-strain relations as input-output functions

SIMPLE ELASTIC

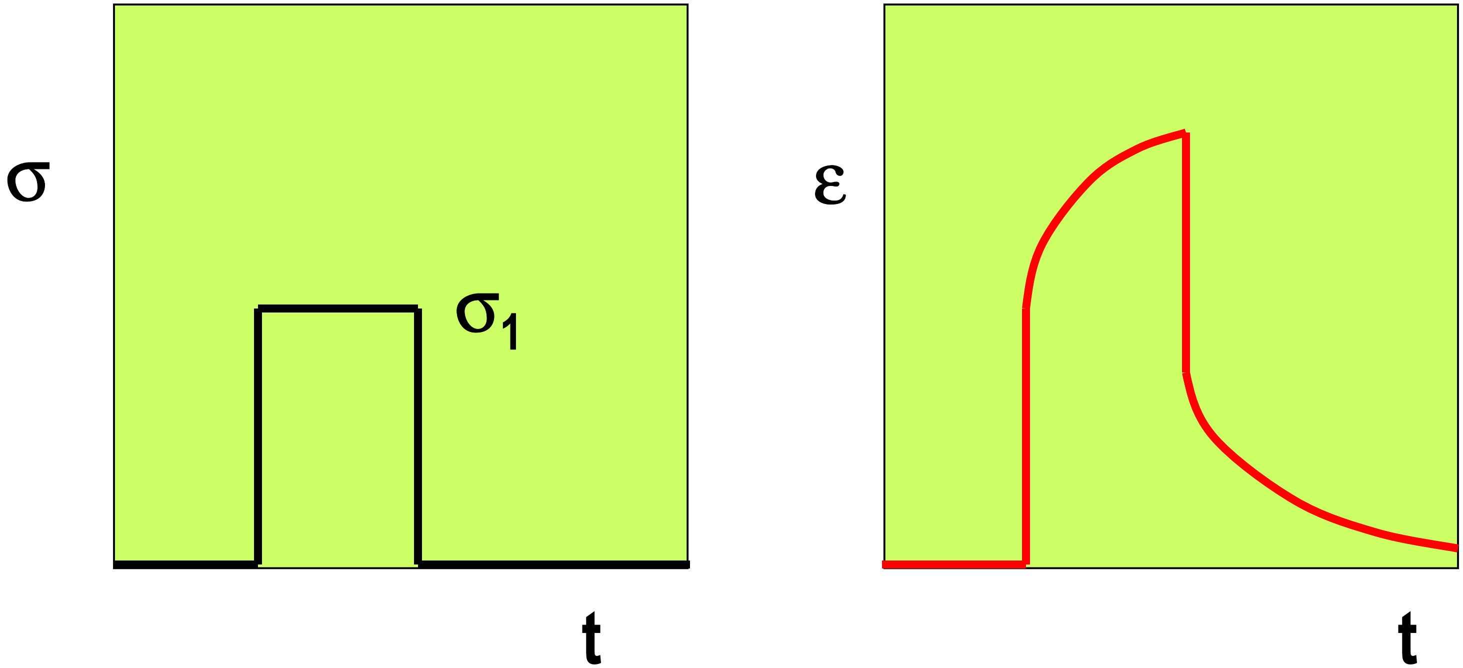


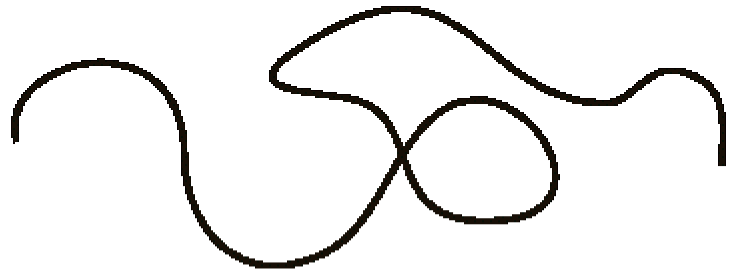


Mechanical properties of materials

Stress-strain relations as input-output functions

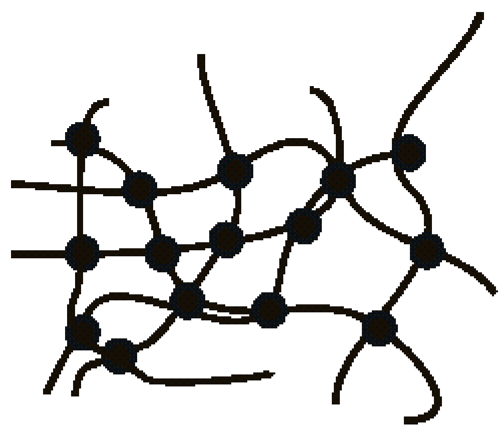
CREEP and RECOVERY IN A VISCOELASTIC MATERIAL





(a)

(b)



(c)

Another linear chain polymer

POLYOXYMETHYLENE
POM
Acetal, Delrin   *trade names*

$-CH_2-O-CH_2-O-CH_2-O-$

Compare with polyethylene PE

Linear, semicrystalline, thermoplastic

Another linear chain polymer
POLYOXYMETHYLENE
POM

Compare with polyethylene PE

Linear, semicrystalline, thermoplastic

...but “heterochain”   chain backbone is not all C
but alternating C and O

Another linear chain polymer
POLYOXYMETHYLENE
POM

Compare with polyethylene PE

	POM	PE
Crystallinity %	65	80

Another linear chain polymer
POLYOXYMETHYLENE
POM

Compare with polyethylene PE

	POM	PE
Crystallinity %	65	80
Density kg/m^3	1450	950

Another linear chain polymer
POLYOXYMETHYLENE
POM

Compare with polyethylene PE

	POM	PE
Crystallinity %	65	80
Density kg/m^3	1450	950
Melting temperature °C	180	120

Another linear chain polymer
POLYOXYMETHYLENE
POM

Compare with polyethylene PE

	POM	PE
Crystallinity %	65	80
Density kg/m^3	1450	950
Melting temperature °C	180	120
Tg °C	-90	-80
Heat of combustion kJ/kg	17	47

Another linear chain polymer
POLYOXYMETHYLENE
POM

Compare with polyethylene PE

	POM	PE
Crystallinity %	65	80
Density kg/m^3	1450	950
Melting temperature °C	180	120
Tg °C	-90	-80
Heat of combustion kJ/kg	17	47

Glass transition temperature

A critical temperature for every polymer material which marks the transition from

brittle/stiff to compliant/tough

$\mathbf{T_g}$

Glass transition temperature

Below T_g the easy movement of the polymer spaghetti chains is essentially frozen out. The entanglement of the chains becomes locked.

Glass transition temperature

Semi-crystalline polymers and rubbers (elastomers) are generally used at temperatures well aboveT_g

Amorphous (glassy) polymers are used at temperatures well below T_g

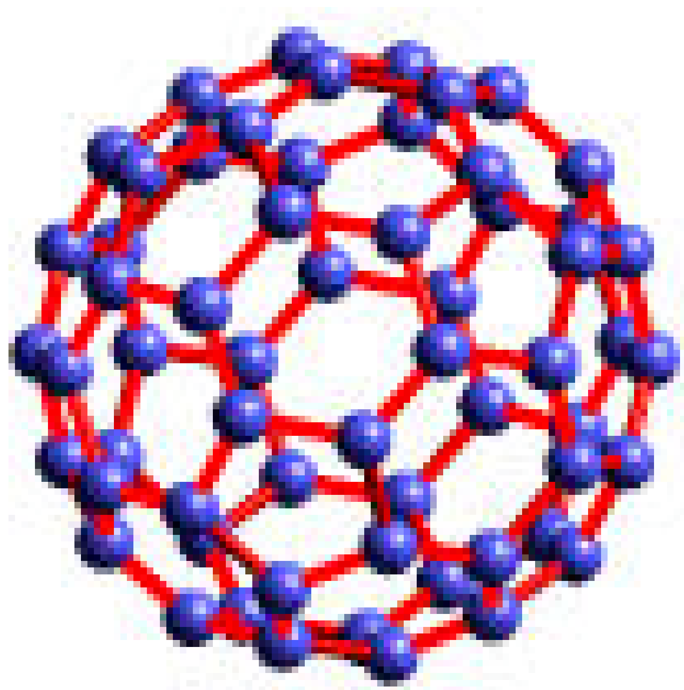
New developments in carbon materials

KROTO, CURL AND SMALLEY
(Nobel Prize 1996)

Discovery of C_{60}

Buckminsterfullerene

The "buckyball" molecule



New developments in carbon materials

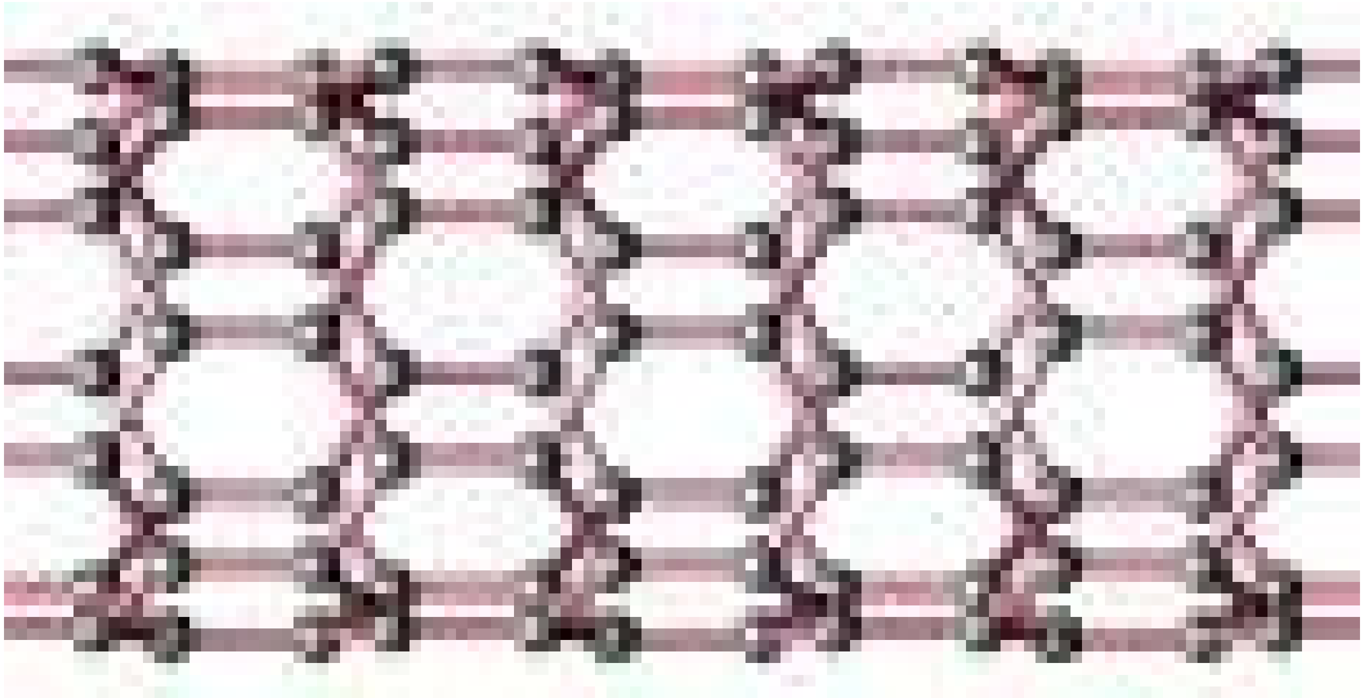
Discovery of C_{60}

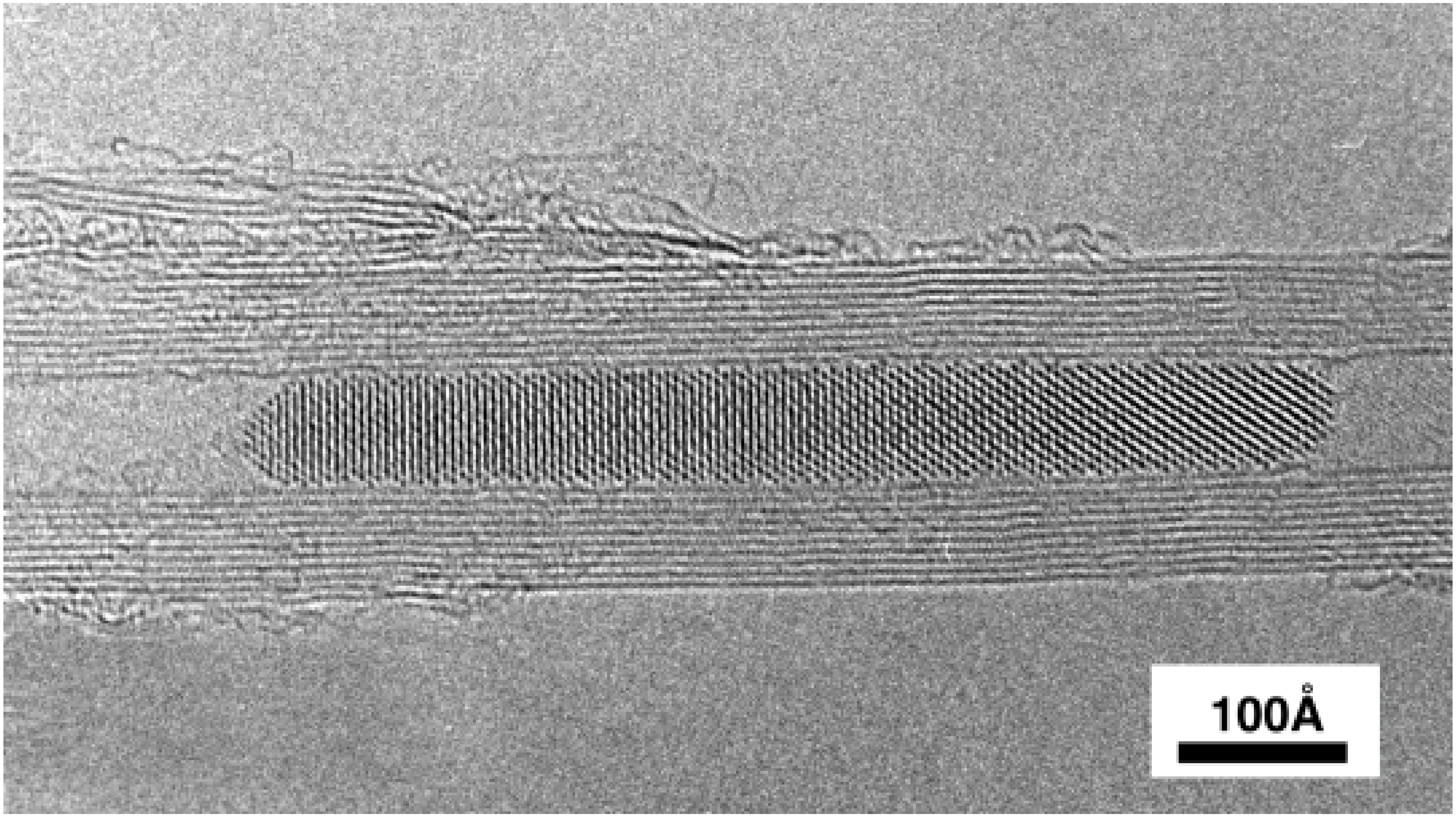
Buckminsterfullerene

The "buckyball" molecule

Discovery of carbon nanotube structures

IIJIMA 1991



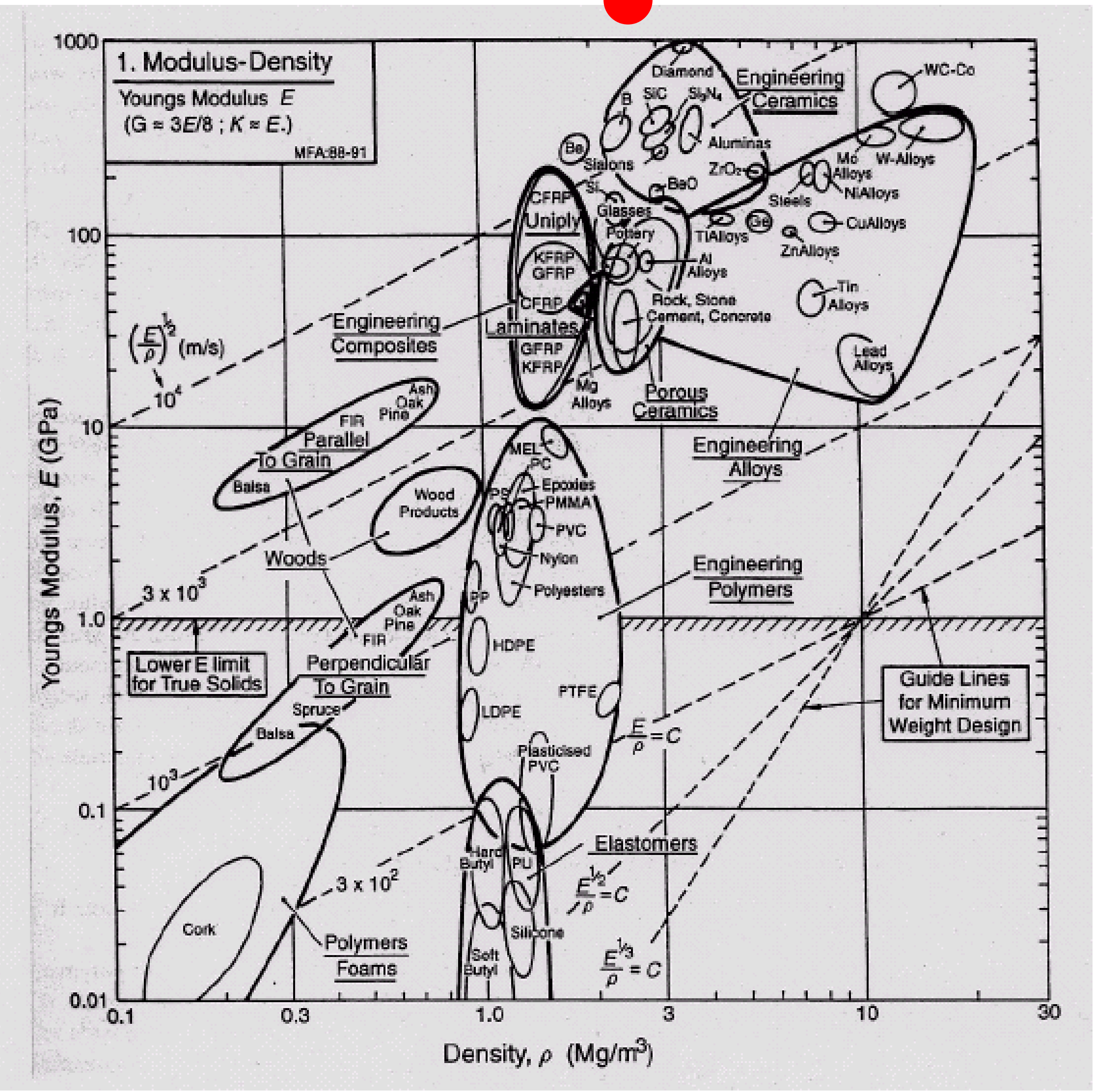

100Å

New developments in carbon materials

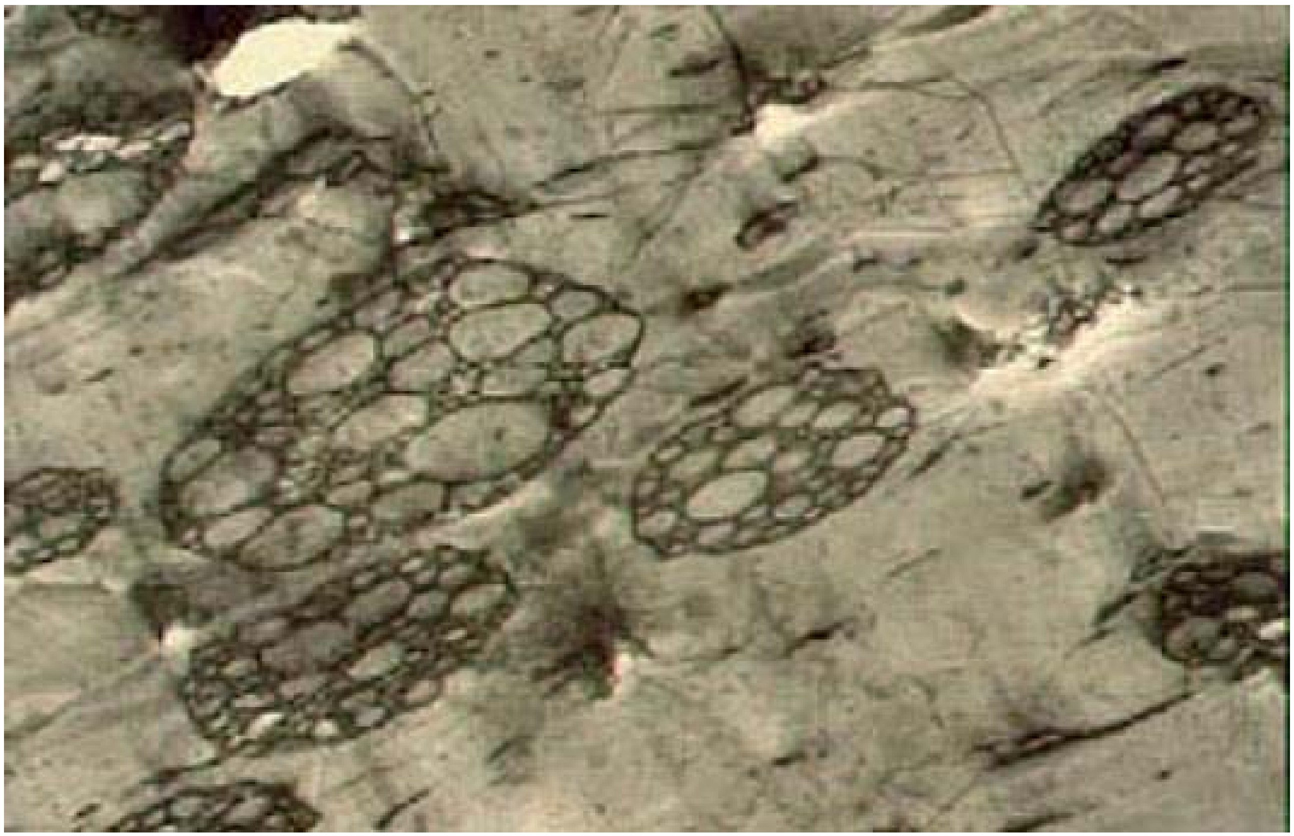
Carbon nanotube structures

Young's Modulus (SWNT)	~ 1 TPa
Young's Modulus (MWNT)	1.28 TPa
Maximum Tensile Strength	~30 GPa

Ashby diagram:
Young's modulus–Density
from Ashby
Materials Selection in
Mechanical Design
2nd edn p37



ABS microstructure



Polymer alloy/blend: rubbery inclusions in glassy matrix