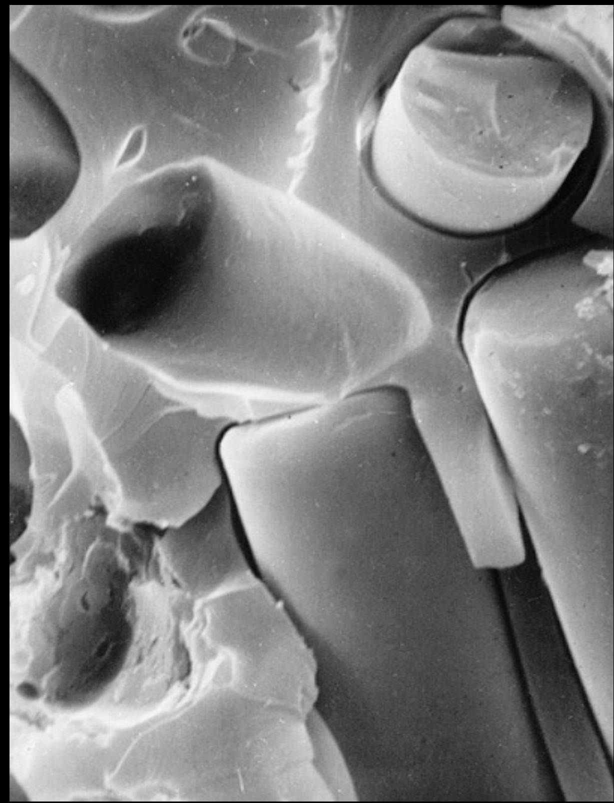


Composite materials

Composite – definition

- **Composite materials** (or **composites** for short) are engineered materials made from two or more constituent materials with significantly different physical or chemical properties which remain separate and distinct on a macroscopic level within the finished structure.

Learning outcomes

WHAT Framework
Materials
- Classifications
- Properties
- Small scale structure (microstructure)
- Processing / manufacturing
- Applications

- To know the definition of a composite (in materials)
- To understand how the definition of a composite applies to conventional engineering composites, and appreciate how the definition can be applied more broadly
- To know and understand about composites, and cellular solids (foams, or porous materials) in terms of the **WHAT** framework
- Have an awareness of composites and foams in your engineering discipline, and reflect on what interests you in terms of applications or the materials themselves – this may be beyond your discipline
- To know about composite materials in the School of Engineering in Edinburgh (honours level courses and research)

WHAT Framework

Materials

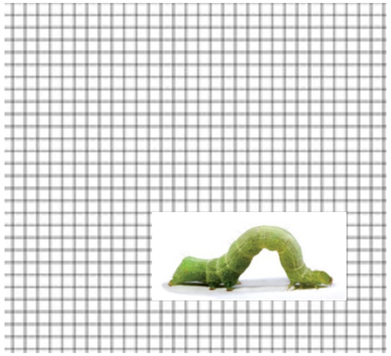
- **Classifications**
- **Properties**
- **Small scale structure (microstructure)**
- Processing / manufacturing
- **Applications**

– different ways in –

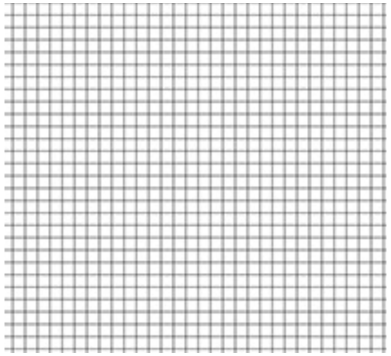
Material classifications

polymer metal ceramic glass & (?)

polymer

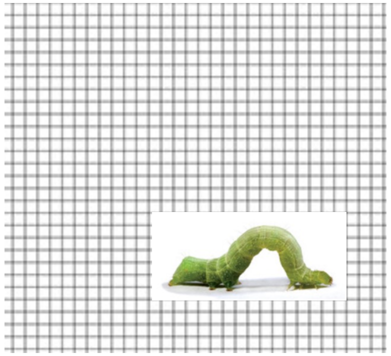


metal

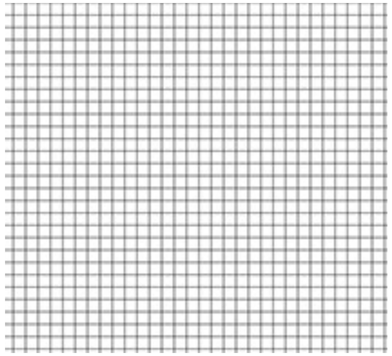


ceramic

polymer

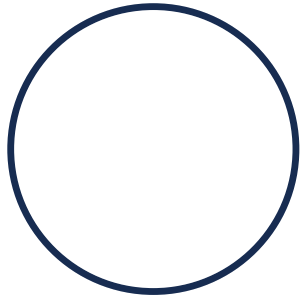


metal

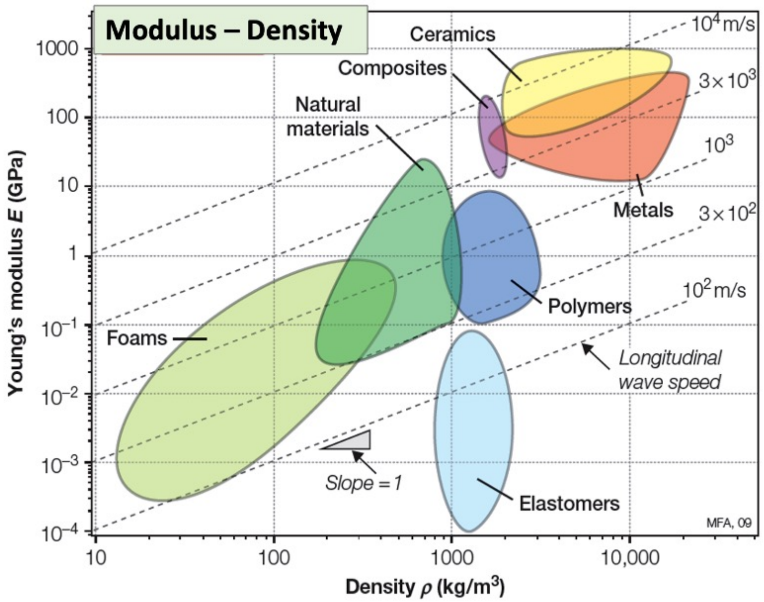


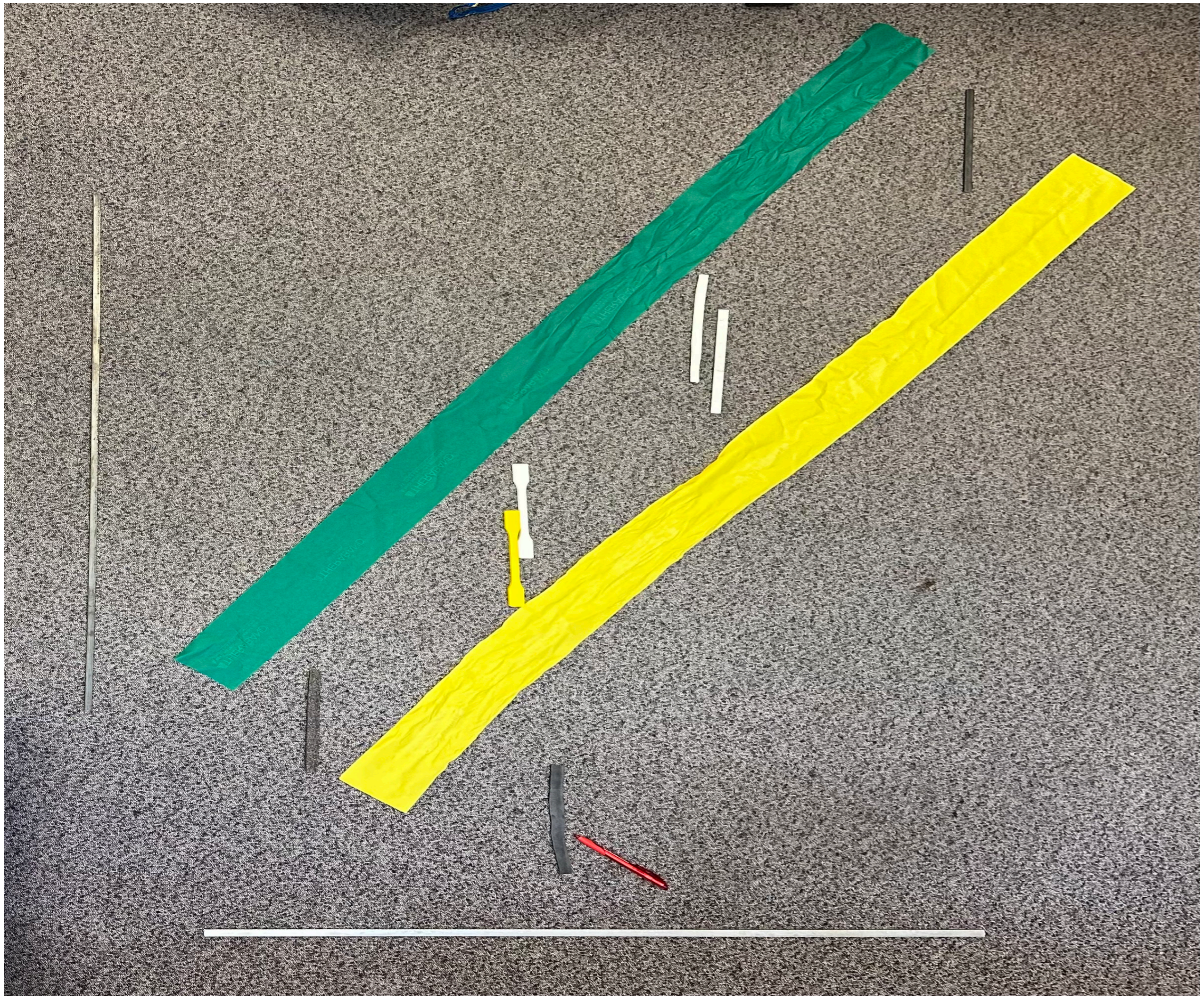
ceramic

glass



‘space’





What remained after the seminars when we constructed these maps?

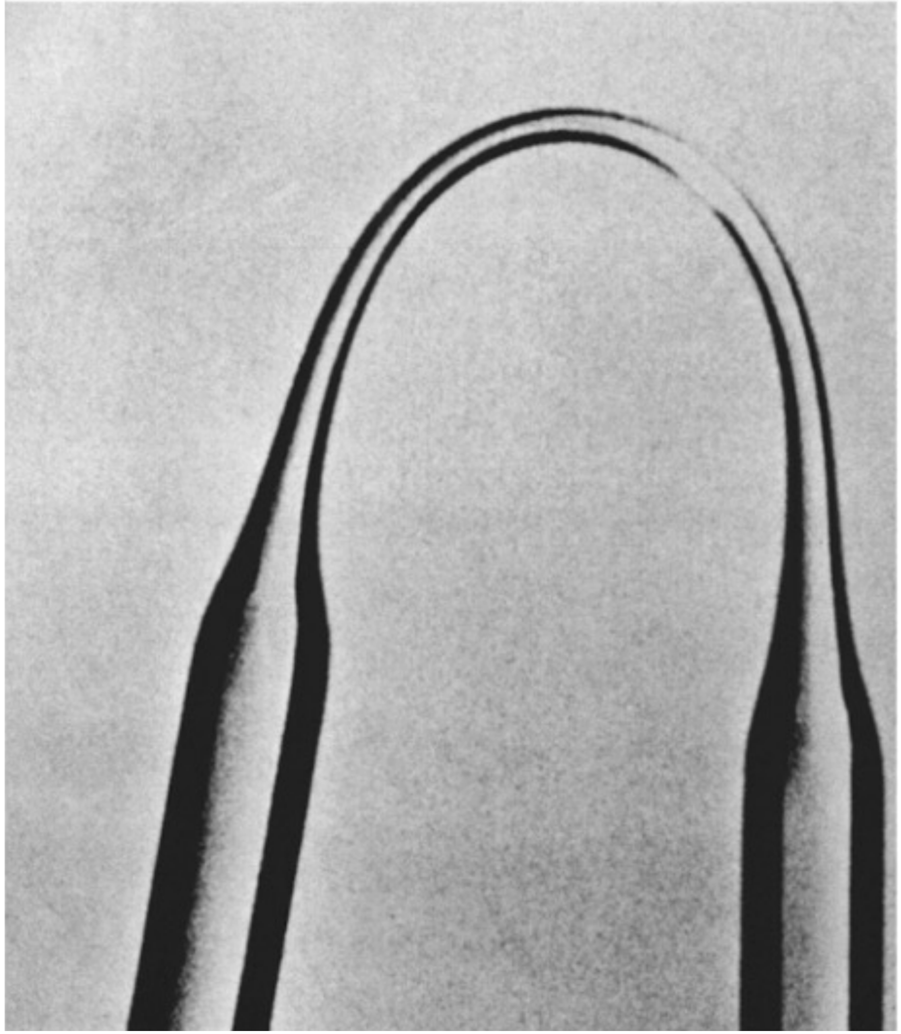
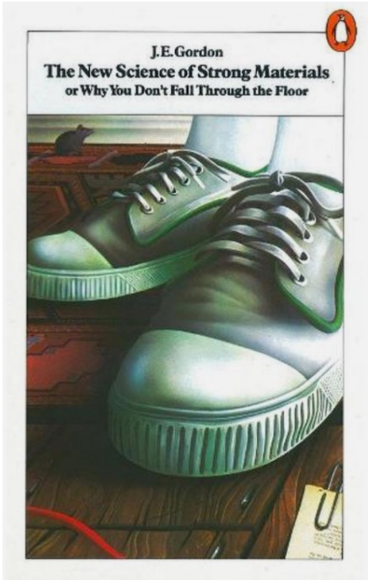


Plate 4 Chapter 3

Glass and other solids when truly free from cracks and defects can exhibit enormous strengths. This silica rod is bent elastically to a strain of 7½ per cent, i.e. a stress of 5000 MN/m^2. (The normal strength of glass is about 100–200 MN/m^2.)



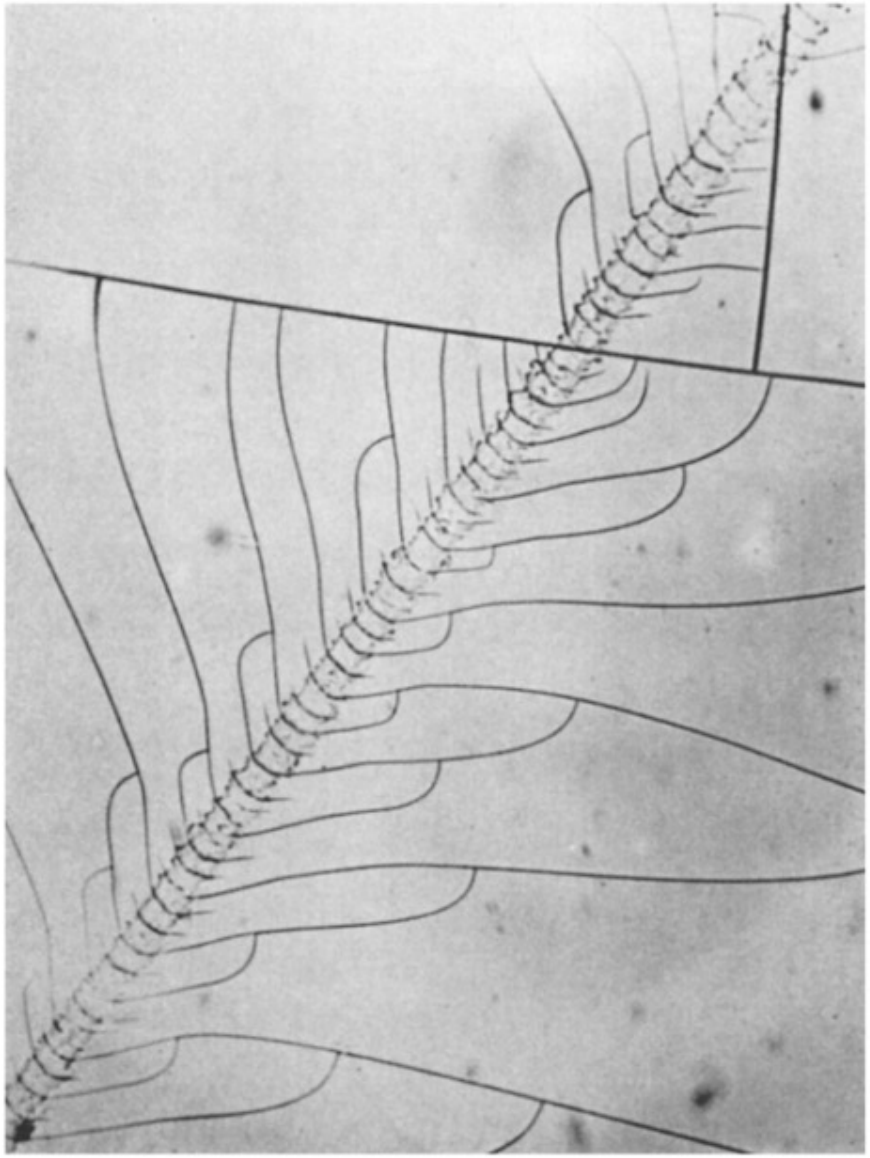


Plate 6 Chapter 4

Cracks resulting from deliberate scrape by a needlepoint on the surface of a microscope cover-glass. Magnification 1000 ×.

Plate 5 Chapter 4

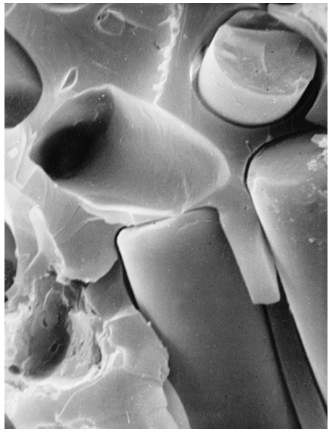
The strength of brittle solids such as glass is dramatically reduced by surface damage. Even slight contact can cause serious abrasion. This is a photograph of cracks caused by slight accidental contact on the surface of Pyrex glass. Magnification 700 ×.

Broad view of composite materials

- ‘Conventional’ engineering **composites**

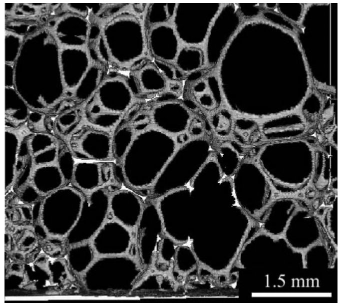
- **Cellular solids**, foams, porous materials
  - Synthetic and natural (wood, bone, snow)

- Concrete, asphalt …



glass fibre polyester composite

20 μm



open cell polymer foam

1.5 mm (1500 μm)

Use of terminology can vary. Check for clarification as needed.

Video c. 8 minutes

The information is mostly core (some core+ & extra).

You don't need to read the blog or watch this – the information is covered in the lecture and supplementary information. But it's interesting to hear one of the pioneering academics in the field to talk – and to recognise the foundational principles of the subject were established in the second half of the last centenary (when people often found more time to work in careful thoughtful ways [jb]).

From British Library Sound and Vision blog:

https://blogs.bl.uk/sound-and-vision/2014/08/rip-to-one-of-the-fathers-of-composite-materials.html

https://www.youtube.com/watch?v=IZUl56XLD5Y&t=5s

applications

processing / manufacturing: kayaks & skeleton bobsled & Rolls Royce components • properties & small scale structure: helmets • bikes Olympic track & road & MTB • ice axes – carbon fibre & beyond • porous functional materials • ice+ and ice axes

New Zealand have won the America's Cup for the third time in a row

www.bbc


INEOS for the win. Credit: Ian Roman / America's Cup

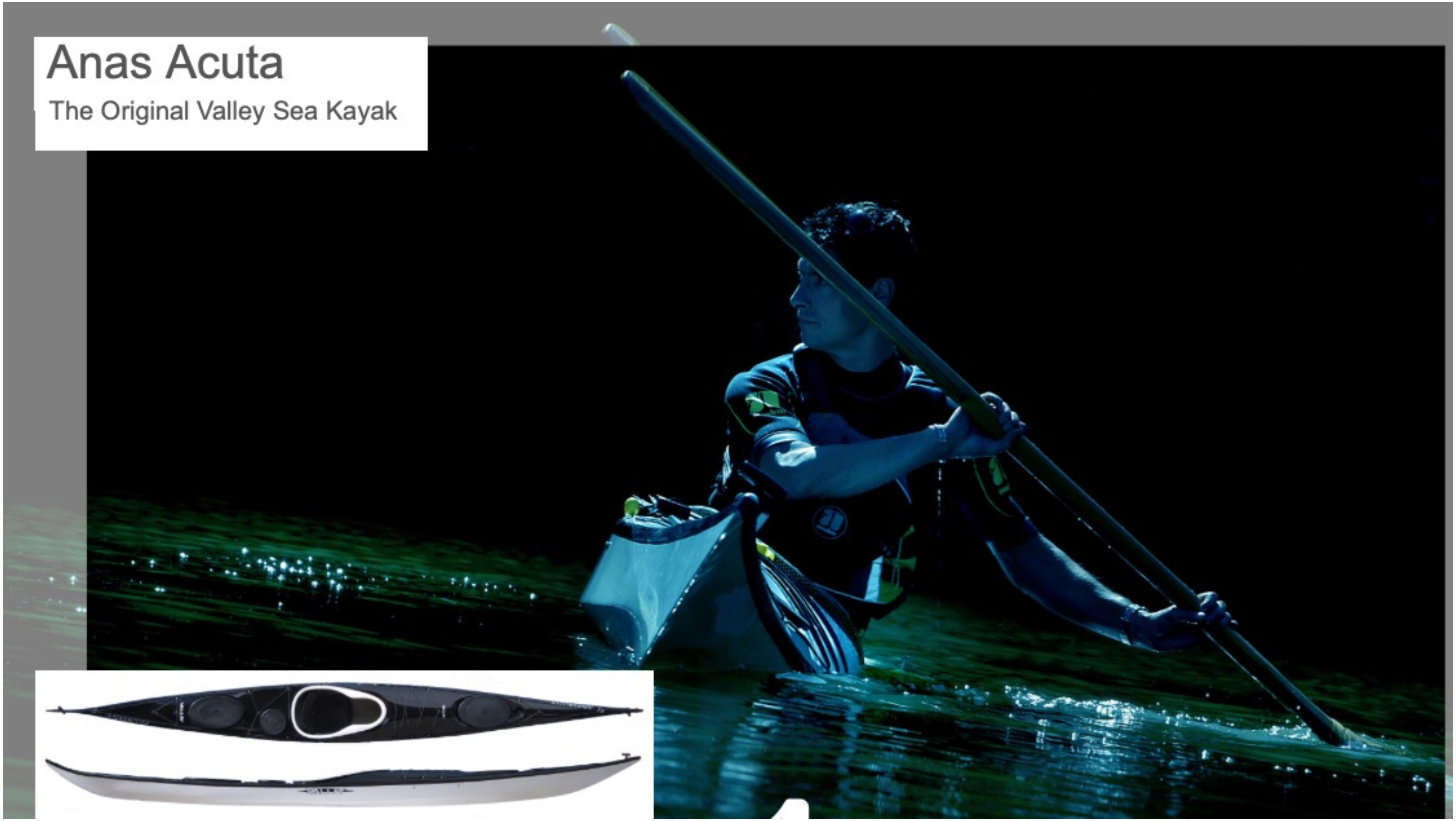
sampics Photographie/Christina Pahnket photo

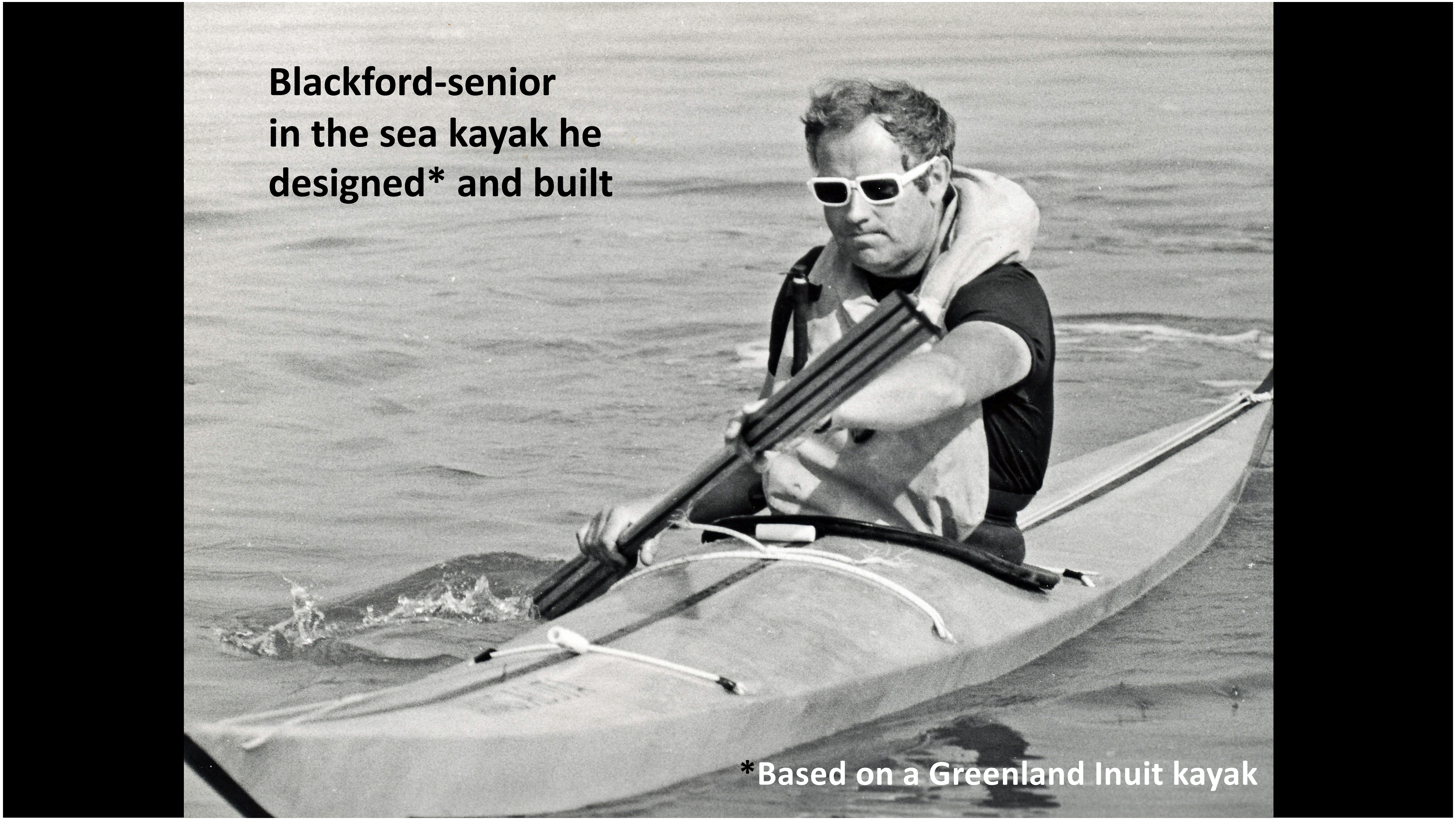
Blake Leeper crosses the finish line as he and his U.S. teammates set a world record in the 400-meter relay at the Paralympics world championships in Lyon, France. Leeper, who was born without lower legs, is wearing carbon-fiber running blades.

plasticsnews.com

Anas Acuta

The Original Valley Sea Kayak




Blackford-senior
in the sea kayak he
designed* and built
*Based on a Greenland Inuit kayak

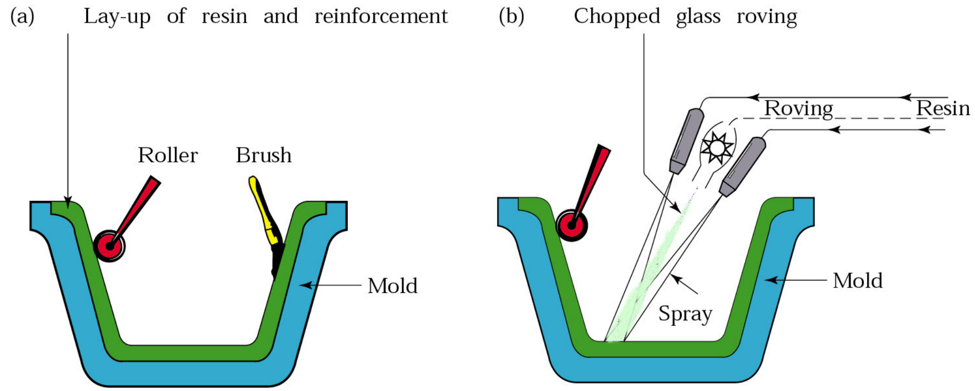
Me (!) in a miniture version of the sea kayak


WERNER


werner
WERNER SR. SIGNATURE EDITION


vancouver 2010
Iain Roberts PhD

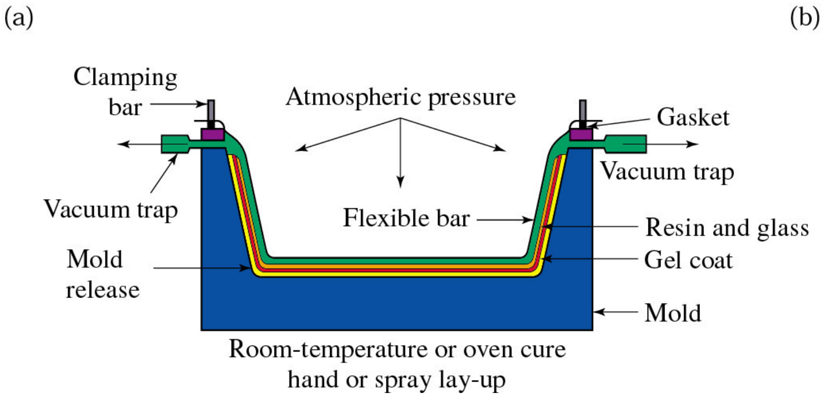
Molding processes - manual



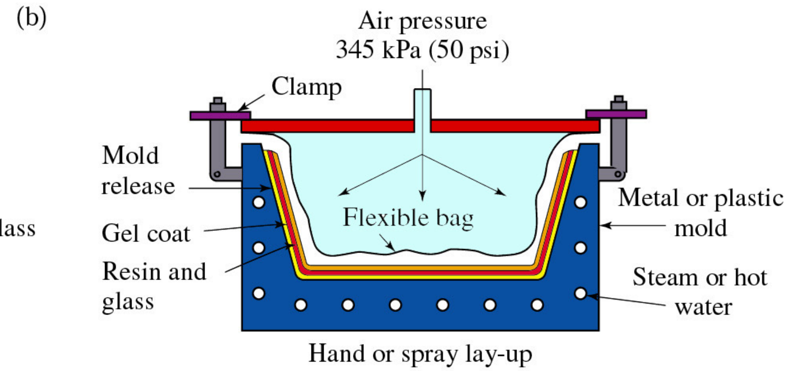
[extra]
more about processing in the Appendix

Sheet molding processes

Vacuum-bag forming



Pressure-bag forming



Rolls-Royce starts manufacture of world's largest fan blades, made with composites

Composite fan blade in production at the Rolls-Royce composite technology center in Bristol, U.K. SOURCE for all images | Rolls-Royce

https://www.compositesworld.com/news/rolls-royce-starts-manufacture-of-worlds-largest-fan-blades-made-with-composites-for-ultrafan-demonstrator

Rolls-Royce starts manufacture of world's largest fan blades, made with composites

Artist rendering of the UltraFan featuring a 140-inch-diameter set of 18 composite fan blades.

FastBlade is the world's first test facility that uses regenerative hydraulic technology to offer high-quality, low-cost fatigue testing of tidal blades and other composite structures for research and product development.

15MNm Static Moment

3MN Static Load

5MNm Fatigue Moment

1MN Fatigue Load

8 x FASTER

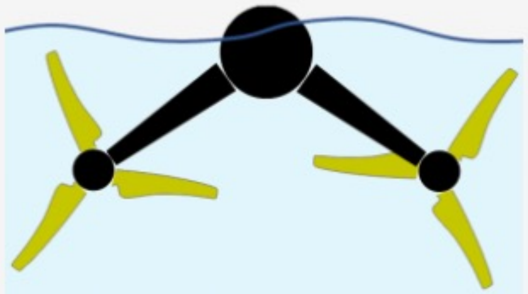
2021

75% Efficient

£4.1M CAPEX

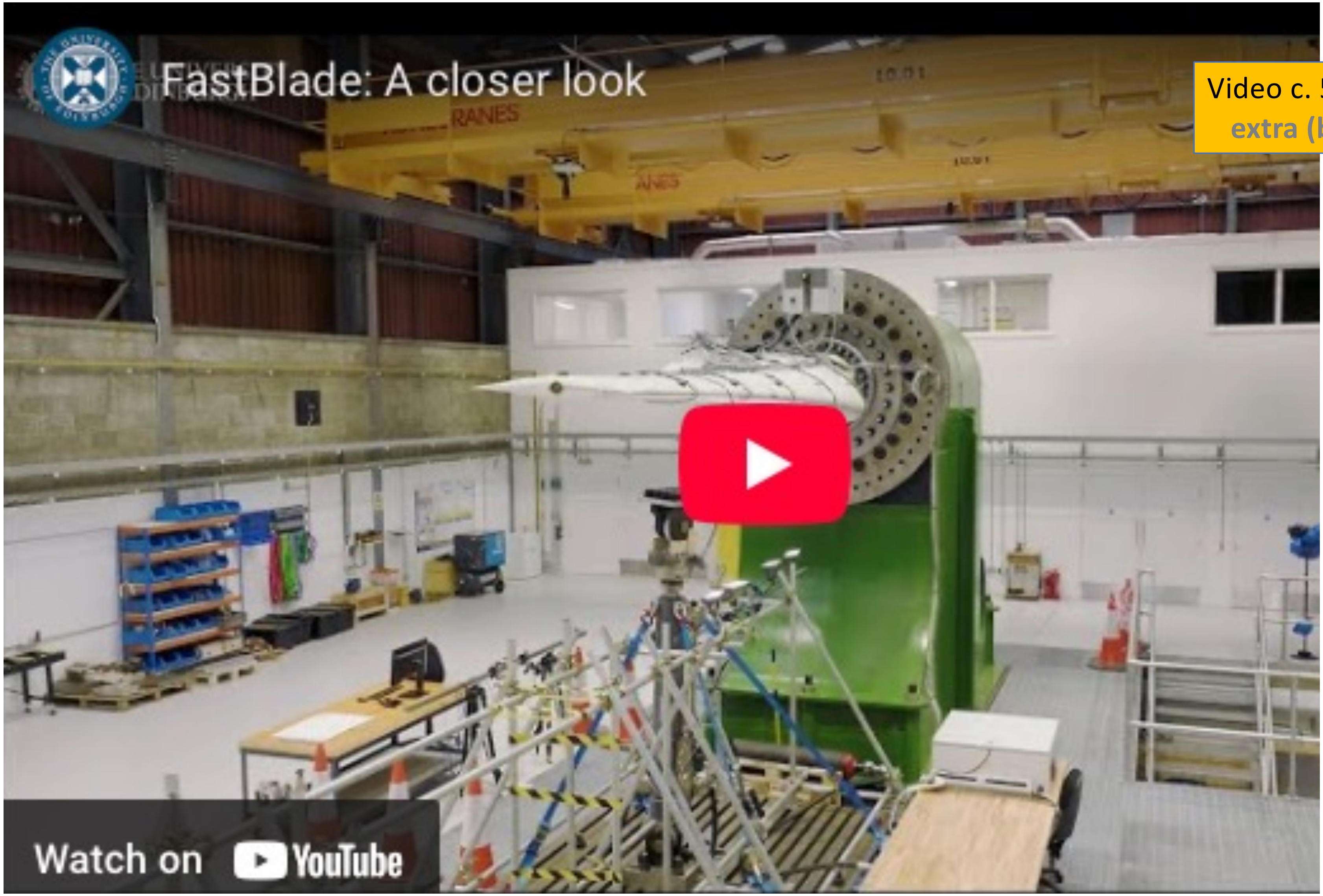
Accelerated Lifetime Testing

The innovative structural composites research facility has been developed by the University of Edinburgh specifically for cost effective, accelerated testing of stiff and slender composite and metal structures, such as tidal turbine blades, composite bridge sections and carbon fibre aircraft wing boxes. The facility will be the first of its kind in the world and will use a Digital Displacement® regenerative hydraulic actuation system to reduce the energy requirements of fatigue testing.



Video c. 2 minutes **extra (but good!)**

https://youtu.be/HStJjv_cEP0



Video c. 5 minutes
extra (but good!)

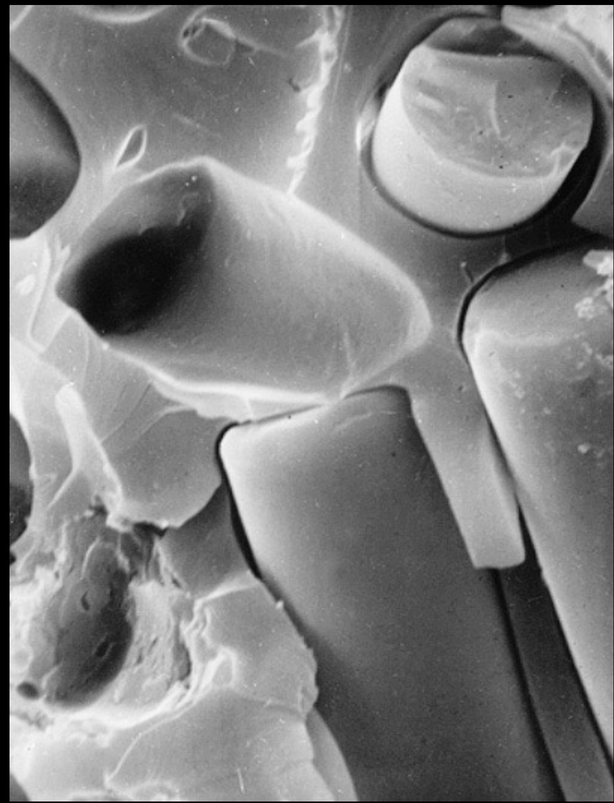
https://youtu.be/2_NDi7bGkYY


cannondale
HOLLOWGRAM
HOLLOWGRAM

2014

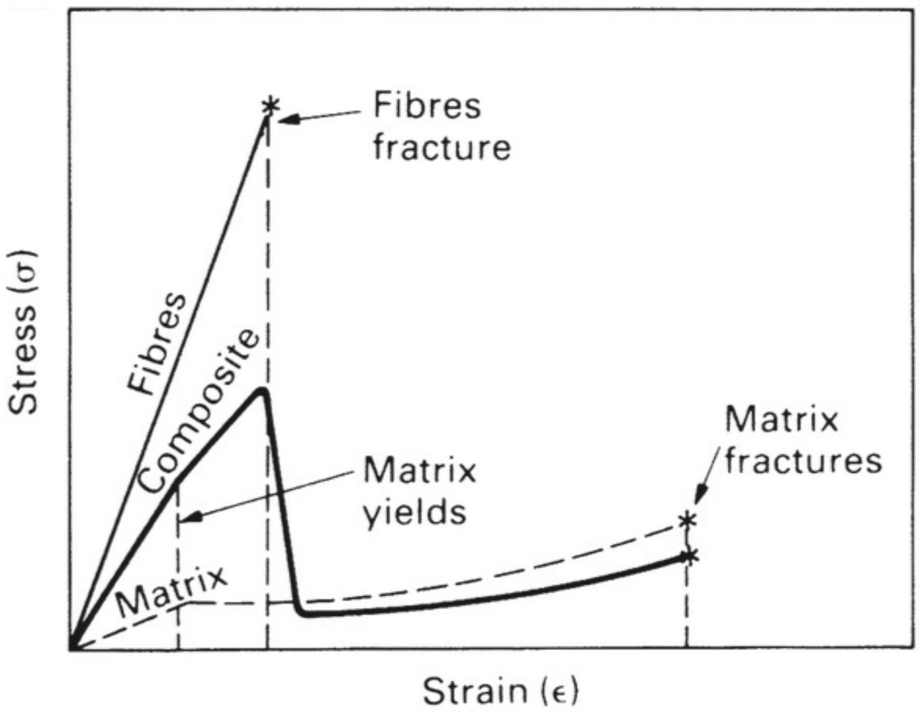
2024

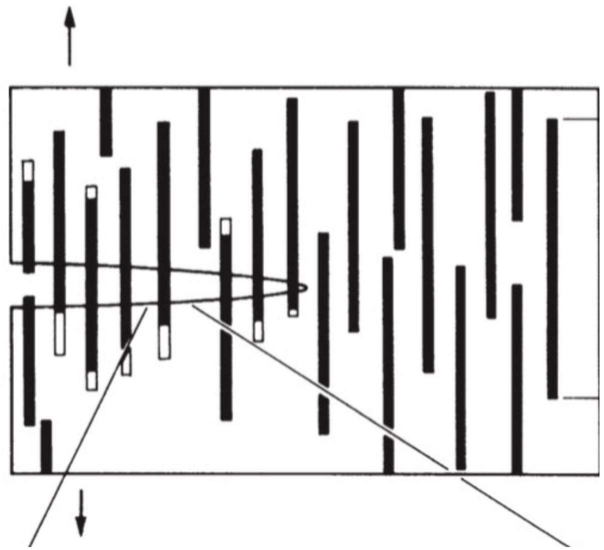
Team GB's track bike



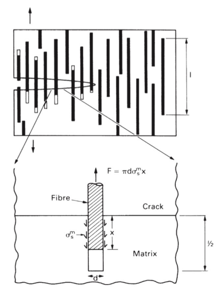
Composite materials

Composite helmets





Core++ / extra
Mechanics of fibre fracture and pullout, covered in Y4/5 courses

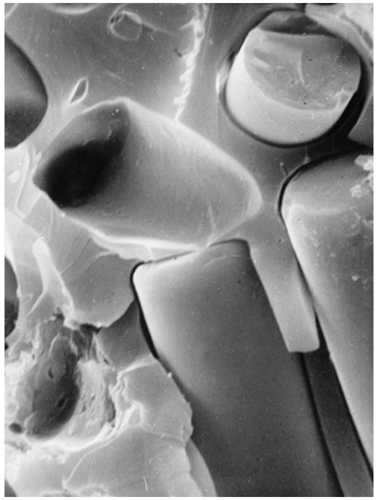


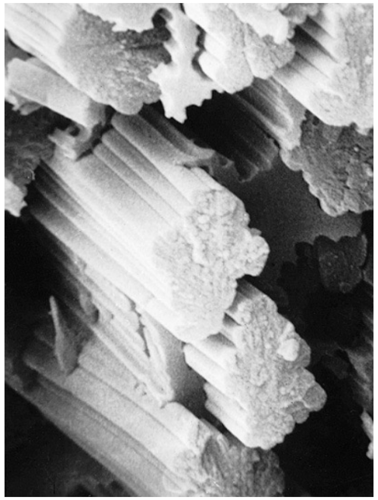
Ref: Engineering Materials 2 p481 & 485

Fracture surfaces of fibre-reinforced composites

Glass-fibre epoxy

Randomly orientated fibres



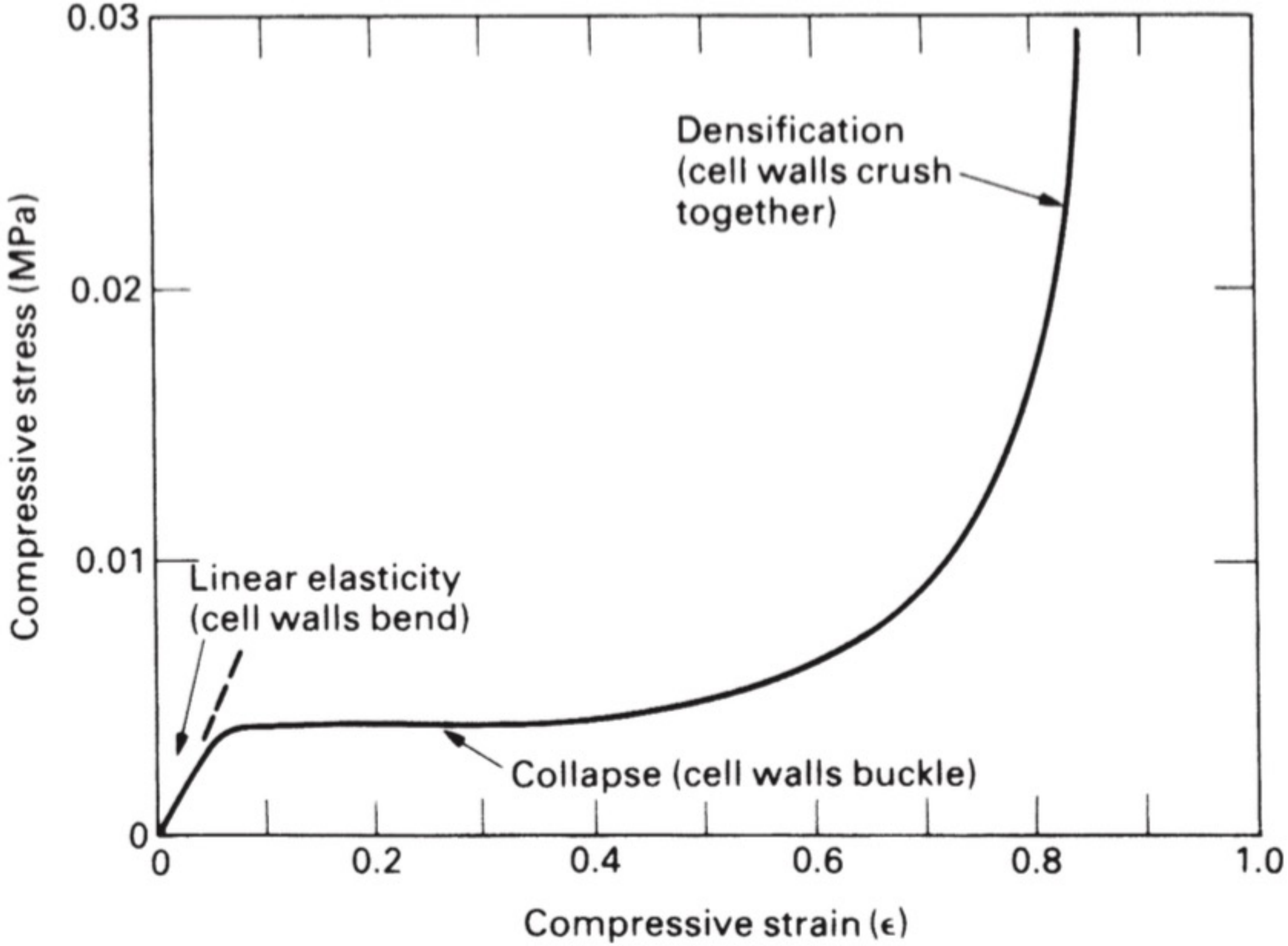


Graphite-fibre epoxy

Aligned long fibres

fibres dia. 10 μm

Foam helmets



Next slide shows small scale structure during these processes

Ref: Engineering Materials 2

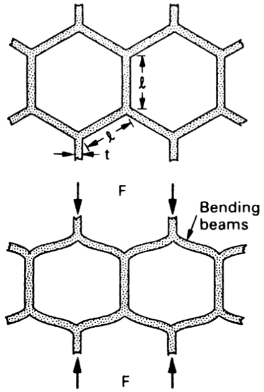


FIGURE 28.9
Cell wall bending gives the linear elastic portion of the stress—strain curve.

Ref: Engineering Materials 2

FIGURE 28.9
Cell wall bending gives the linear elastic portion of the stress—strain curve.

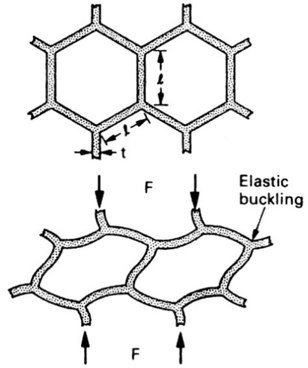


FIGURE 28.10
When an elastomer foam is compressed beyond the linear region, the cell walls buckle elastically, giving the long plateau shown in Figure 28.8.

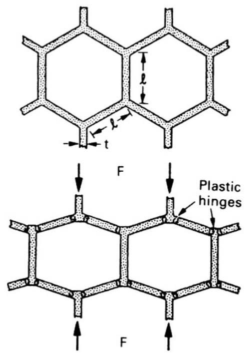


FIGURE 28.11
When a plastic foam is compressed beyond the linear region, the cell walls bend plastically, giving a long plateau like that of Figure 28.8.

2009

Carbon fibre composite

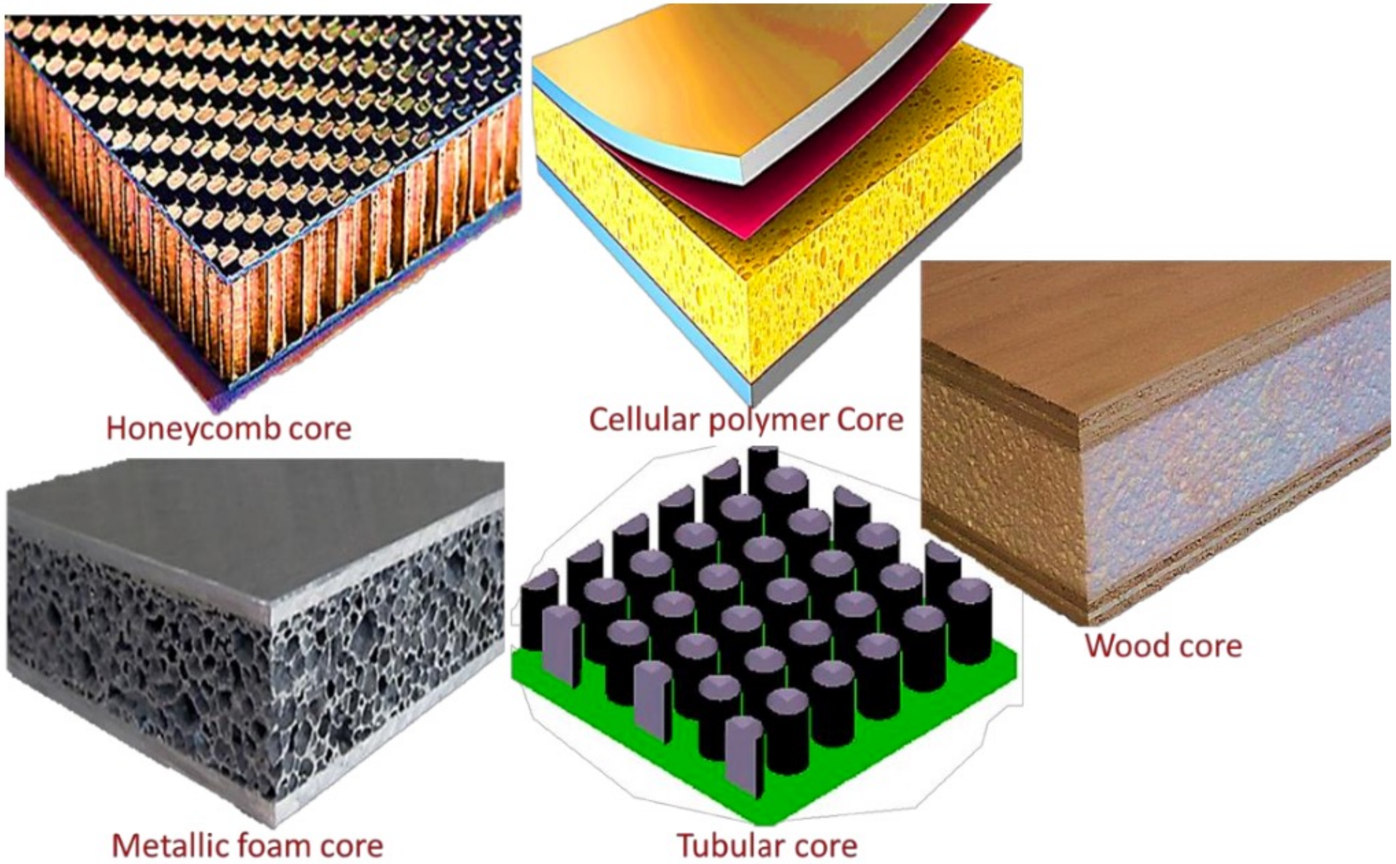
Black Diamond Cobra Hammer and Adze
© Black Diamond

2025

Aluminium alloys

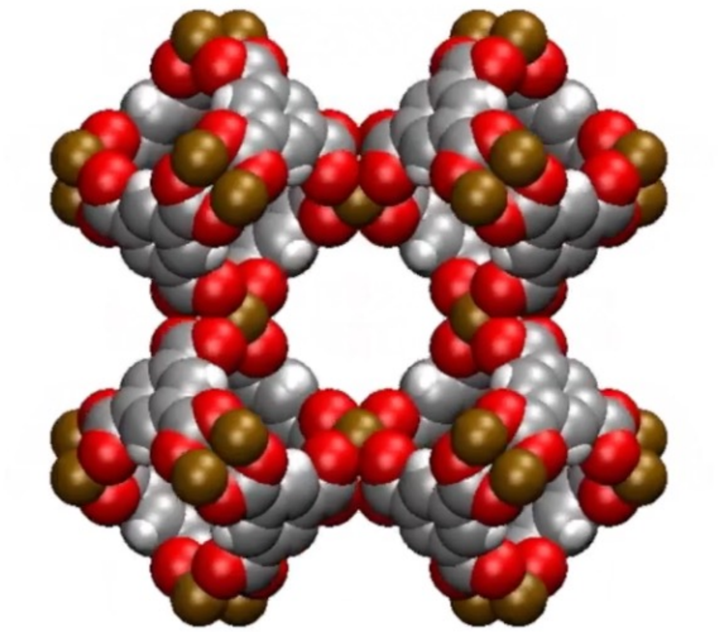
2025 Black Diamond
‘Hydra’ ice tool

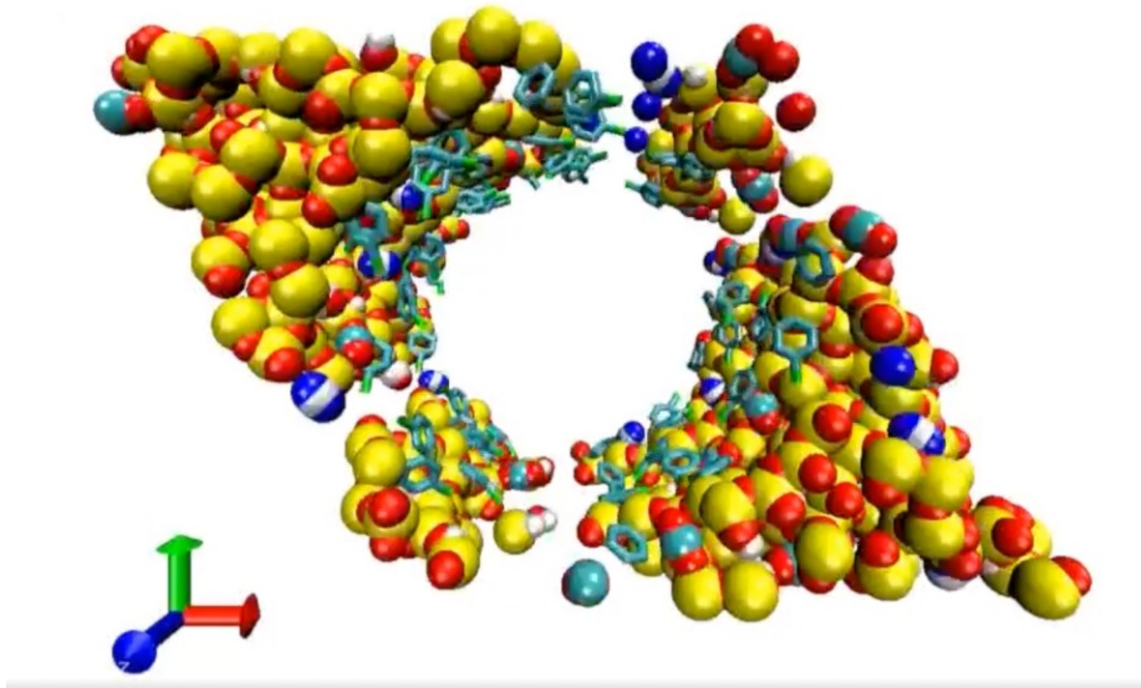
Different core structures in sandwich composites



Applications in
- aerospace
- automotive
- skis
- …

Review, State-Of-The-Art of Sandwich Composite Structures: Manufacturing—to—High Performance Applications
J. Compos. Sci. 2023, 7, 102. https://doi.org/10.3390/jcs7030102





Video 1 minute **core+** extra

Well worth one minute if you are interested in the topic BUT also well worth a minute if 'chemistry' is not that interesting to you (now)

https://media.ed.ac.uk/media/Tina+Duren-+Engineering-+Research+In+A+Nutshell+-+School+of+Engineering+-05+03+2013/1_fdwjlxms

ice

ice composites, foams of ice = snow

Ice composites:
ice reinforced with wood pulp, or paper

A DESCRIPTION OF THE ICEBERG AIRCRAFT CARRIER AND THE BEARING OF THE MECHANICAL PROPERTIES OF FROZEN WOOD PULP UPON SOME PROBLEMS OF GLACIER FLOW

By M. F. Perutz (Cambridge)

(Paper read at Meeting of the Society on 28 November 1946. See Vol. 1, No. 2, 1947, p. 51)

classic publication from 1948 'serious' high quality science – the ice sword and the next slide are more fun ways in to the material –

Video c. 6 minutes extra

Perutz, M. F. (1948), A Description of the Iceberg Aircraft Carrier and the Bearing of the Mechanical Properties of Frozen Wood Pulp Upon Some Problems of Glacier Flow. *Journal of Glaciology*, 1 (3), 95–104. https://doi.org/10.3189/S0022143000007796

Ice sword: https://www.youtube.com/watch?v=S7ju8iKex9o

Drop tests with ice and ice composites

Video c. 2 minutes extra
quite a neat 'everyday-materials' demonstration of the effect of reinforcement on material properties

ice

fractures into many pieces

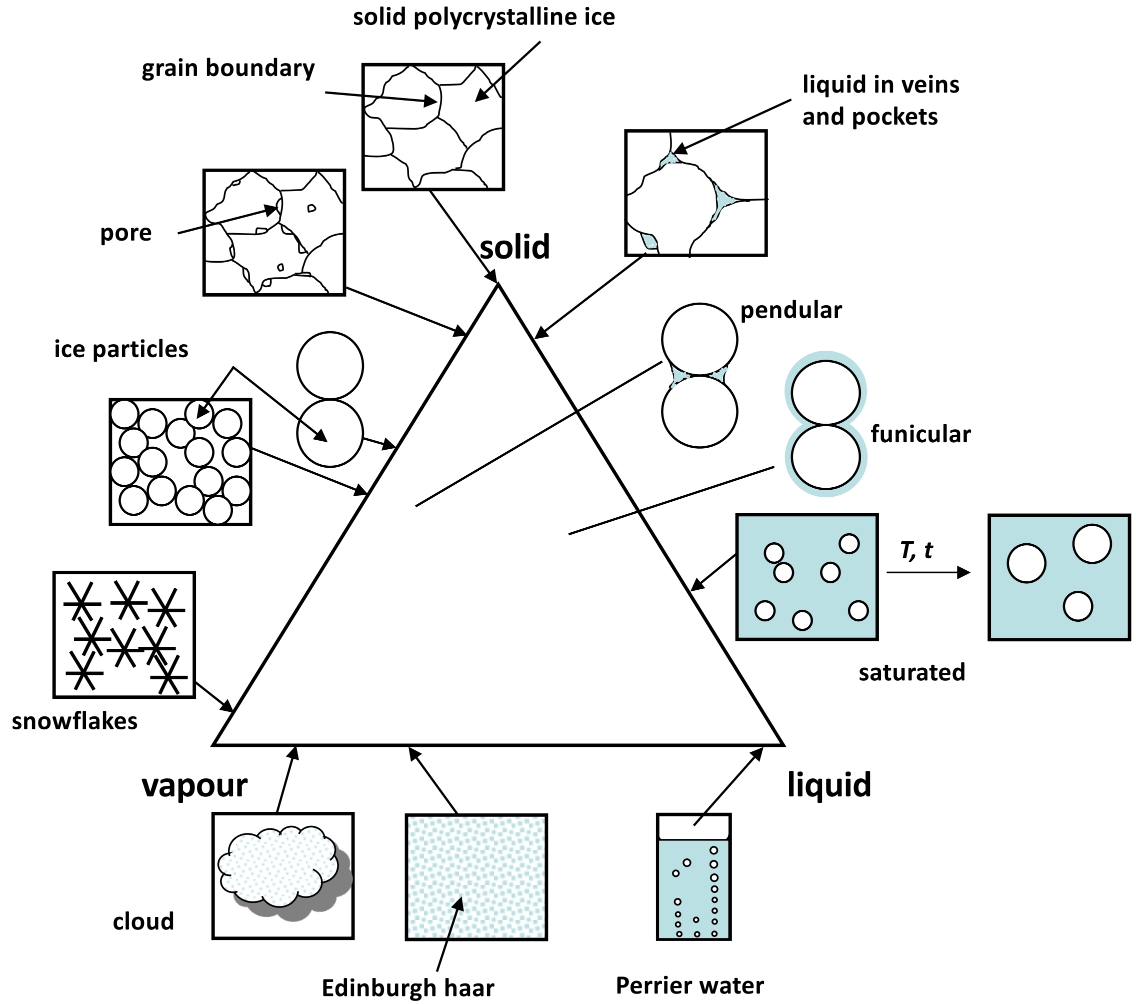
ice + wood pulp

fractures into two pieces

ice + paper

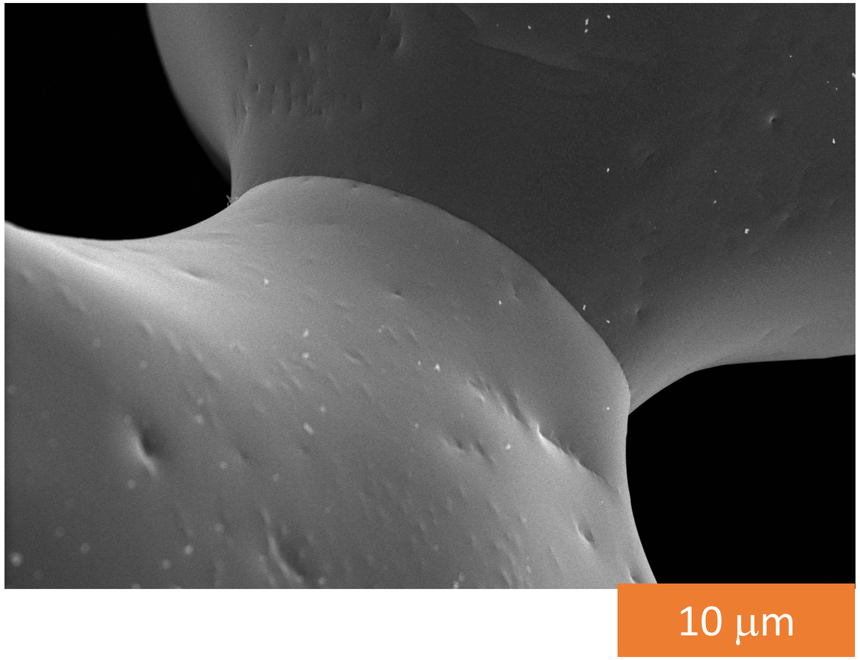
didn't fracture

https://www.youtube.com/watch?v=UMKis4FPykw

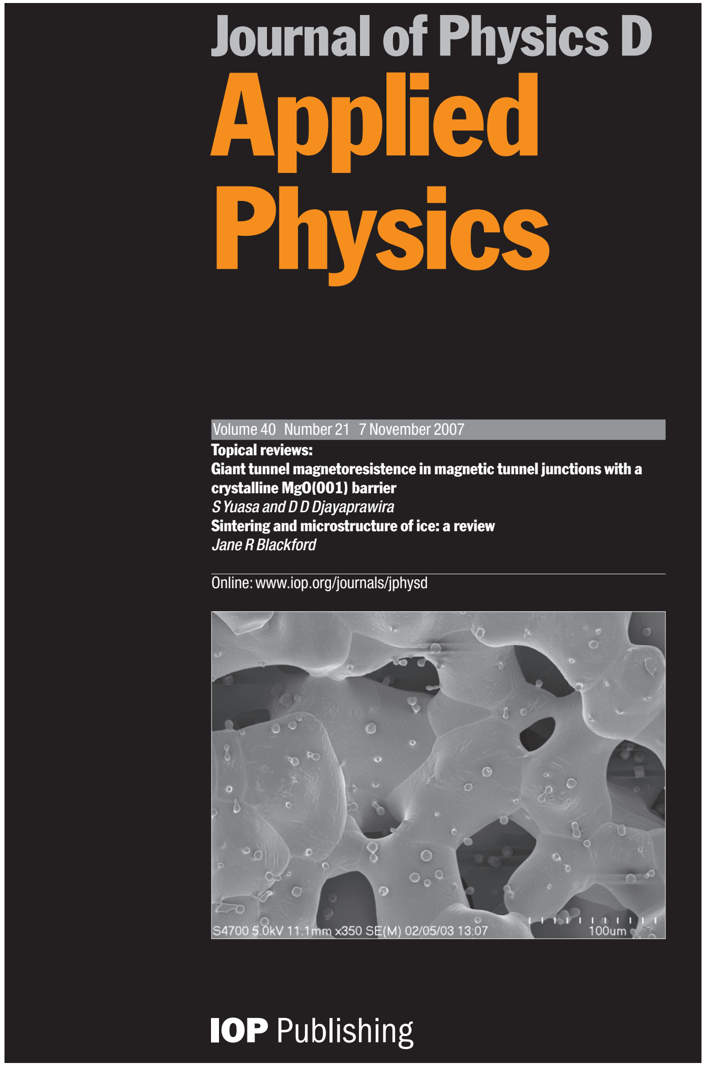


TOPICAL REVIEW: Sintering and microstructure of ice: a review,
Jane Blackford, J. Phys. D: Appl. Phys. **41** (2007) R1–R31

Sintering –
(ice) particles joining together



This is what often happens to snow 'on the ground'
- snow can be considered as a foam of ice -
Hence the technical understanding of cellular solids can be applied to snow, or vice versa, understanding from snow science can be applied to other cellular solids.



Nevis Faces - Blair Fyffe

Dave MacLeod

snow as a (hot) material
avalanche forecasting in Scotland

https://www.youtube.com/watch?v=-D8axWrNN3g

Video c. 5 minutes
extra

Watch if you're interested in snow, Scotland's mountain environment, avalanches and materials.

Beautifully filmed video, with an interesting story – Blair did his PhD supervised by Michael Zaiser and me, he now works as an avalanche forecaster (among other things).

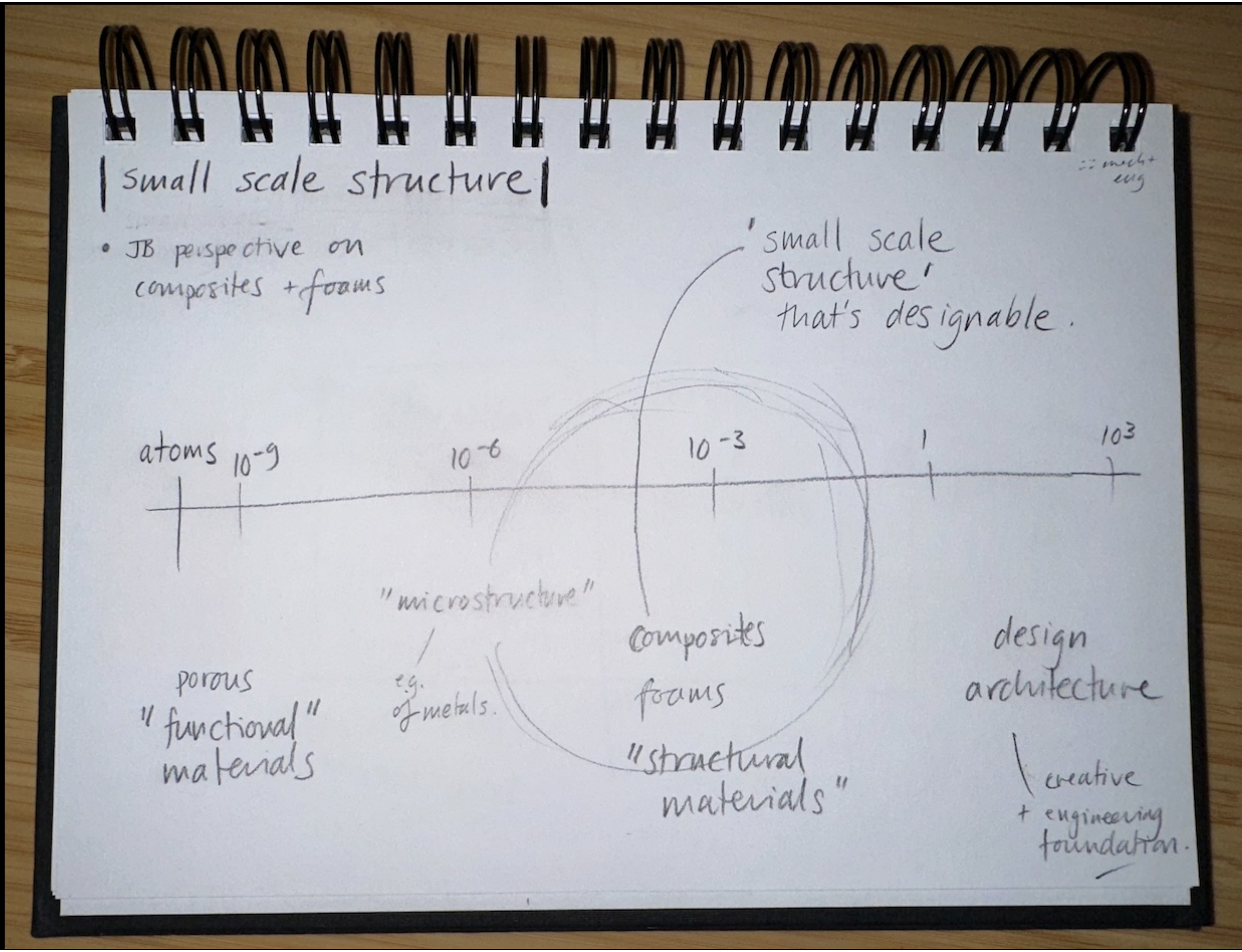
Scottish Avalanche Information Service
sportscotland

https://www.sais.gov.uk

Small scale structure

what is ‘small’ ? … it depends

& my personal view on possibilities creativity in making materials – space to play


small scale structure
• JB perspective on
composites + foams
'small scale
structure'
that's designable.
atoms
10-9
10-6
10-3
1
103
"microstructure"
e.g.
of metals.
porous
"functional"
materials
composites
foams
"structural
materials"
design
architecture
creative
+ engineering
foundation.

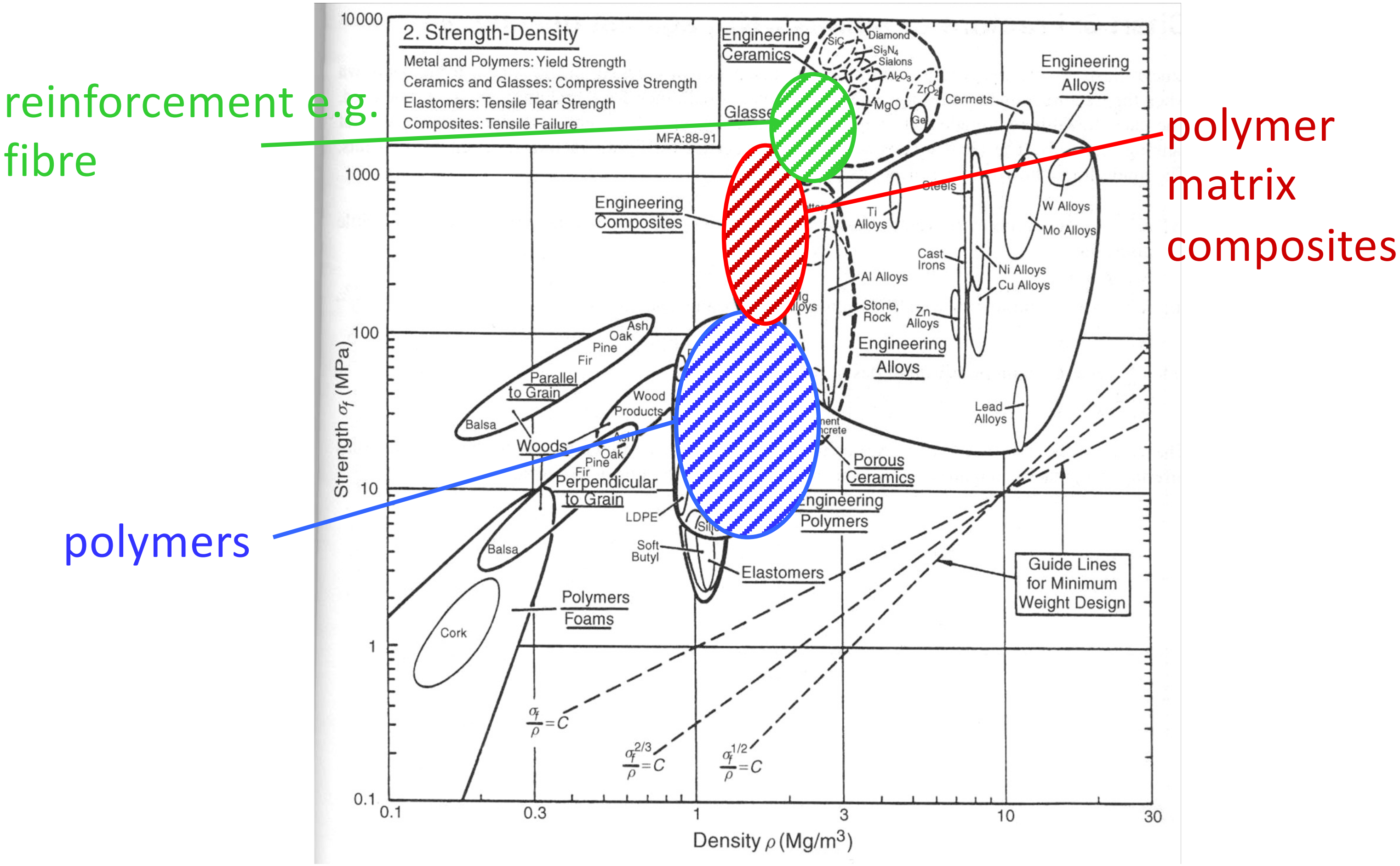
Properties

Ashby maps – notice where composites fit

Rule of mixtures (a reminder) – in composites

Materials selection map – strength vs. density

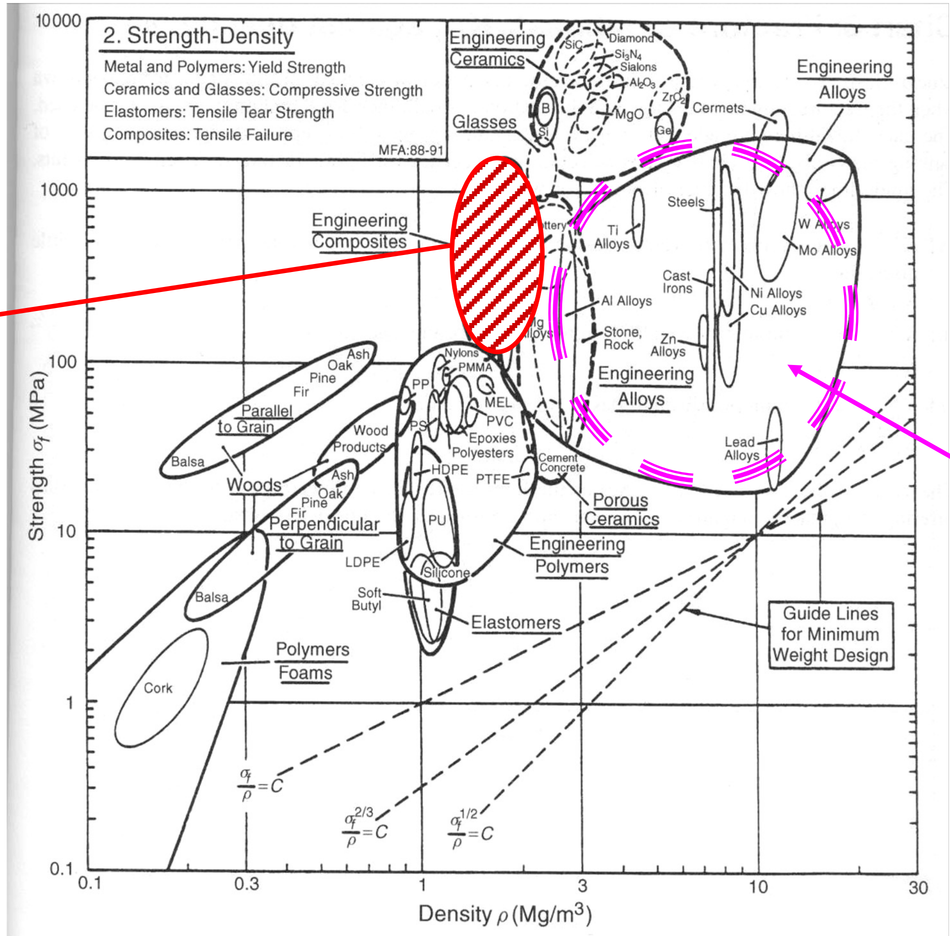
Composites → “intermediate” strength



Materials selection map – strength vs. density

composites cf. alloys: similar strength but lower density

polymer matrix composites



Metallic alloys

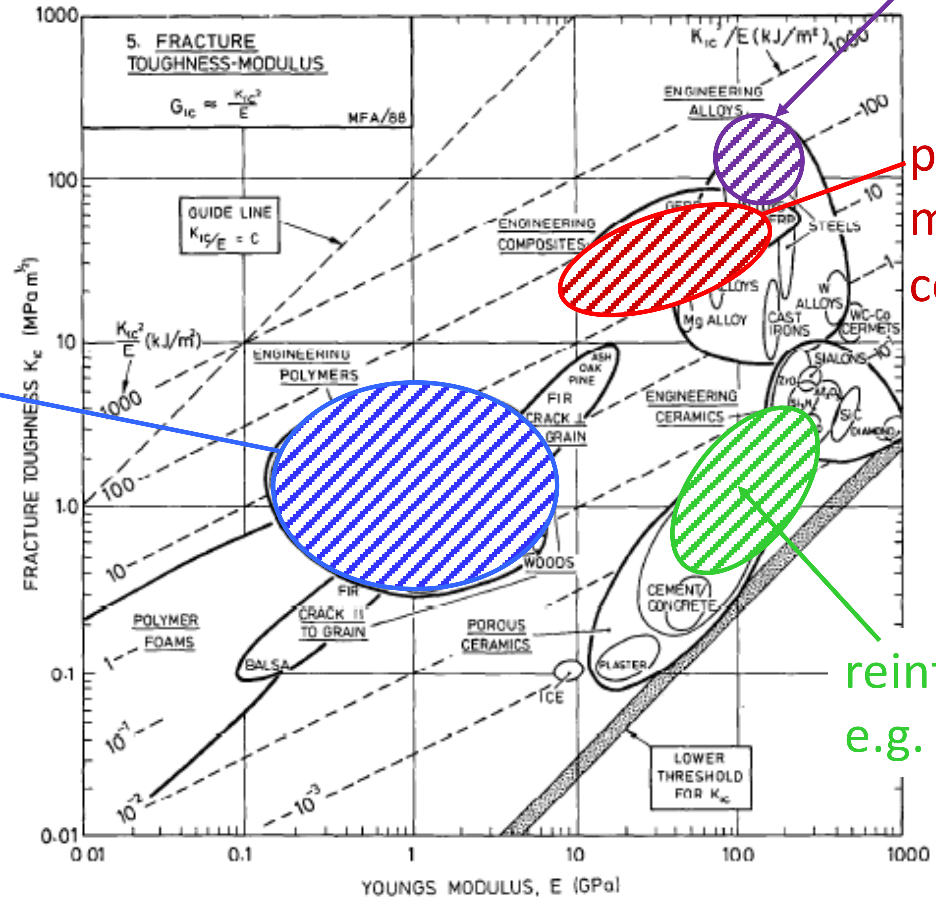
What are the implications for the use of composites?

Materials selection map – fracture toughness (Kc) vs. modulus (E)

Composites “intermediate” E (and strength)

BUT MUCH BETTER Kc

although not cf. all metals



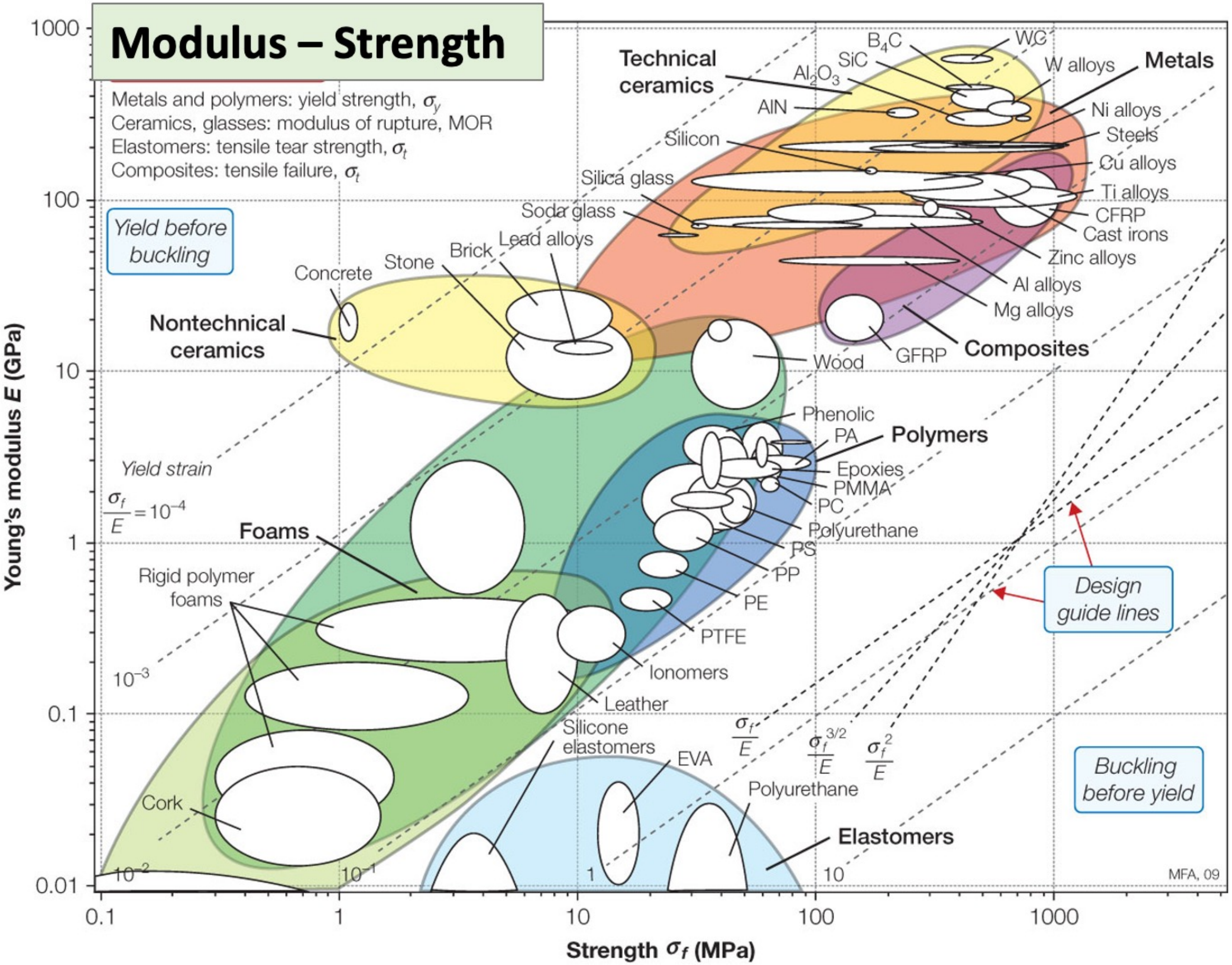
polymers

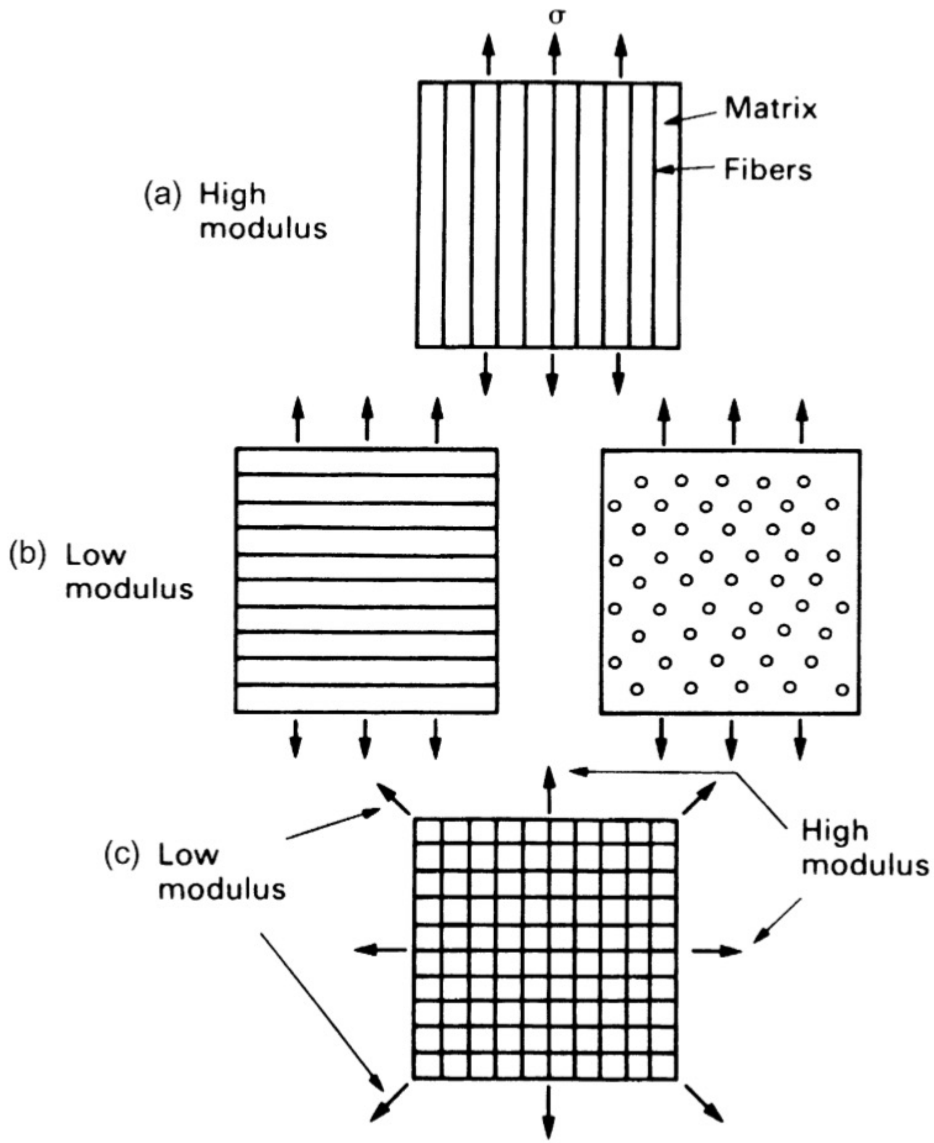
* some metals have higher Kc *

polymer matrix composites

reinforcement e.g. fibre

Modulus – Strength





Engineering Materials 2 p480

(a) When loaded along the fibre direction the fibres and matrix of a continuous fibre composite suffer equal strains.

(b) When loaded across the fibre direction, the fibres and matrix see roughly equal stress.

(c) 0-90 degree laminate has high and low modulus directions; 0-45-90-135 degree laminate is nearly isotropic.

Rule of mixtures

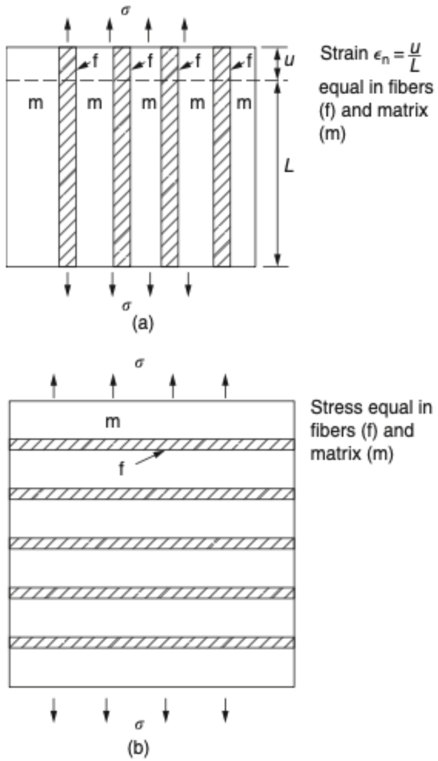


FIGURE 6.3
A fiber-reinforced composite loaded in the direction in which the modulus is (a) a maximum, (b) a minimum.

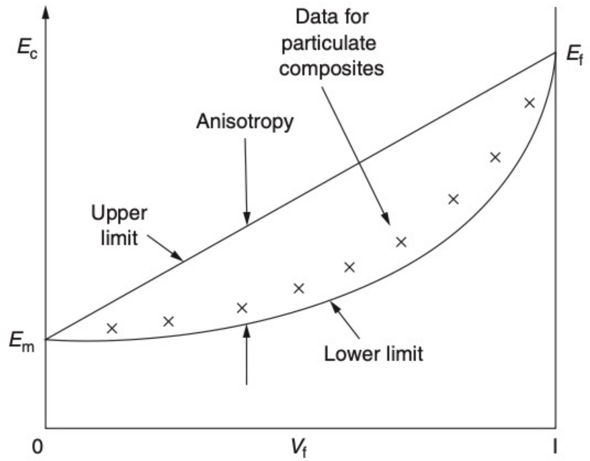


FIGURE 6.4
Composite modulus for various volume fractions of stiffener, showing the upper and lower limits of Equations (6.7) and (6.8).

$$E_c = V_f E_f + (1 - V_f) E_m \tag{6.7}$$

This gives us an upper estimate for the modulus of our fiber-reinforced composite. The modulus cannot be greater than this, since the strain in the stiff fibers can never be greater than that in the matrix.

$$E_c = 1 \Big/ \left\{ \frac{V_f}{E_f} + \frac{(1 - V_f)}{E_m} \right\} \tag{6.8}$$

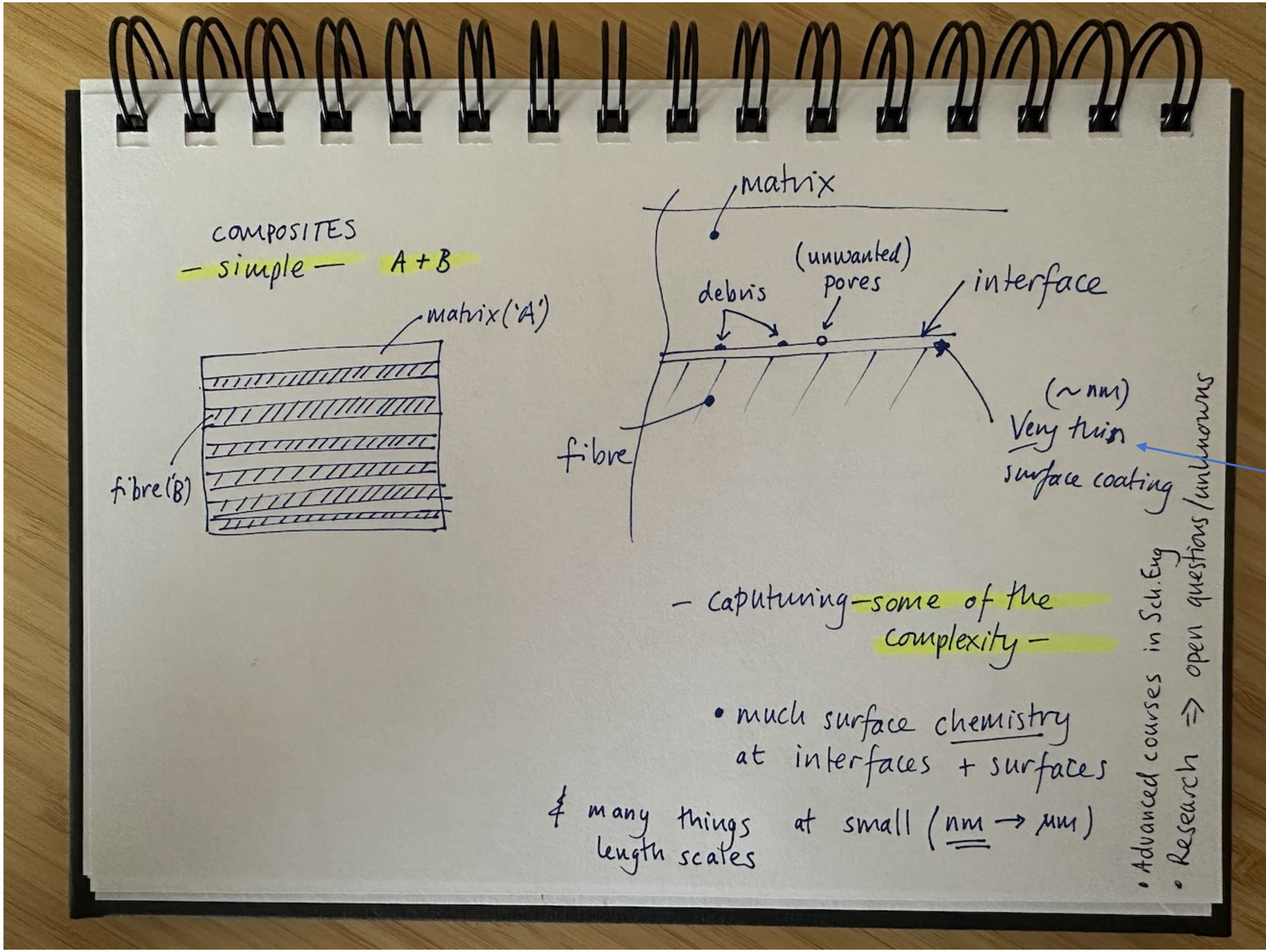
This is a lower limit for the modulus—it cannot be less than this.

Ref: Engineering Materials 1

what happens in practice is more complex, and there are imperfections that strongly affect material behaviour

interfaces & surfaces

challenges, defects and imperfections



Interfaces and surfaces

much science & open research questions

JB: I'm not expert in this area but I know enough to know there's much I don't know


Composites Part A: Applied Science and Manufacturing
Volume 127, December 2019, 105619

Review

Glass fibre sizing: A review

J.L. Thomason

Show more

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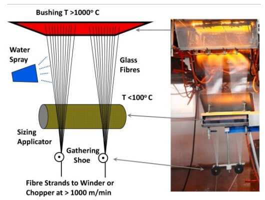
https://doi.org/10.1016/j.compositesa.2019.105619 Get rights and content

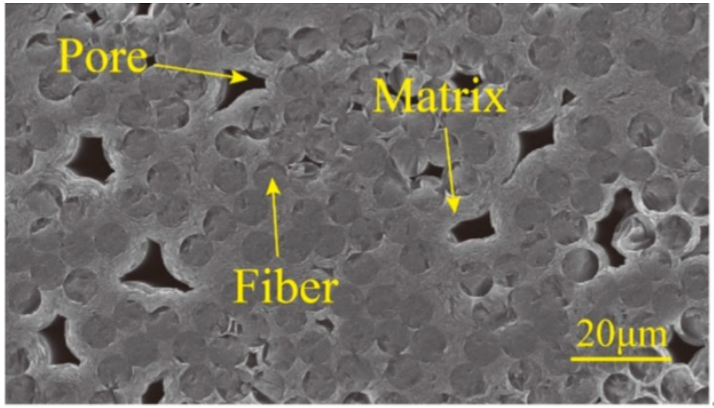
Abstract

Glass fibre reinforcements form the backbone of a composites industry with a global annual production of more than 10 million tons of high performance, light-weight materials. Possibly the most critical component involved in the manufacture of glass fibres and their composites is the fibre sizing. Yet because of the intense level of secrecy surrounding size formulations there are very few people in the vast supply chain of composite materials suppliers, processors and end users who have more than a superficial understanding of glass fibre sizings. Given the importance of sizings to the continuing success and growth of the composites industry this paper reviews some of the most relevant articles from the widely dispersed literature available around glass fibre sizings. The review covers size formulation, sizing effects in fibre and composite processing, sizing and fibre performance, sizing and interphase adhesion, and sizing effects on composite performance. The conclusions highlight the fragmented nature of the knowledge base on sizings and the lack of reliable and reproducible reference materials on which to build real progress in this critical technology.



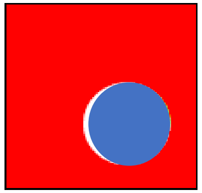
Potential challenges

- pores in the matrix

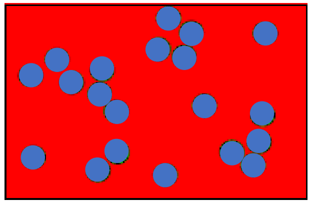


Ge et al. https://doi.org/10.3390/polym16182577

- **Poor bonding between phases**

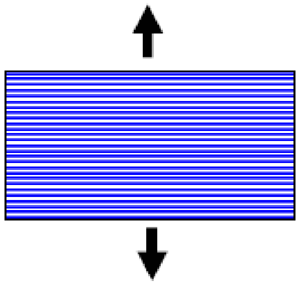


- **Poor dispersion of reinforcing phase**



- **Anisotropy**

often beneficial – but can be problematic



Composite materials in Edinburgh University School of Engineering

Possibilities beyond Materials 2

Composite materials in Edinburgh School of Engineering

Advanced courses

- Polymers and Composite Materials 4 (MECE10009), Dipa Roy
- Advanced Composite Materials 5 (MECE11019), Dongmin Yang
- Surface Engineering and Coatings 5 (MECE11018), Vasileios Koutsos
- Composite materials research group

  Including final year undergraduate research projects
- FastBlade

  FastBlade is the world's first test facility that uses regenerative hydraulic technology to offer high-quality, low-cost fatigue testing of tidal blades and other composite structures for research and product development.

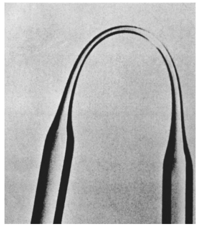
http://www.drps.ed.ac.uk - to look up course information

Summary composite materials

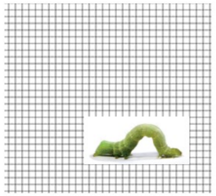
- **Polymer matrix**: modulus and fracture toughness increase with reinforcement: widely used.

  Metal matrix: improvement in creep and wear properties.
- **Ceramic matrix**: improved toughness (still not great), exceptional high temperature properties.
- MMCs and CMCs less widely used, but important niche applications.
- **Cellular solids**, foams, porous materials: various materials, widely used and some niche applications.

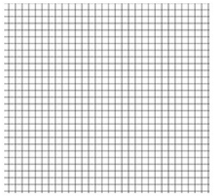
Composites & cellular solids
my summary



polymer

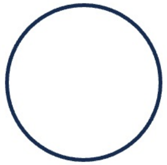


metal



ceramic

glass

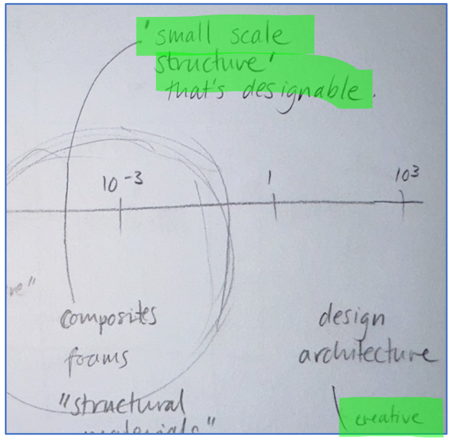


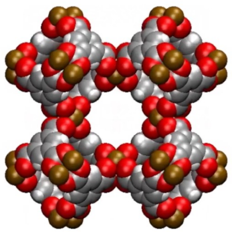
'space'

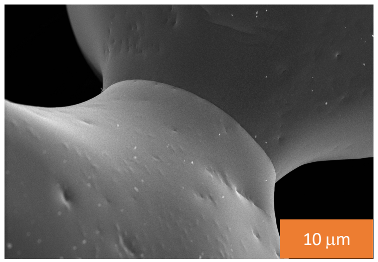
WHAT Framework

Materials

- **Classifications**
- **Properties**
- **Small scale structure (microstructure)**
- Processing / manufacturing
- **Applications**







THE UNIVERSITY of EDINBURGH | FASTBLADE

- all sorts of amazing applications and possibilities to put different materials together in creative ways -

Appendix

‘Conventional’ engineering composites

- Polymer matrix composites PMC

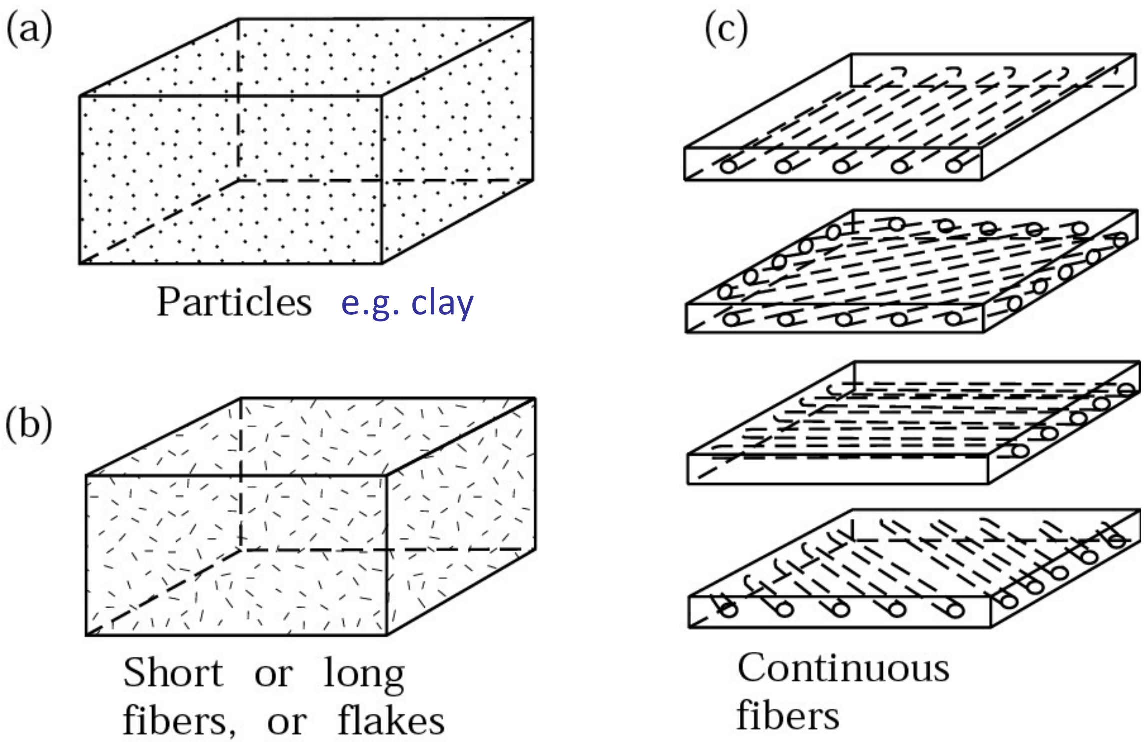
  e.g. glass fibre reinforced polyester

VERY widely used cf.
MMCs or CMCs

- Metal matrix composites MMC
- Ceramic matrix composites CMC

important in
niche applications

Composite materials
Methods of reinforcing



e.g. clay

layers of continuous fibres assembled into a laminate structure

e.g. glass, carbon, Kevlar (aramid), boron

Processing / manufacturing

Two classes of polymers are used for composites:

Thermosetting polymers: initially liquid, polymerize during the process & release heat.
Thermoplastic polymers: already polymerized, melted and pressed in shape.

Thermoset vs Thermoplastic Composites manufacturing from industrial standpoint

Thermoset Composites	Thermoplastic Composites
• low initial viscosity	• high toughness
• ability to attain high fiber volume fraction with good properties	• recyclable
• More expensive: low volume manuf.	• can be welded
• exotherm	• unique repairability
• outgassing of VOCs	• Less expensive: high volume manuf.
• relatively brittle	• high viscosities: porosity
	• moulds must be heated

Going further: composite manufacturing methods table

	Thermoset	Thermoplastic
Short fibres	• Resin transfer molding (RTM) • Vaccum Infusion (VI) • Vaccum assisted resin transfer molding (VARTM) • Bulk molding compound (BMC)	• Injection molding • Compression molding • Sheet molding compound (SMC)
Continuous fibres	• Filament winding – Robot • Tape-Laying – Automated fibre placement • Hand layup • Pultrusion • RTM/VI/VARTM	• Filament winding – Robot • Tape-Laying – Automated fibre placement • Hand layup + Autoclave • Stamping/Press forming

Credits to TUDelft OpenCourseWare: full lecture here.
https://ocw.tudelft.nl/course-lectures/2-4-3-lecture-composite-manufacturing/

Video 6 minutes
extra ('core+' level of information
but 'extra' for Mat2 course)
but excellent information if you are
interested and want to know more

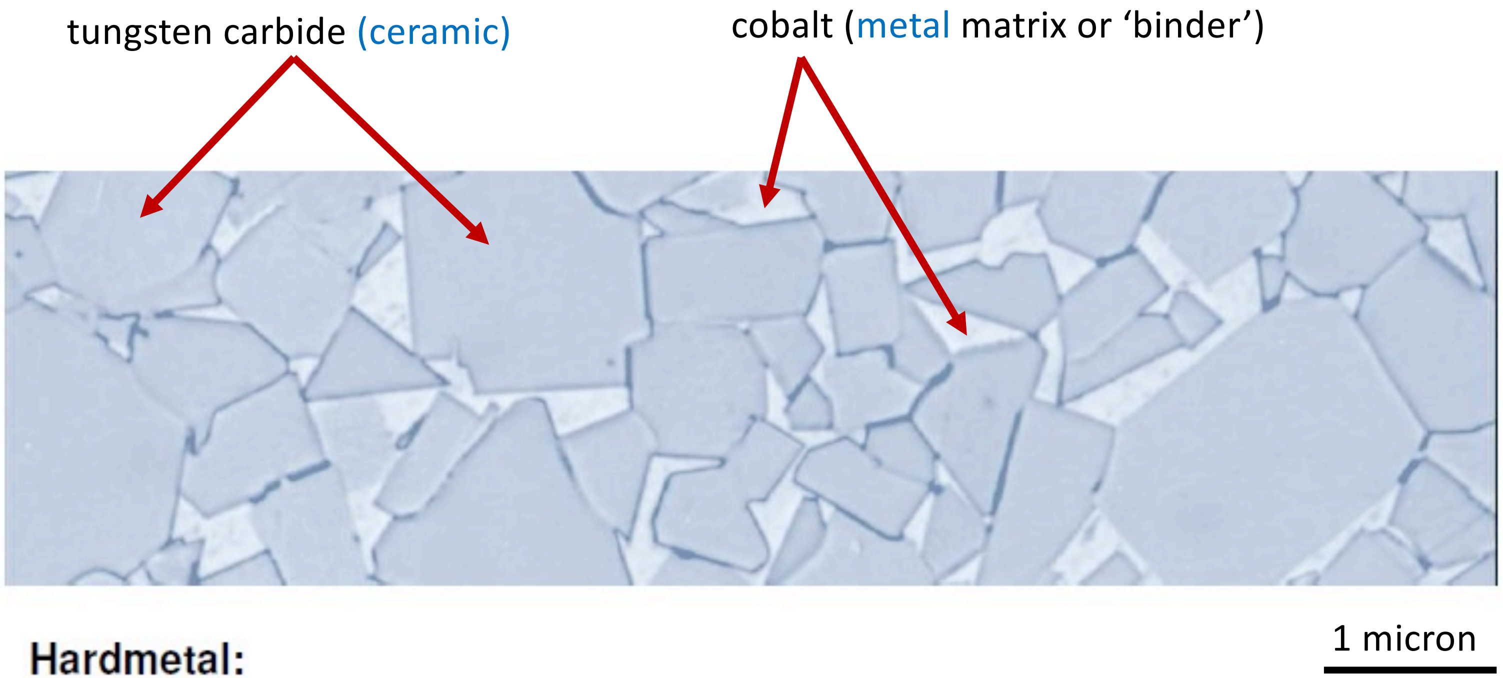
https://ocw.tudelft.nl/course-lectures/2-4-3-lecture-composite-manufacturing/

more applications

Metal matrix composites
Ceramic matrix composites

niche applications,
processing less routine

Metal matrix composites

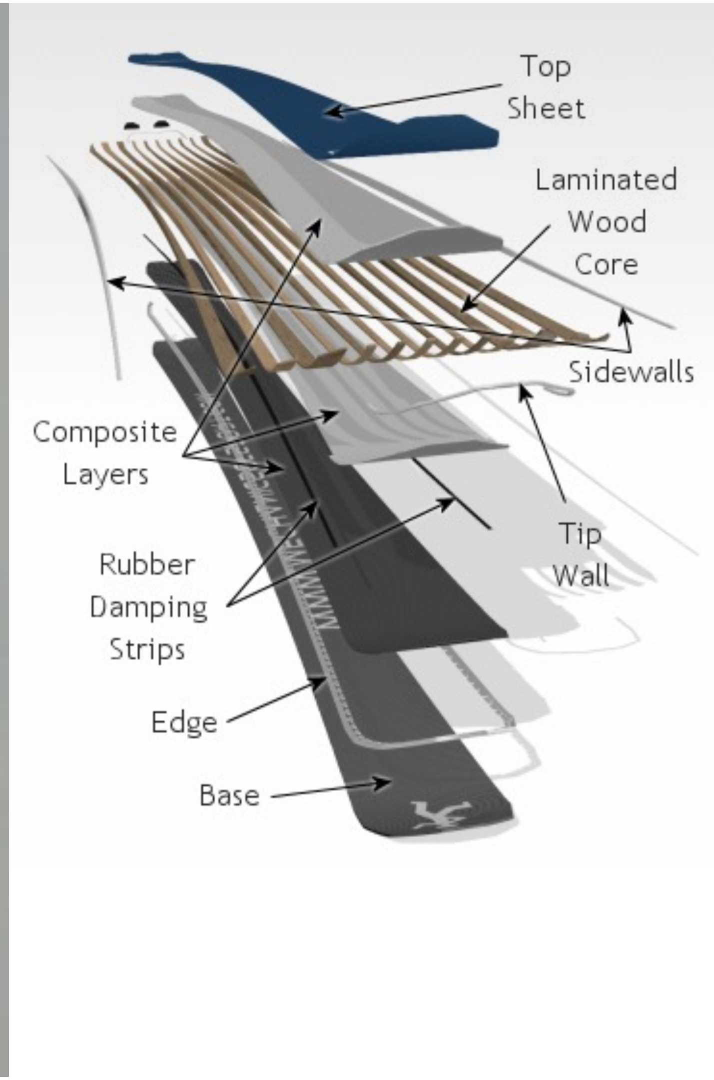


Hardmetal:

Tungsten carbide (hard, wear-resistant) + cobalt (tough)

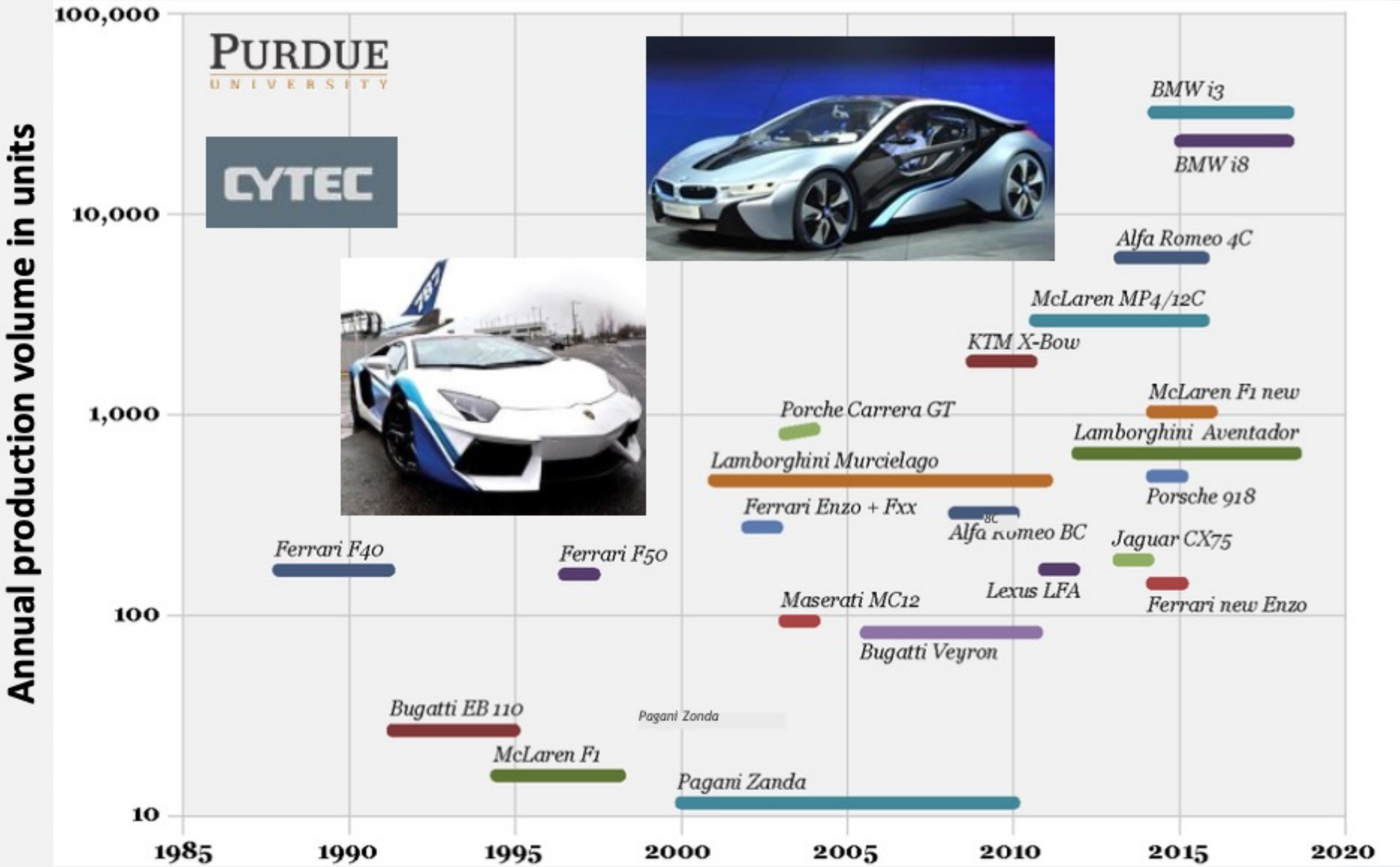
Problems with MMCs

- Interfacial bond strength can be poor
- Brittle intermetallic phases can form at the matrix-reinforcement interface if MMC held at elevated temperature
- Tool wear (in primary or secondary processing) due to hard reinforcement phase
- Reuse / recycling is challenging


Top
Sheet
Laminated
Wood
Core
Sidewalls
Composite
Layers
Tip
Wall
Rubber
Damping
Strips
Edge
Base

Automotive Utilisation: The Rate Challenge

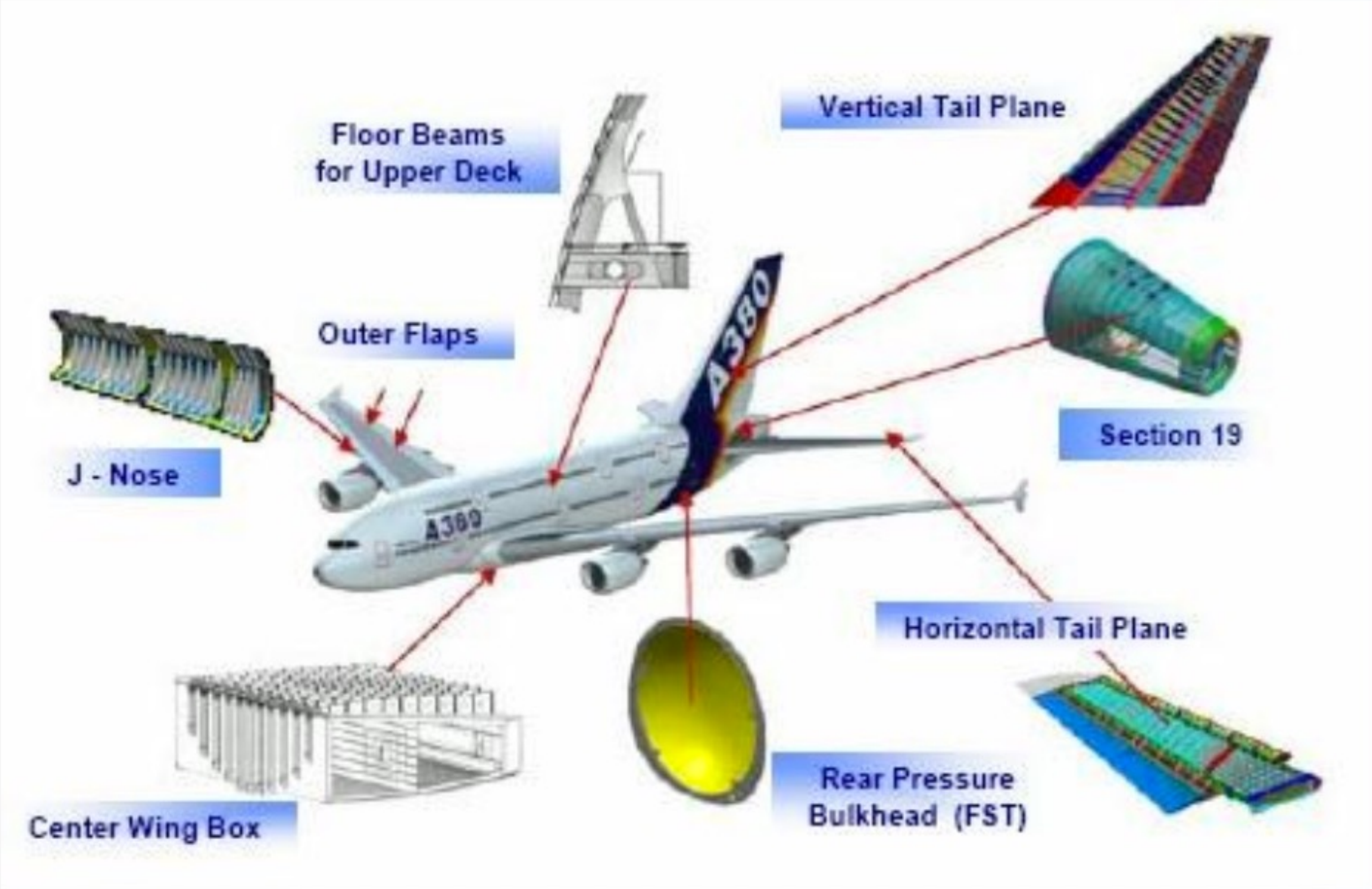
Several new programs considering composites at high rates



A – 380 “Super-Jumbo”

- **Entry into service 2007**
- **Many innovative composite applications**
- **25% structural weight in composites**

Composite Innovations on the A380



Source: EADS Deutschland