Lecture 8

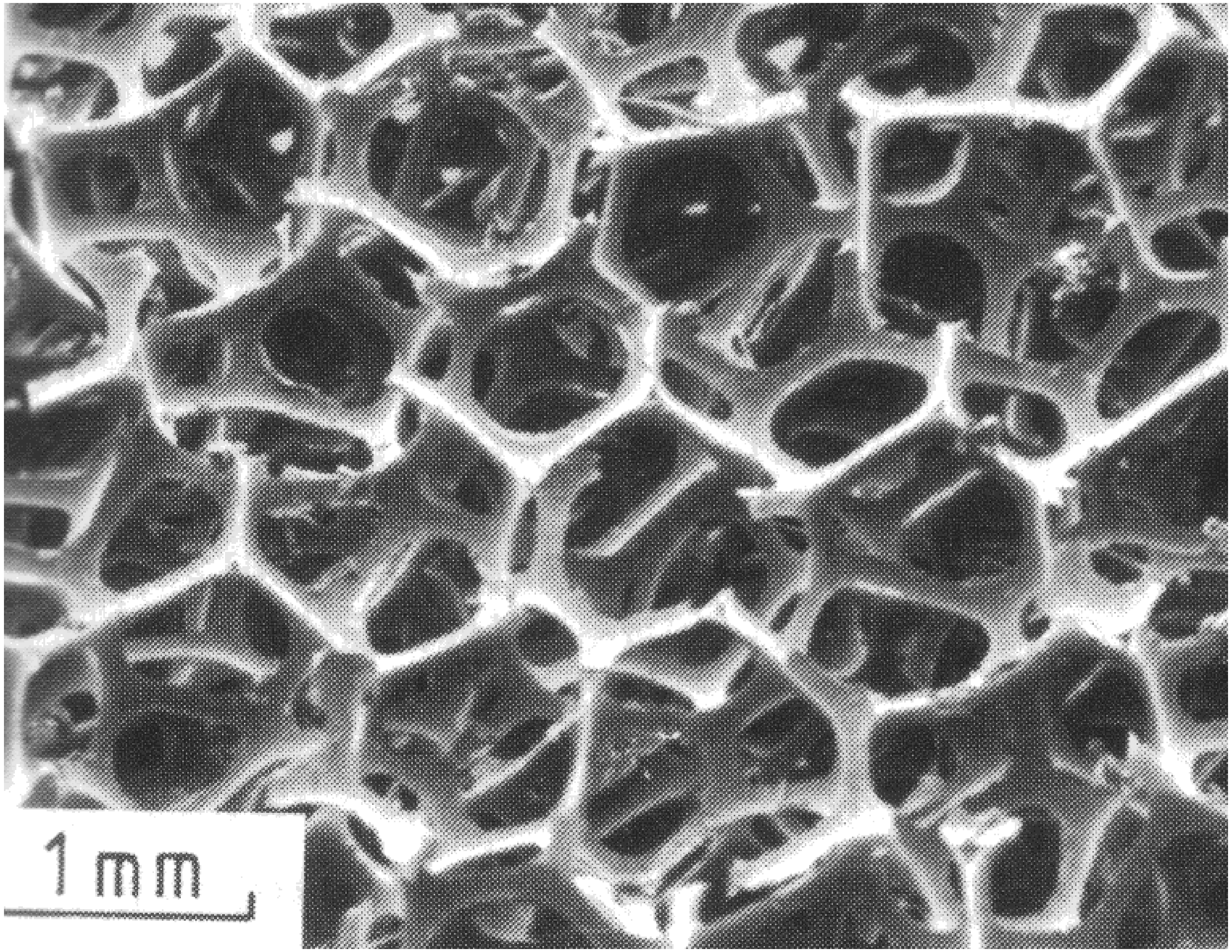
Polymer foams
Tissue scaffolds

Foams

- Low density material

‘composite’ consisting of a polymer matrix filled with a gas (air or nitrogen)

Example microstructure



Applications

Wide range of applications -

thermal insulation - coffee cups to space shuttle booster rockets

packaging - energy absorption, low density

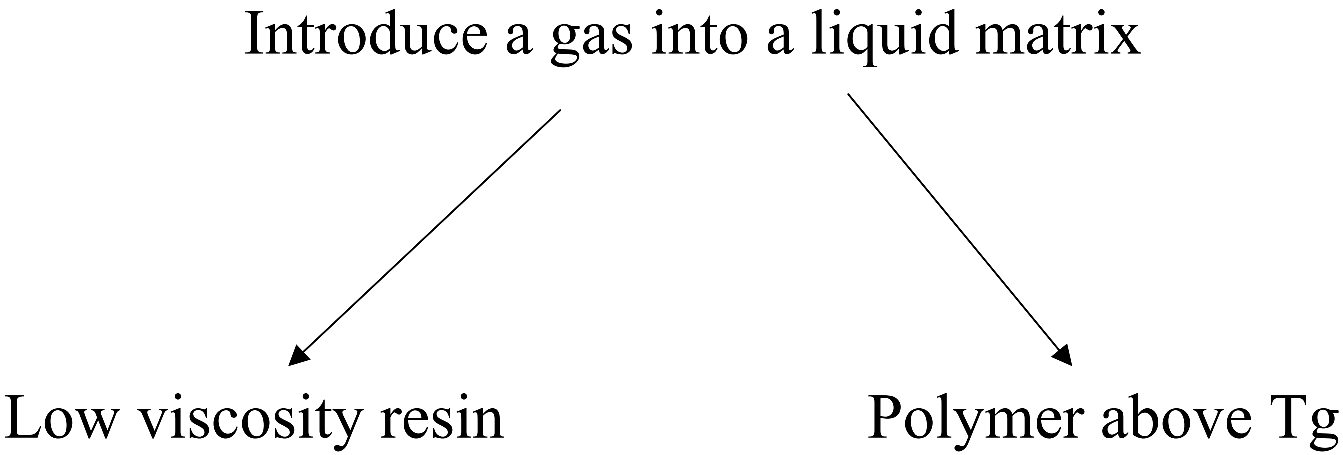
buoyancy - trapped air, low density - floatation

structural - wood, bone and coral. Can be a sandwich -e.g. leaves

Waterproof fabrics - foamed PTFE - Goretex.

Filters - allow air to move but not bacteria

Production



Introduce a gas into a liquid matrix

Low viscosity resin

Polymer above Tg

⇨ Gas generation

Gas generation

CFC - boil at 24ºC (1 bar)

Carbonated drinks bottles

Boil volatile liquids
Low pressure release of dissolved gases
Chemical decomposition
Mechanical stirring
Removal of fillers

reaction

Add salt/sugar and remove by dissolving out

Stabilisation of the foam structure

Need to rapidly increase the viscosity of the matrix

- Cooling (thermoplastic)
  - Below Tg
  - Below Tm
- Cross-linking (thermoset)

How much air?

Typical density of an unfoamed polymer is approximately 1000 kg m^{-3}

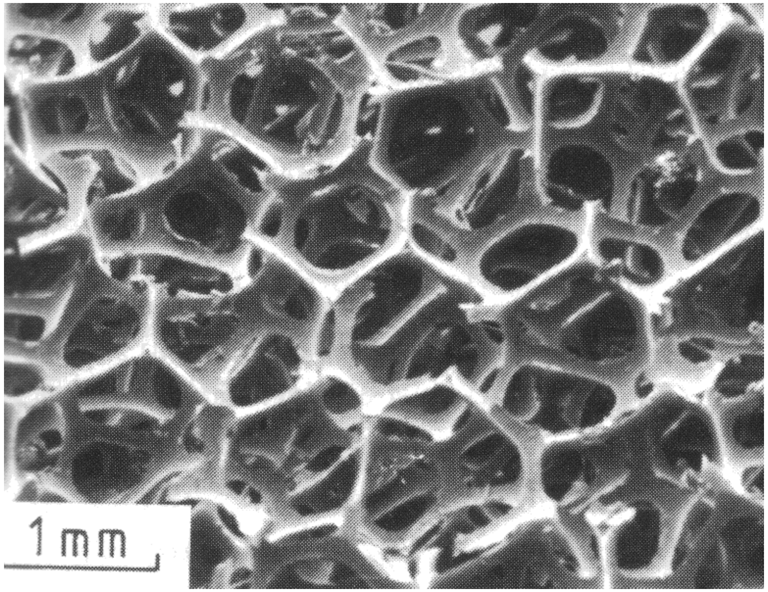
Low density foam ≈ 30 kg m^{-3} - 97% air
High density foam ≈ 400 kg m^{-3}

Examples

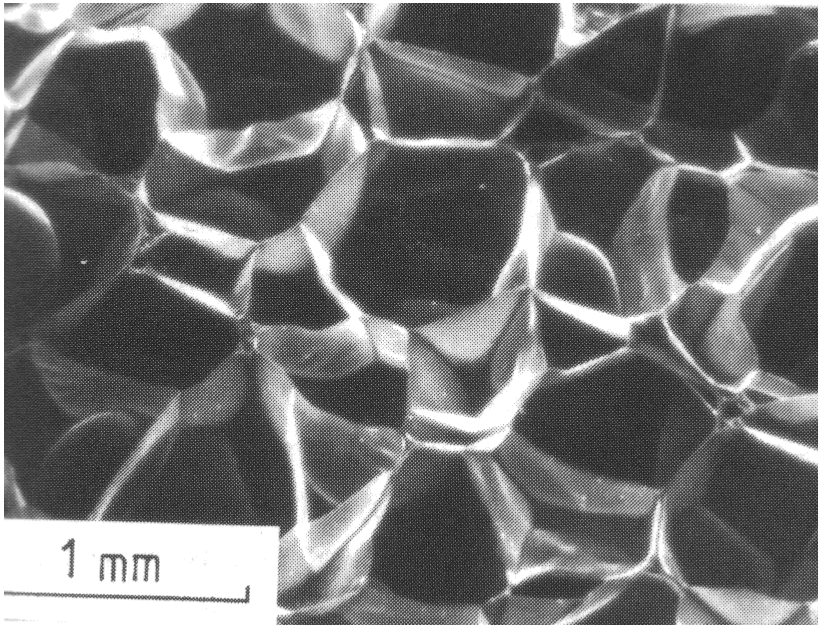
PU foam - gas generation by volatile liquid then cross-linked

PVC foam - gas generation by volatile liquid then cooling to below Tg

Foam microstructures



Open Cell



Closed cell

Culinary Examples

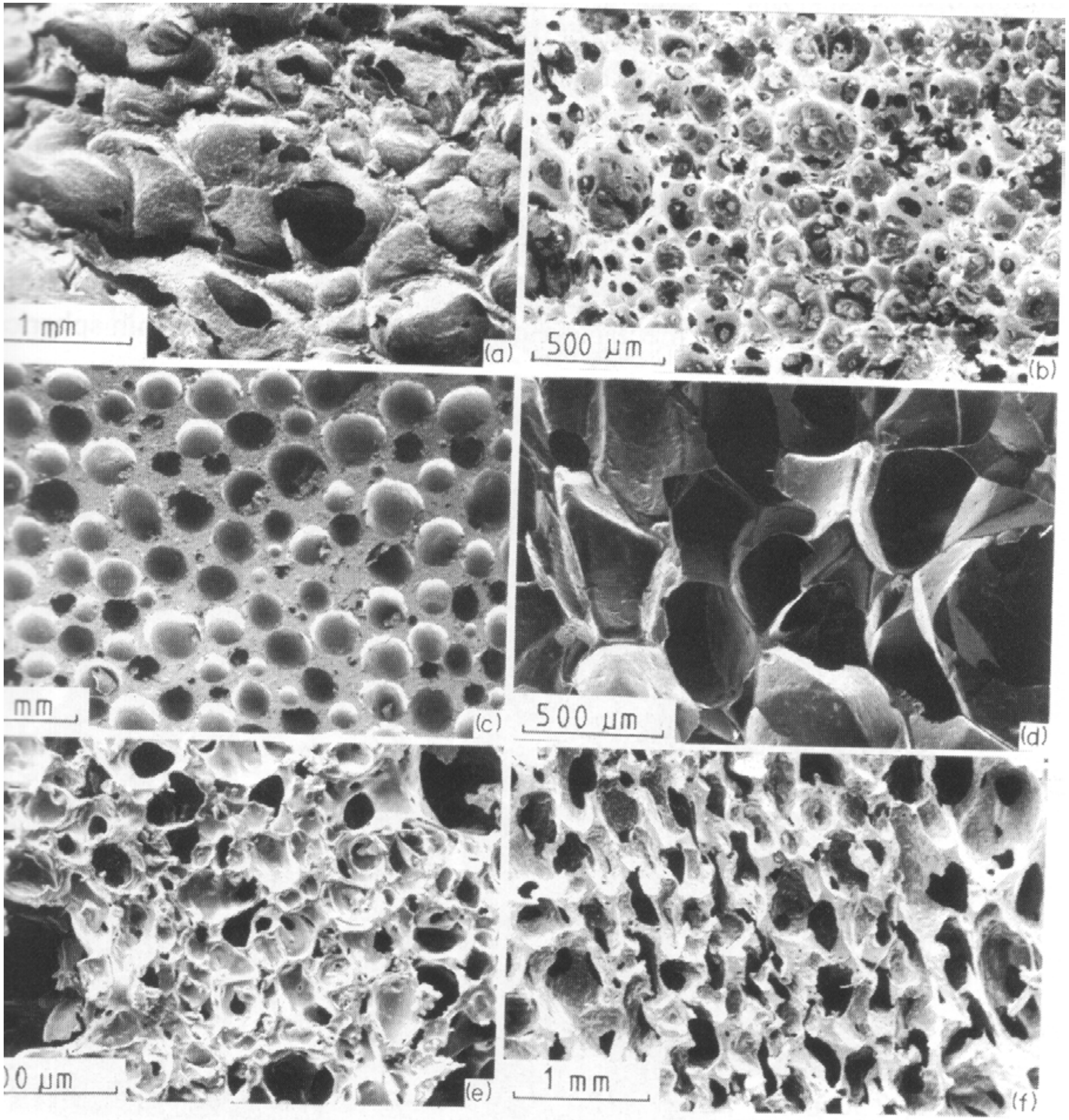
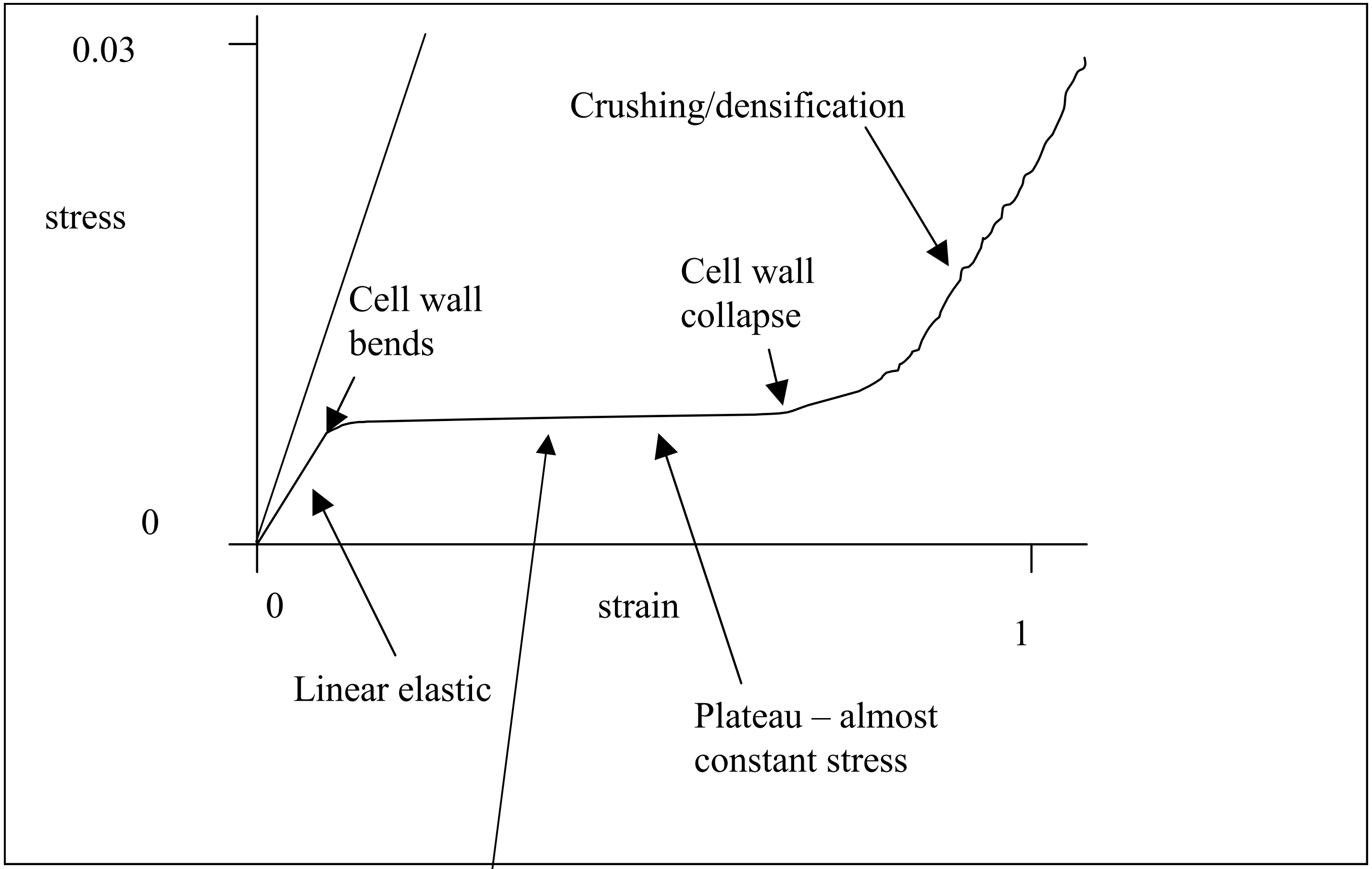


Figure 2.7 Food foams: (a) bread, (b) meringue, (c) chocolate bar, (d) junk food crisp, (e) Malteser, (f) Jaffa cake.

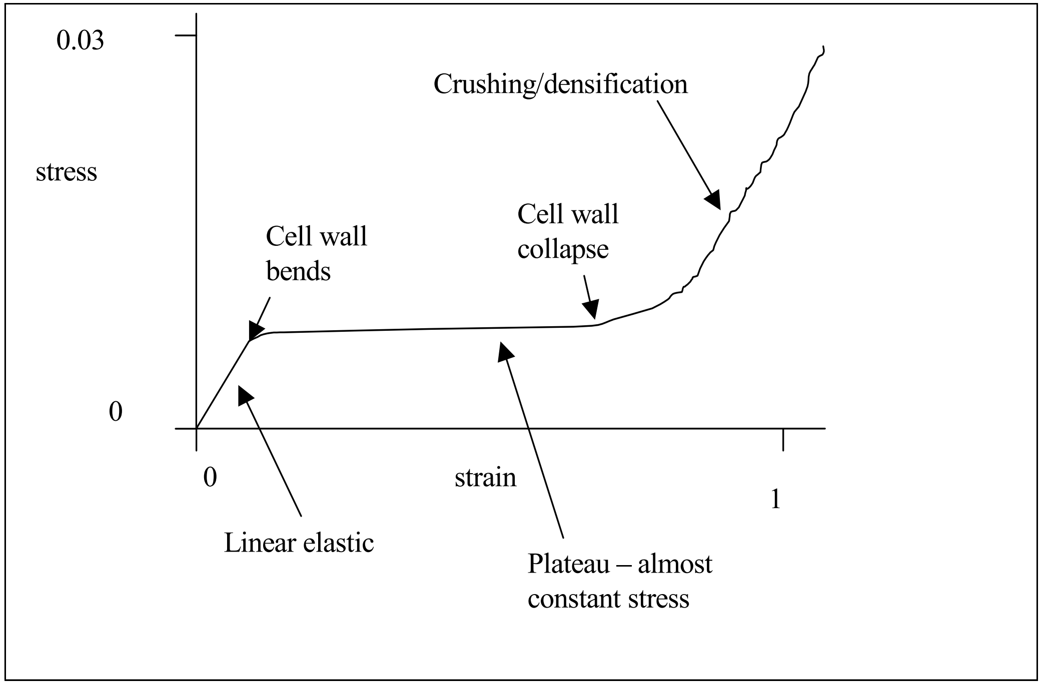
Mechanical properties - compression



Energy absorption

Energy Absorption

Energy is absorbed as the cell walls bend plastically or buckle or fracture. The stress is limited by the long flat plateau on the stress-strain curve



Work is done when a force is applied. Work done / unit volume in deforming the foam to a strain ε is simply the area under the stress strain curve

$$W = \int_{0}^{\varepsilon} \sigma(\varepsilon) dt$$

“cell collapse by buckling, yielding or crushing allows large energy absorption at near constant load”

Applications II

Not only used in trainer insoles, may be used for tissue scaffolding.

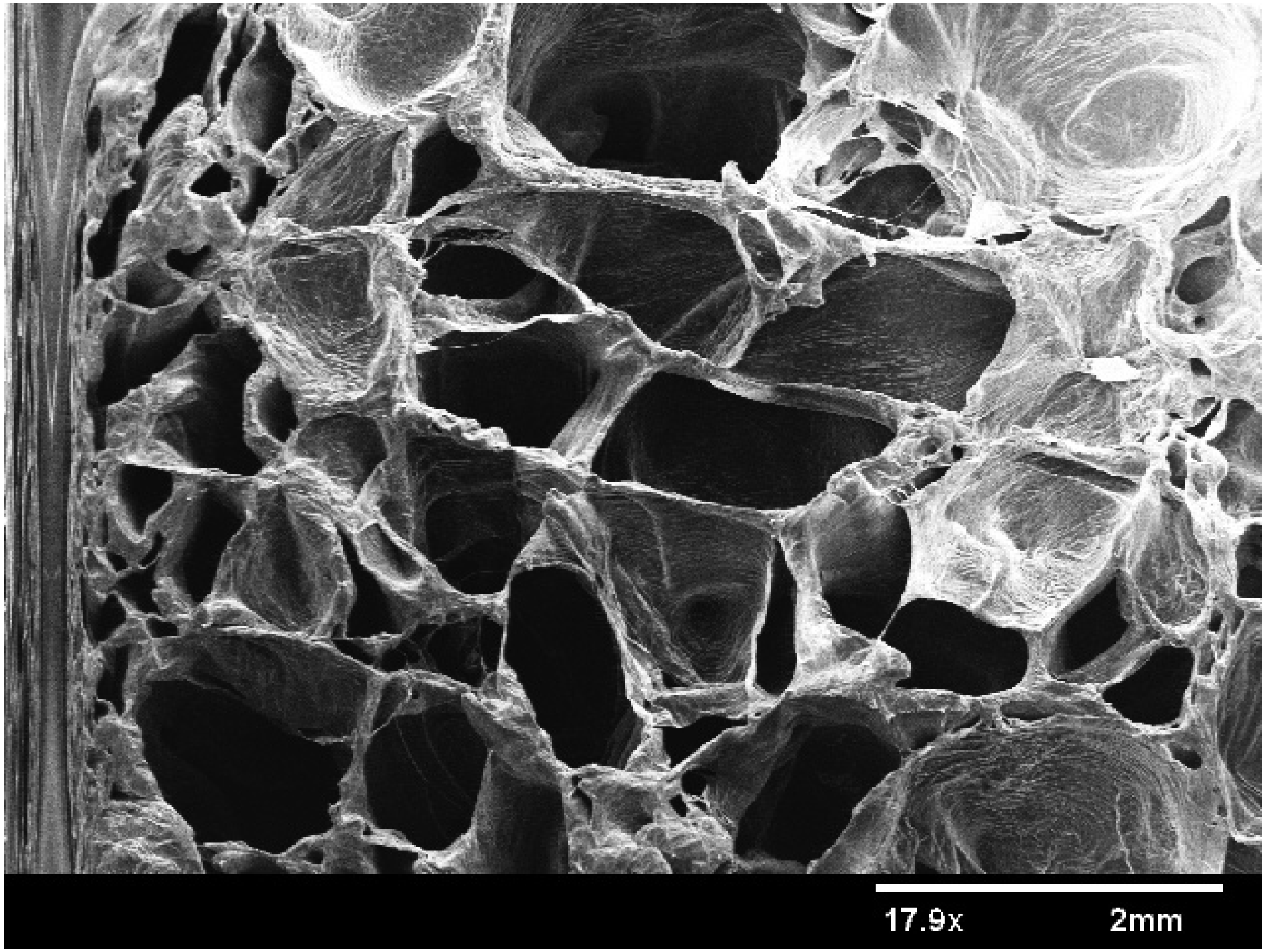
Tissue scaffolds provide a matrix for the attachment of cells in tissue engineering (artificial organs)

Scaffold must be porous, biodegradable and biocompatible.

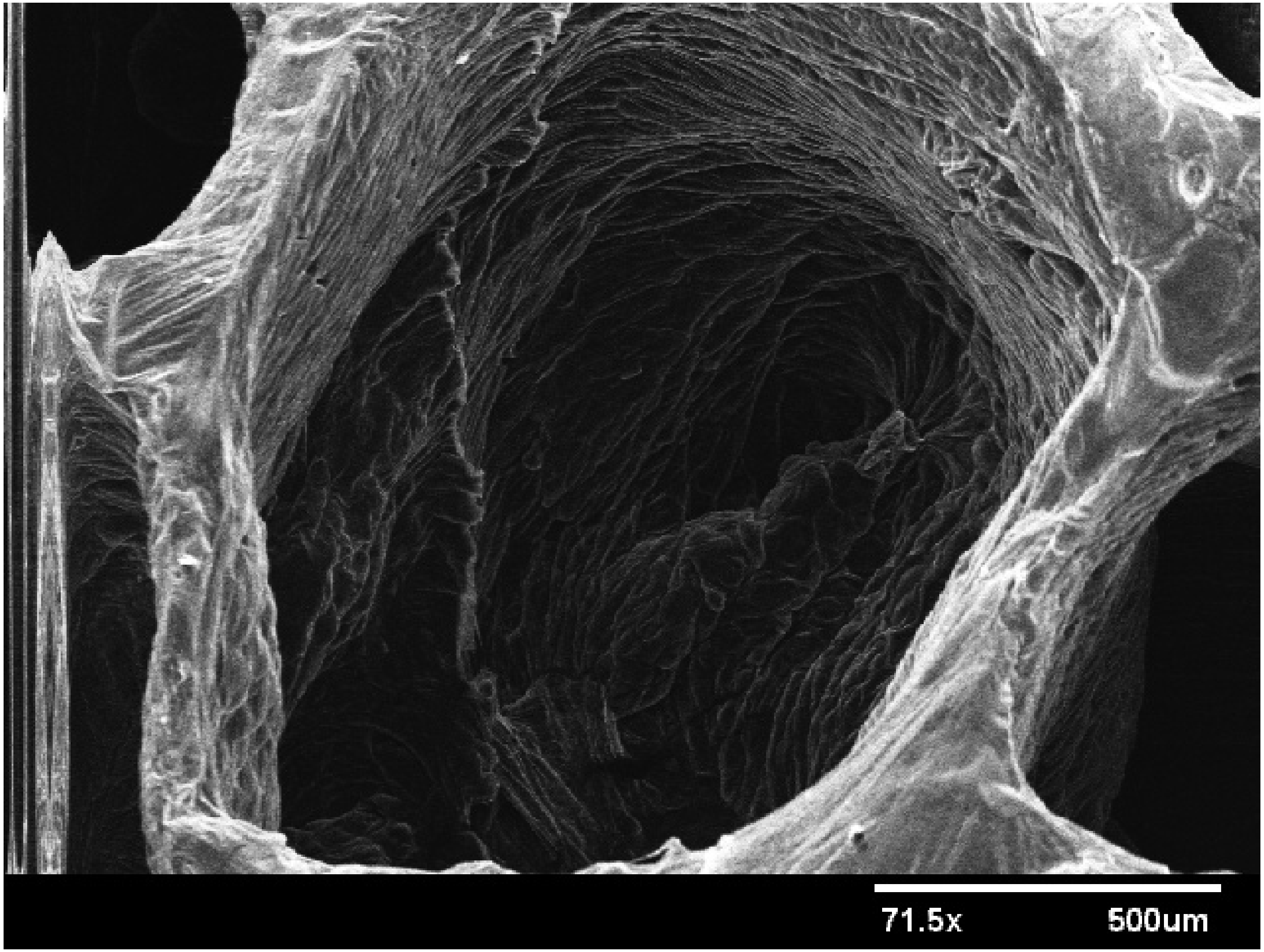
Wide range of biodegradable polymers, PLA, PLGA, PCL and PHB (not all are approved for use in the human body).

Foaming a biodegradable polymer provides a way of creating a tissue scaffold

PCl - Polycaprolactone



Lamellar structures

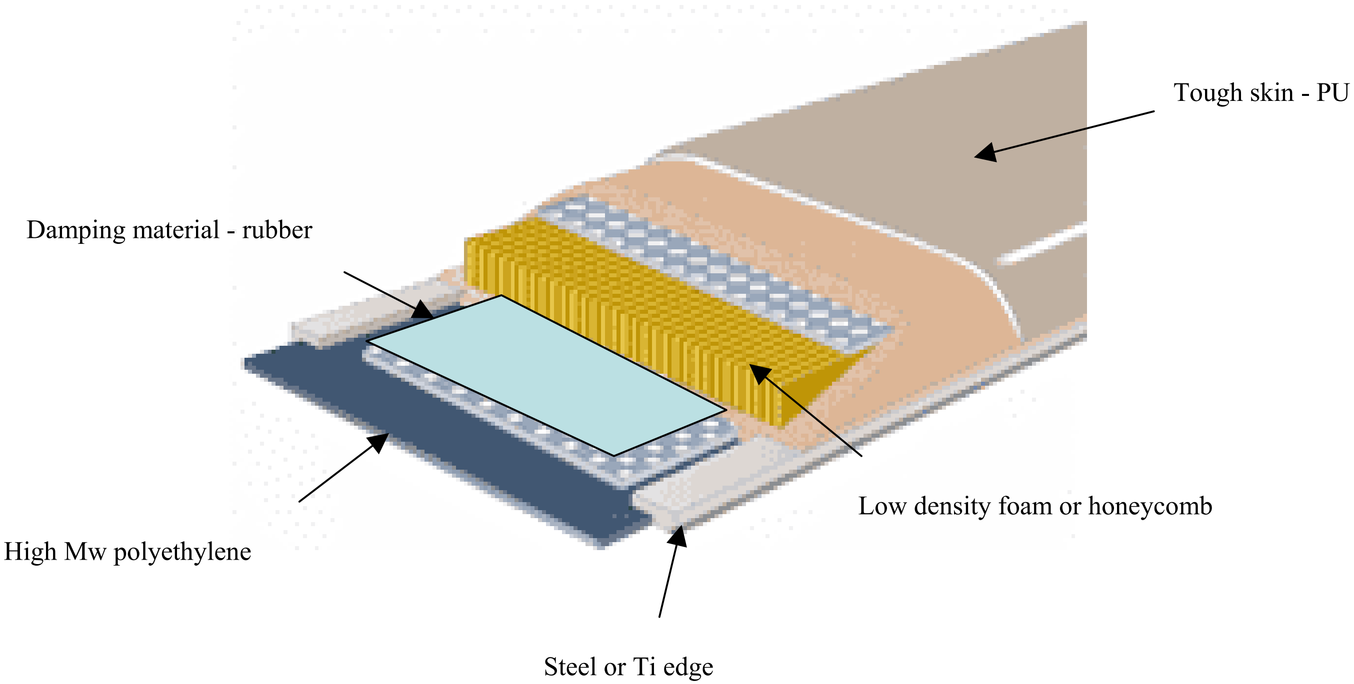


Class (lecture) tutorial

Lecture 8

Introduction to polymer composites I

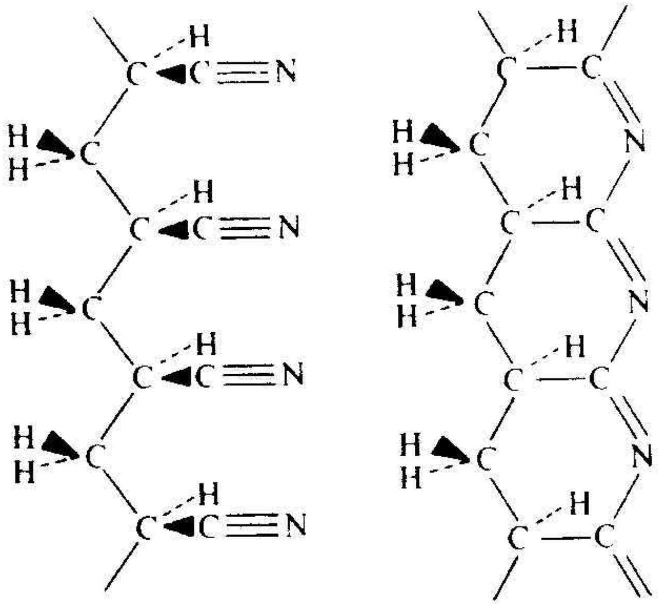
There are many sports applications for these materials. Typical ski construction



Fibre Production

- There are three main production routes:
  - PAN (polyacrylonitrile)
    - Mesophase pitch
    - pyrolytic deposition

Focus on
PAN



Transformation of a PAN molecule into a rigid ladder polymer.

PAN

Effect of heat treatment

Fibres and matrices

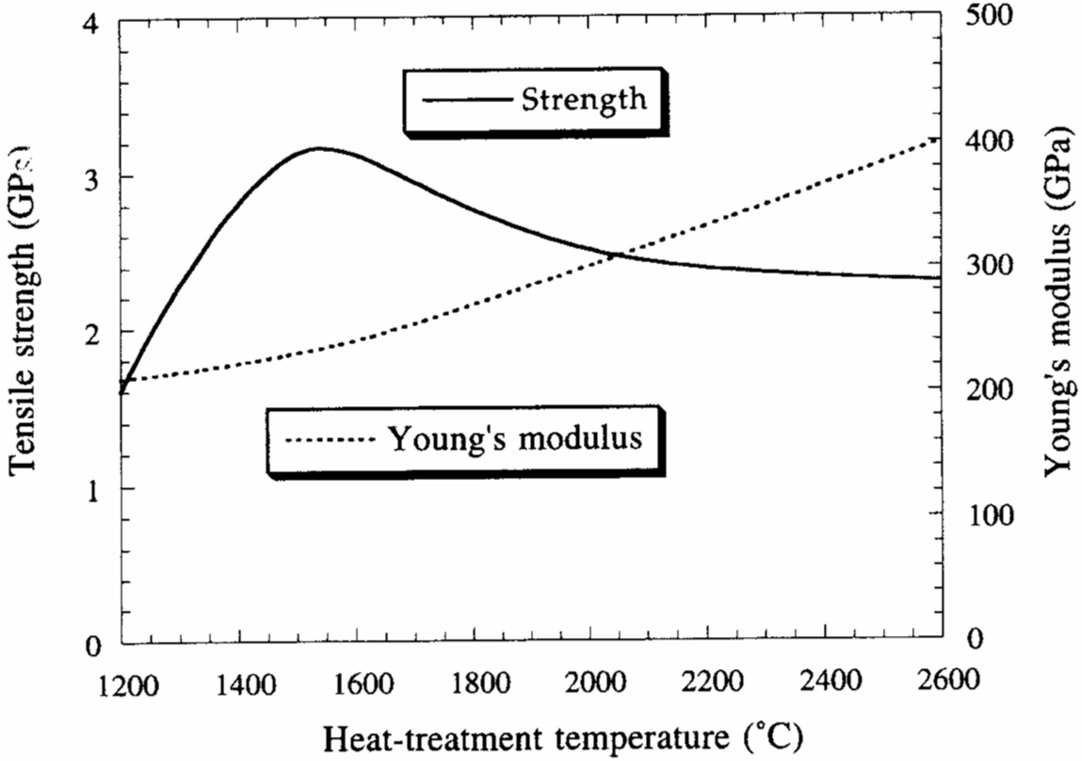
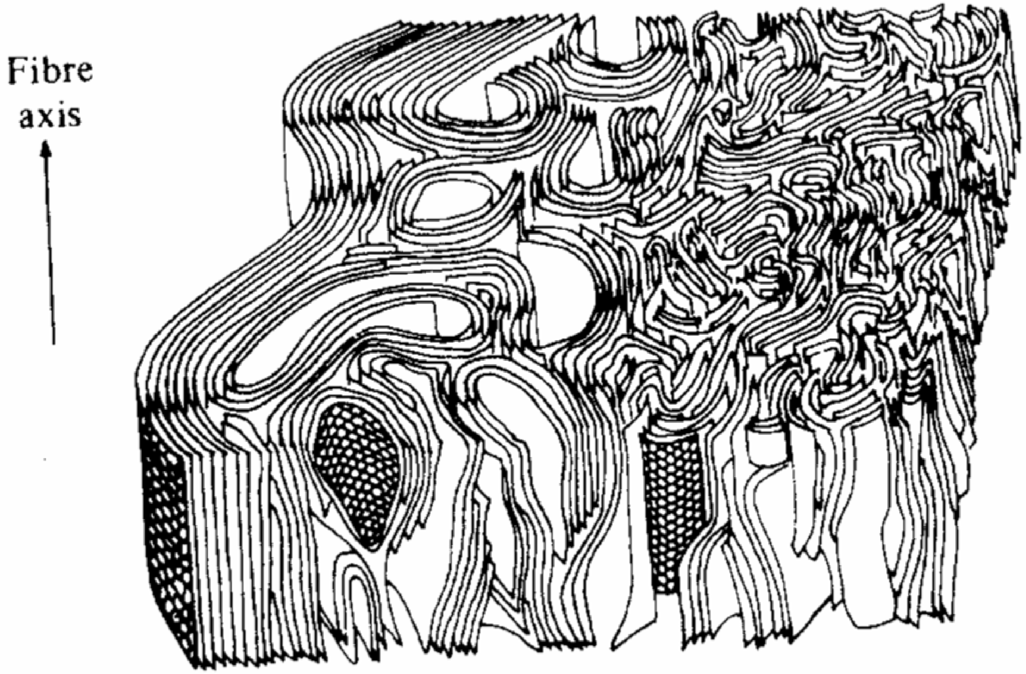


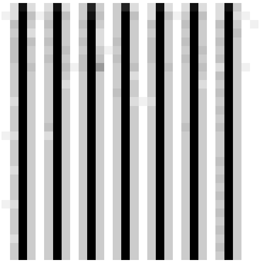
Fig. 2.3 Effect of heat-treatment temperature on the strength and Young's modulus of carbon fibres produced from a PAN precursor. (From Moreton *et al*. 1967).



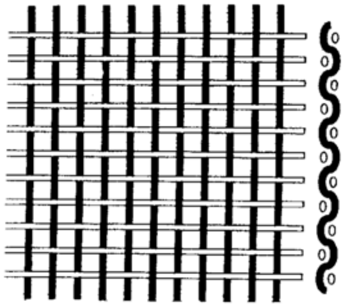
Schematic representation of the structure of carbon fibres. (From Bennett and Johnson, 1978).

Fibre Architecture

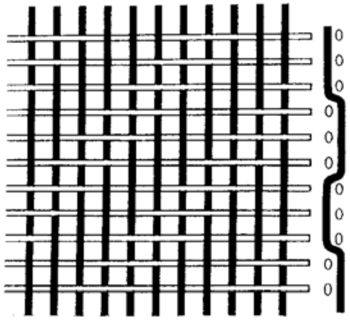
- Uni directional (UD)



- Woven:
  - plain weave
  - twill weave



PLAIN WEAVE.



TWILL WEAVE.

Matrices

- Polymeric:
  - Epoxy
  - polyester
  - nylon
  - PP
  - PEEK

Table 2.5 *Selected properties for different types of matrix*

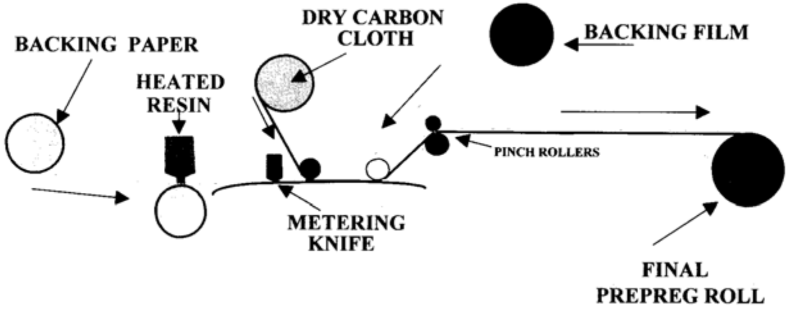
Matrix	Density ρ (Mg m^{-3})	Young's modulus E (GPa)	Poisson's ratio ν	Tensile strength σ_* (GPa)	Failure strain ϵ_* (%)	Thermal expansivity α (10^{-6} K^{-1})	Thermal conductivity K (W m^{-1} K^{-1})
Thermosets							
epoxy resins	1.1–1.4	3–6	0.38–0.40	0.035–0.1	1–6	60	0.1
polyesters	1.2–1.5	2.0–4.5	0.37–0.39	0.04–0.09	2	100–200	0.2
Thermoplastics							
Nylon 6.6	1.14	1.4–2.8	0.3	0.06–0.07	40–80	90	0.2
polypropylene	0.90	1.0–1.4	0.3	0.02–0.04	300	110	0.2
PEEK	1.26–1.32	3.6	0.3	0.17	50	47	0.2
Metals							
Al	2.70	70	0.33	0.2–0.6	6–20	24	130–230
Mg	1.80	45	0.35	0.1–0.3	3–10	27	100
Ti	4.5	110	0.36	0.3–1.0	4–12	9	6–22
Ceramics							
borosilicate glass	2.3	64	0.21	0.10	0.2	3	12
SiC	3.4	400	0.20	0.4	0.1	4	50
Al_2O_3	3.8	380	0.25	0.5	0.1	8	30

Table 2.6 *Comparison between thermosets and thermoplastics of properties relating to dimensional and environmental stability*

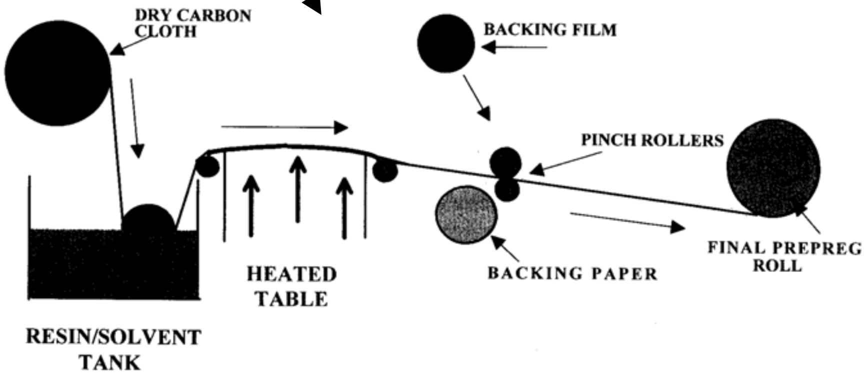
Property	Thermosets		Thermoplastics		
	epoxy resins	polyester resins	Nylon 6.6	polypropylene	PEEK
Melting temperature (°C)	—	—	265	164	334
Distortion temperature (°C)	50–200	50–110	120–150	80–120	150–200
Shrinkage on curing (%)	1–2	4–8	—	—	—
Water absorption (24h @ 20 °C) (%)	0.1–0.4	0.1–0.3	1.3	0.03	0.1
Chemical resistance	Good, attacked by strong acids	Attacked by strong acids and alkalis	Good, attacked by strong acids	Excellent	Excellent

Fabrication

- Wet lay up
- Pre-preg:



HOT MELT METHOD

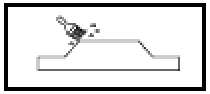


SOLVENT DIP METHOD

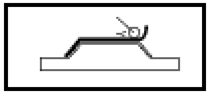
Curing

- Two main methods:
  - Vaccum bag
  - Autoclave

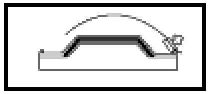
Preparation



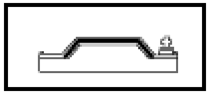
Apply release agent to polished Al tooling block- Frekote



Lay up composite

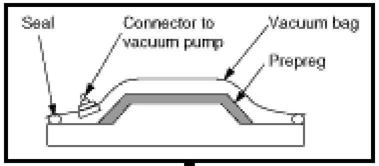


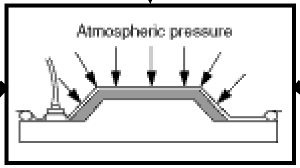
Seal outer edge of the tooling block with adhesive gum/tape and cover with vacuum bag



Apply vacuum and check for leaks

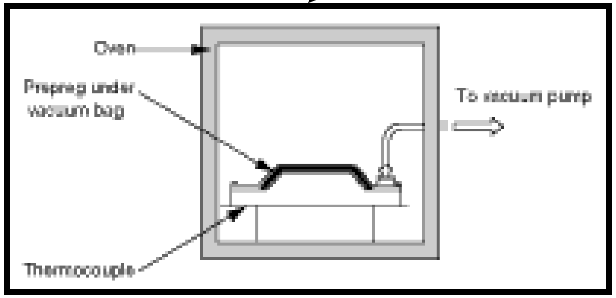
Vacuum bag - Autoclave

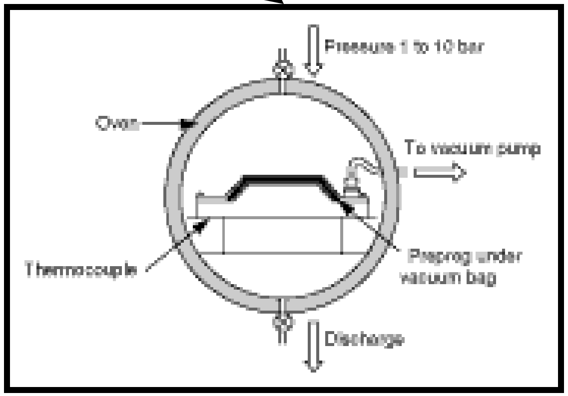




Autoclave

Vacuum bag





Curing reaction

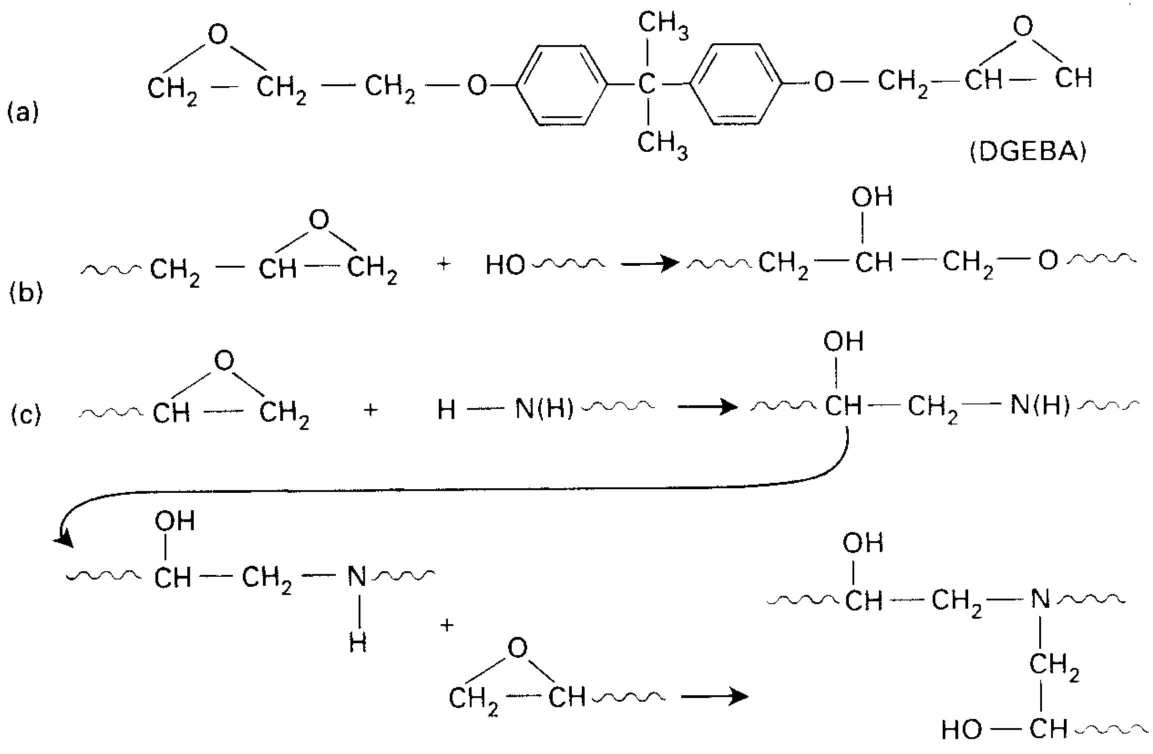


Fig. 5.5. Structures and mechanisms relevant to the formation of an epoxy resin from DGEBA and bisphenol A.

Lecture 9

Introduction to polymer composites II

Case study

Review of course content

Introduction to case studies
The windsurfing mast

Aims of Case Study

- Suggest a number of potentially suitable materials for the construction of a windsurfing mast given the design criteria.
- Describe the production methods for the mast based on the selected construction material

Learning Objectives

By the end of this case study, students should be able to:

-identify materials used in the construction of a windsurfing mast and explain why they have been chosen in terms of the design criteria of the mast

-Quantify the effect of fibre type and winding pitch on the stiffness of a mast

- describe applicable manufacturing processes.

The windsurfing rig

Universal
Joint

Mast

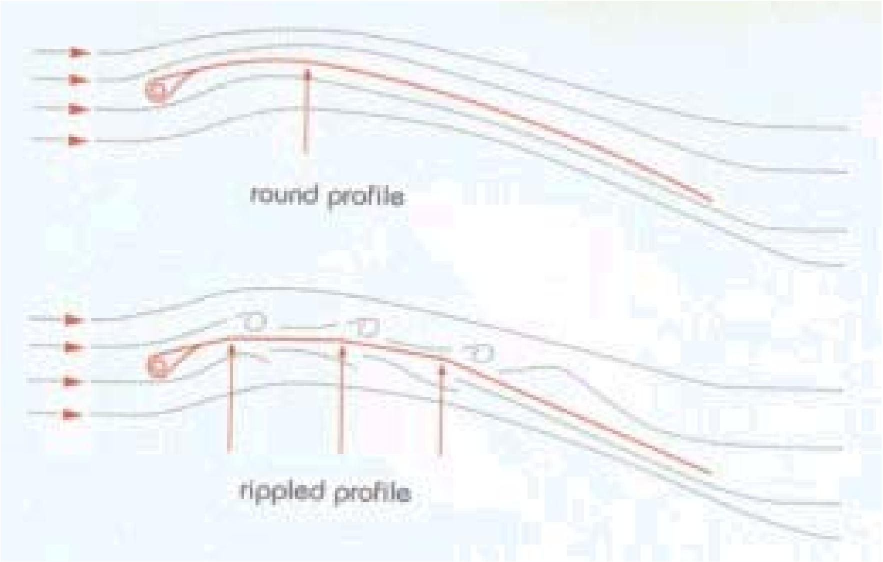
Battens

Boom

Mast Technology

Sail works as an aerofoil. The shape is maintained by two forces.

One acting along the boom and the other acting towards the base of the mast



The mast acts as a backbone for these forces to act against

Design requirements

- The ideal mast
  - High stiffness and strength
  - Able to flex with pressure variations
  - Low weight
  - Good environmental resistance
  - Value for money?

Materials Selection

- Wide variety of possibilities
  - Wood
  - Metal
  - Polymers
  - Composites
- What are the masts actually made from?

→ Internet

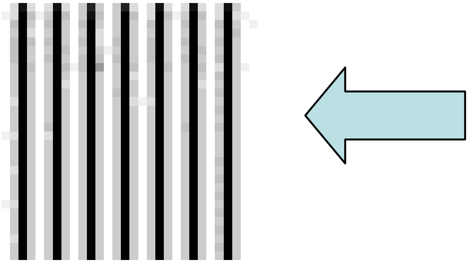
Keyword list

- Carbon fibre composite
- Epoxy resin
- Glass fibre composite
- Filament winding
- UD + woven fibres
- High stiffness
- High strength
- Low density
- Autoclave
- Vacuum bag

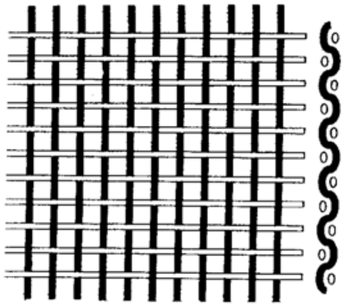
Learn about 4 of the above by looking at the some of the mechanical properties

Composite Architecture

- Uni directional (UD)



- Woven:
  - plain weave
  - twill weave



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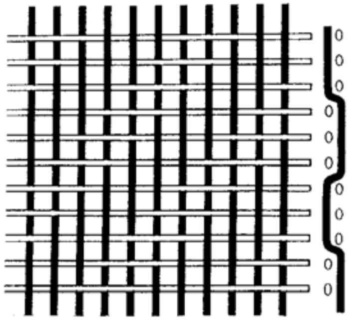


TWILL WEAVE.

Pre-preg

Pre-impregnated

Carbon fibres are mostly supplied with the resin/matrix material already included

Mechanical properties

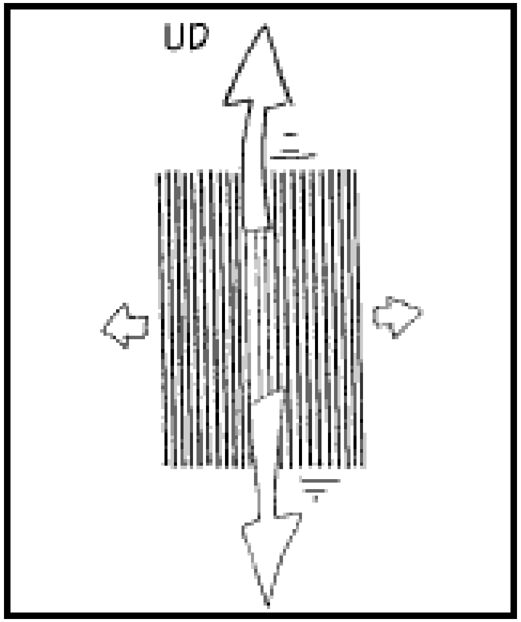
For a force applied along the fibres

$$E = (1 - f)E_{matrix} + fE_{fibre}$$

Modulus - composite

modulus – matrix or resin

modulus - fibre



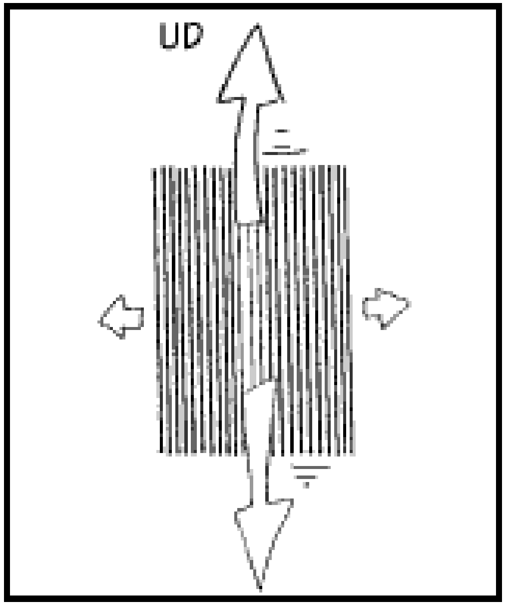
f=fibre volume fraction

f=0.7	*Epoxy resin E = 2.4 GPa*	*Eglass = 50 Gpa* *Ecarbon(intermediate) =100 Gpa* *Ecarbon (high stiffness) = 230 GPa*

Mechanical Properties

For a force applied across the fibres

$$E = \left[\frac{f}{E_{fibre}} + \frac{(1-f)}{E_{matrix}} \right]^{-1}$$



Challenge: use the data supplied to work out E along and across the fibres in a UD composite

Mechanical Properties

Note on the units of modulus - GPa

1 GPa = 1 x 10^9 Pa

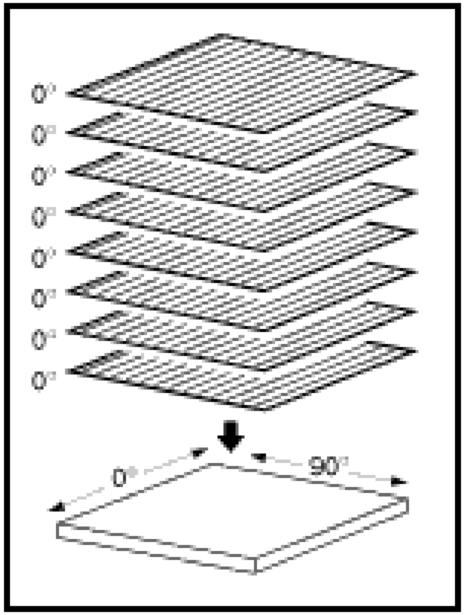
Pa = Pascals (measurement of stress)

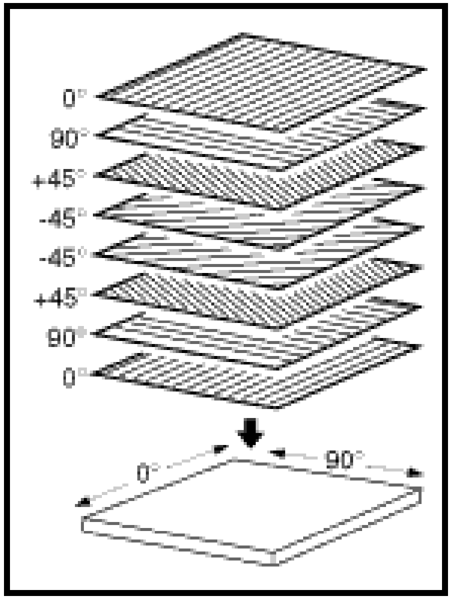
Stress = force / area

Describing a laminate

Composite structures are laminated. Individual layers are stacked up to increase stiffness and strength

- Find the long axis, define this as 0°
- From one face of the laminate describe the orientation of each lamina.



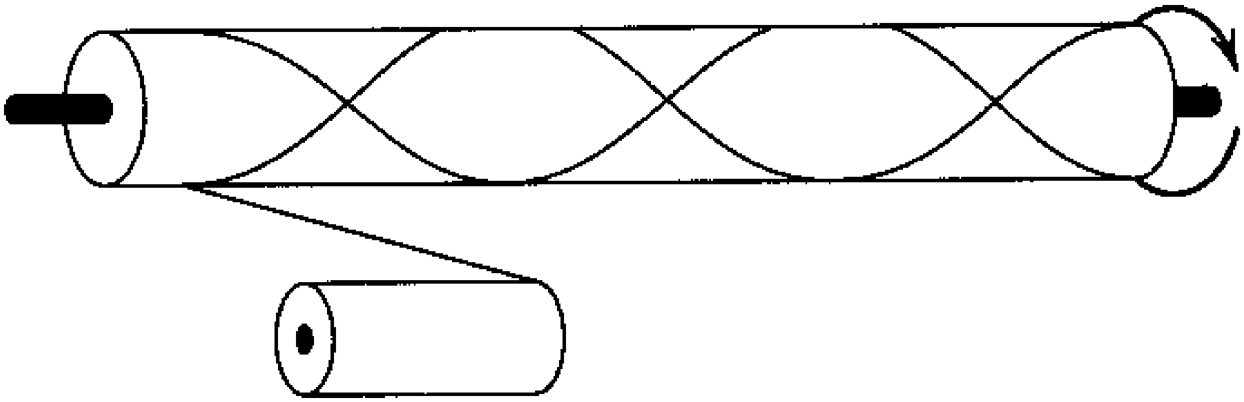


E. g. 0 ° 0 ° +45 ° -45 ° 90 ° 90 ° -45 ° +45 ° 0 ° 0 °

$[0_2 / \pm 45 / 90]_S$

Predicting the mechanical properties is difficult

Mast can be made using filament winding – more details in session 3



Helical winding

<u>Inner and outer diameter of mast may not be constant</u>

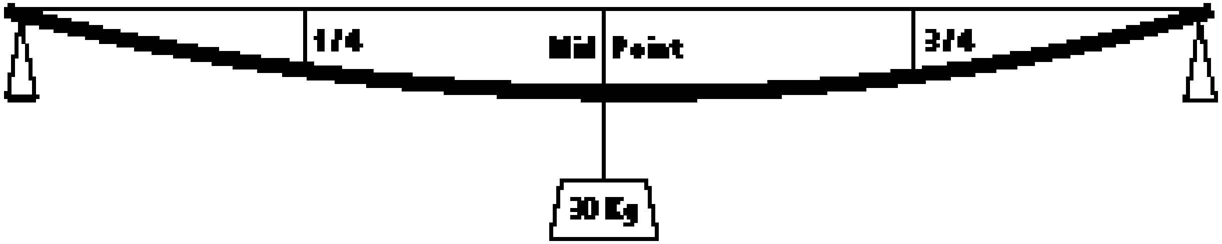
Can we make an assumption?

We need to calculate a modulus for the composite, but how can we simplify the calculation?

Assume

The mast has a constant cross section, (inner and outer diameter are constant)

Calculation – MCS
Mast check system



$$MCS = \frac{length \times 10}{d}$$

d = mid point deflection / cm

Length / cm

Mast must have an MCS of 80 and length 400 cm

Q. What is the expected mid point deflection?

Mast diameter = 37mm and wall thickness = 2mm

$$d = \frac{mgL^3}{48EI}$$

$$I = \frac{\pi}{64}\left(d_o^4 - d_i^4\right)$$

m – mass / kg, L – length / m

d_o – outer diameter / m
d_i – inner diameter / m

Calculate the required modulus of the composite material

Mast/composite structure production

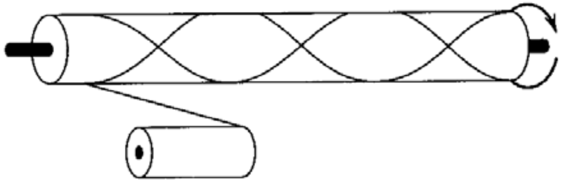
Summary of progress

Filament winding

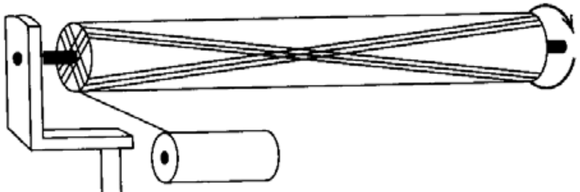
Autoclave vs vaccum bag

Filament winding

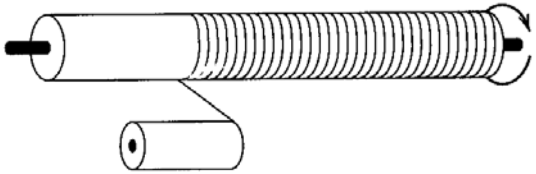
Strands or tows of fibre are dipped in a resin (epoxy) bath and then wound onto a mandrel prior to curing in a vacuum bag or autoclave



Helical winding

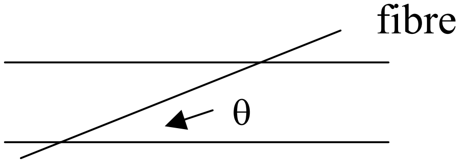


Polar winding



Circumferential winding

$$E = (\cos\theta)\left(E_m f_m + E_f f_f\right)$$



θ = winding pitch

f = volume fraction of fibre or matrix (m=matrix)

Filament winding

Use the modulus value that you have calculated following session 2 in the calculation of the required winding pitch.

What is the maximum attainable modulus from the filament winding process?

Production

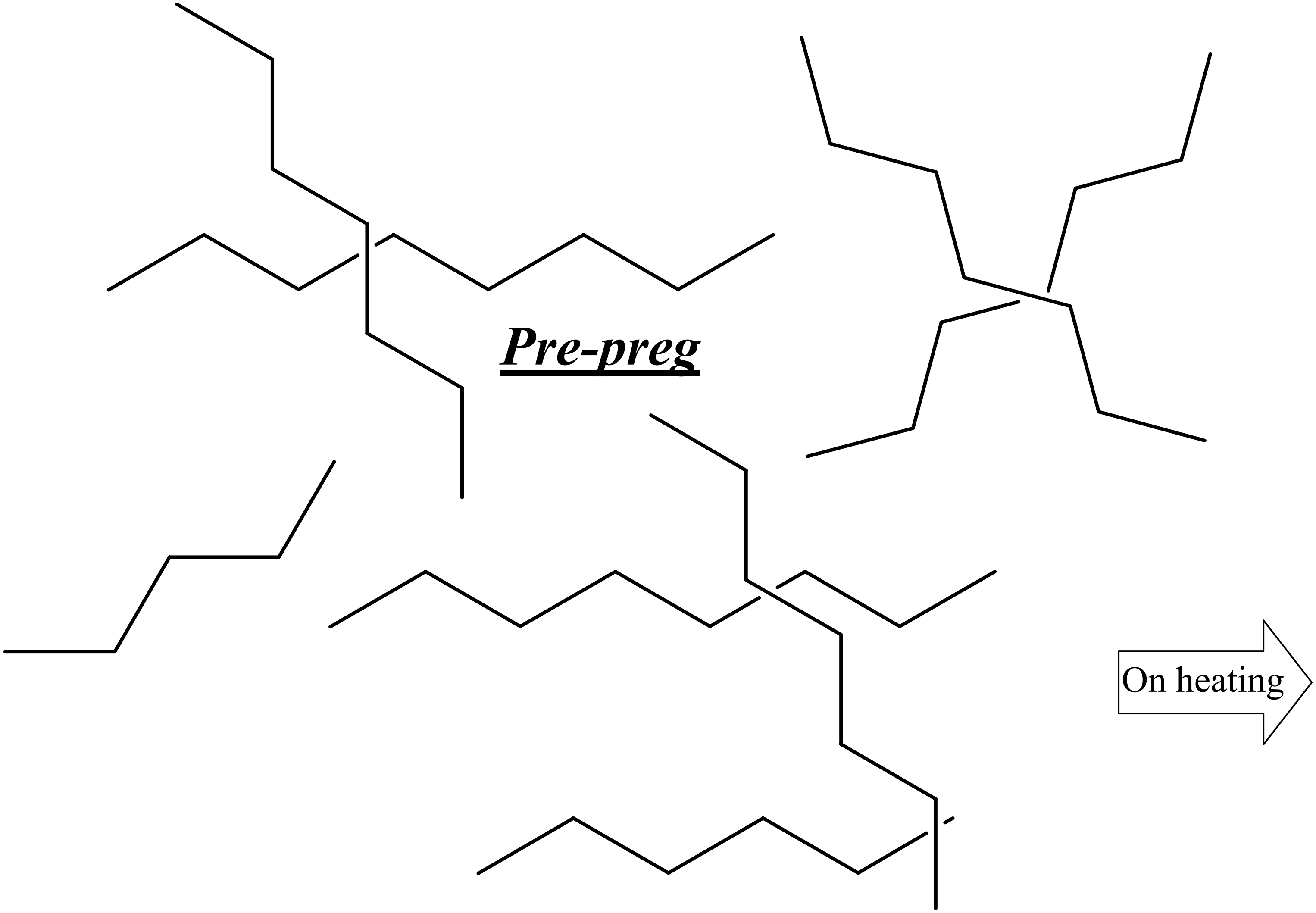
Composite material is supplied with the epoxy resin in a slightly ‘tacky’ state.

The resin must be transformed into a relatively high stiffness polymer (2.4 GPa) to provide the required structural properties for the composite (70GPa)

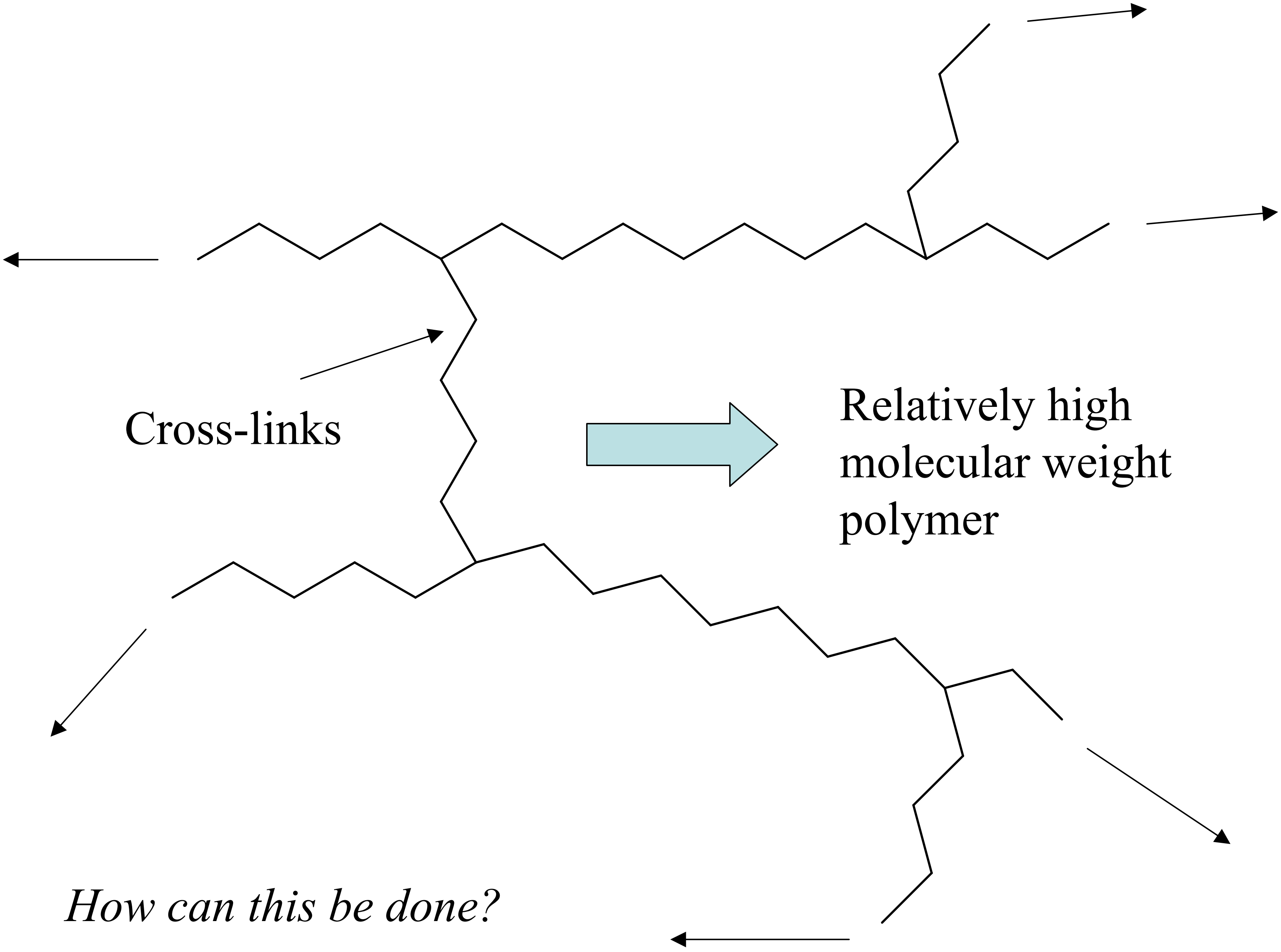
This process is called ‘curing’

What happens during the cure?

Pre-preg



Low molecular weight ‘oligomers’ 7 to 15 carbons long



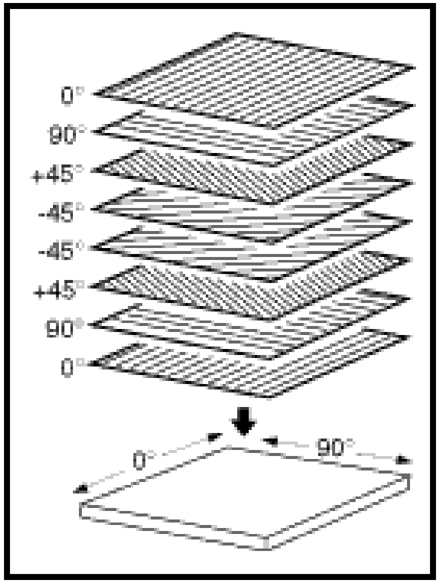
Cross-links

Relatively high molecular weight polymer

How can this be done?

Delamination

During the cure cycle, the resin flows under pressure and seals the gaps between the layers.



If a void is present, it can concentrate the force at that point – causing the layers to simply peel apart.

A problem if the mast breaks at sea!

Production

Based on what you have heard in this teaching session, what production process would you suggest for the fabrication of the mast?

Consider the costs. Vacuum bag system £2000. Autoclave £80000.

Identify the type of windsurfer that would purchase a mast made by an autoclave.

HINT: Think about how many you could sell and the unit cost

Report

1500 word report (about 4 pages) not including diagrams or summary

TITLE: Carbon fibre composites in the windsurfing mast

Main text: 12 point text size and 1.5 line spaced

200 word summary – 10 point, single line spaced, on page 1 below the title.

Report

Introduction – page 1 – background to the mast and the sport

Materials Selection – page 2 – design criteria, ideal materials, what properties they have.

Specification of the winding pitch – page 3 – outline the steps and working in the calculation

Mast production – page 4 how could the final product be made?

Conclusions – end of page 4 – bullet points

Conclusions

- Decide on the design requirements for the mast
- Select a range of materials based on these criteria
- *Refine selection based specific cases described*
- Choose a production process

Review of course content