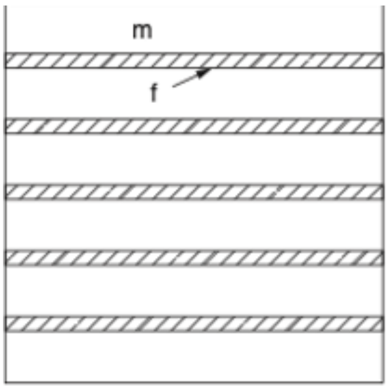
Materials 2 Questions set 7, Comments and answers
Composite materials, and including cellular solids

1. For fibre reinforced composites, to determine properties e.g. the elastic modulus we can use the rule of mixtures. Imagine you're asked to explain both the upper and lower bound rule of mixtures to a first year engineering student who's not familiar with it. Design a way to illustrate/convey both forms of the rule of mixtures using 'everyday' materials. Use a sketch to convey your answer.

It'll be interesting to see what people come up with.
An idea:
cf. figure below.
Two fabrics joined together.
One fabric one is stretchy [corresponds to low modulus];
the other fabric is unstretchy (almost rigid) [corresponds to high modulus].

Pull in different directions; it will stretch more in configuration in Fig 6.3 (b); and barely stretch (perhaps imperceivably) in configuration in Fig 6.3.

The dimensions of the fabric strips could be changed to alter the proportion of the two materials.



Slide 59 in slide set for composite materials

Rule of mixtures

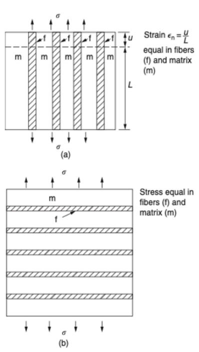


FIGURE 6.3
A fiber-reinforced composite loaded in the direction in which the modulus is (a) a maximum, (b) a minimum.

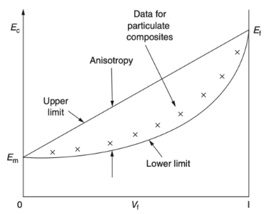


FIGURE 6.4
Composite modulus for various volume fractions of stiffener, showing the upper and lower limits of Equations (6.7) and (6.8).

$$E_c = V_f E_f + (1 - V_f) E_m \quad (6.7)$$

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.

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

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

Ref: Engineering Materials 1

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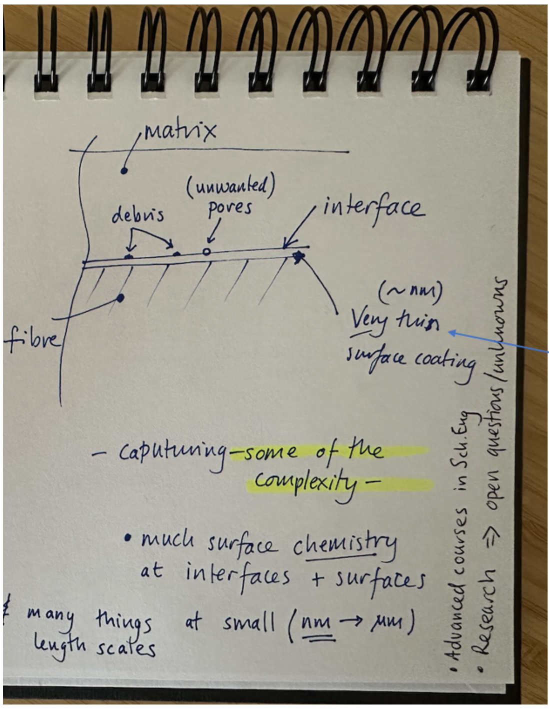
2. The rule of mixtures approach works with ideal/‘perfect’ composites. But in practice materials are more complex and <u>very</u> rarely perfect. Make sketches to show what aspects and imperfections can affect composites in practice.

Slides 61 & 62 from slide set deal with this, and also recognise that this is a huge subject.

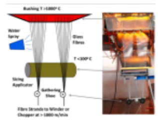
Be aware of the following in engineering practice

In practice defects and imperfections that occur in processing (or that develop when materials are in use) can be extremely important as they can dominate the behaviour of the material /component.



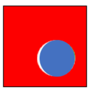
Interfaces and surfaces
much science & open research questions

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

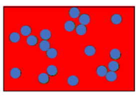


Potential challenges

- **Poor bonding between phases**

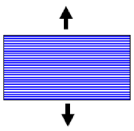


- **Poor dispersion of reinforcing phase**

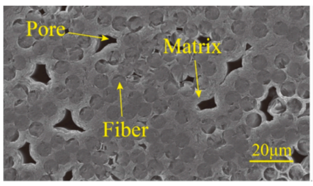


- **Anisotropy**

often beneficial – but can be problematic

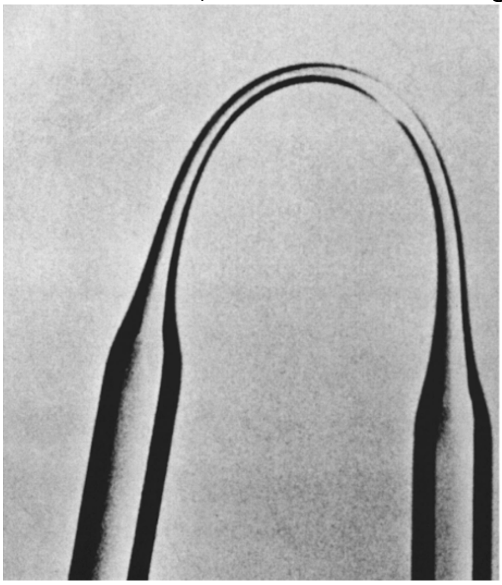


• pores in the matrix



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

3. Below is an image of a bent glass rod
(from JE Gordon, New Science of Strong Materials, 1968)



In an earlier seminar we bent a steel paperclip, which looked similar to the shape of the glass rod above. But typically, you can't bend a normal piece of glass, why not? How could this behaviour link to composites?

You typically can't bend glass as it has flaws or cracks on the surface (see slides 10 & 11 in slide set; slide 11 below), these act as stress concentrations, and the cracks propagate [grow] through the material – this is covered more in the section of the course on deformation & fracture.

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 ×.

Glass fibres, similar to the one above, are used in reinforcement of polymer composites; and those fibres are small (e.g. typically c. 5 to 20 microns diameter) compared with glass we typically think of e.g. in windows.

Fibres can be exceptionally strong (also see video mentioned in lecture on slide 13 – where this is mentioned). That's largely because they can be perfect [i.e. not have flaws or defects] because they are so small, it is also influenced by the way the fibres and the composites are manufactured.

Having stronger fibres results in stronger composites. (Note this is a further application of the rule of mixtures. When we have used the rule of mixtures in the course so far, we have used it to predict elastic modulus).

Anthony Kelly: Composite materials and carbon fibre

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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=IZUI56XLD5Y&t=5s

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4. Give three examples of the use of composite materials in engineering applications, and briefly consider their advantages and disadvantages (use a few bullet points in your response).
This question is open ended
Carbon fibre – epoxy used in bike frames
Advantages: excellent combination of modulus and density – giving lightweight bike frames (or exceptionally stiff track bike frames) – see slides 31-33 in composites slide set
Disadvantages: high cost, and again recycling/sustainability is an issue

Glass fibre – polyester used in greenhouse panels. Advantages: stiff enough, relatively cheap
Disadvantages: can become brittle over time, possible issues with joining panels, and recycling/sustainability

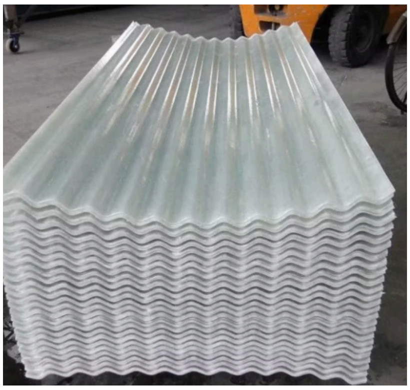

Image: glass fibre greenhouse panels

Glass fibre – epoxy used in wind turbine blades
Advantages: can be made consistently in huge sizes
Disadvantages: recycling/sustainability is an issue – see question 6 (which has some possibilities for what can be done differently).

5. a) Give examples of cellular solids* (foams, porous materials) that are used in engineering because of their chemical, mechanical and thermal properties (use a few bullet points in your response).
*NB in the course we use the terms cellular solids, foams, porous materials to mean materials with holes or pores. The specific terminology, and its usage, varies between the different technical domains where the materials are used.
This question is open ended

- Metal organic frameworks used for adsorption, gas separation and catalysis
- Expanded polystyrene foam EPS Cycle helmets, used for impact absorption
- Fibre glass thermal insulation – used for house insulation

b) Investigate and discuss one cellular solid, or porous material, what are its advantages and disadvantages/challenges?
Ideally, choose something that interests you, this can be in engineering, or outside conventional engineering. Use the WHAT framework to structure your response; but you can go into more depth in an aspect(s) of the WHAT framework, if that interests you. Use bullet points and sketches appropriately (aim to write about a page).

This question is open ended. In investigating this aim to find out something you didn't know before. Some possibilities you could consider protective helmets that absorb energy, RAAC, aerogels, foams in food, foams of ice i.e. snow, metal-organic frameworks e.g. in chemical adsorption.

Suggestion: you could use bullet points, or tabulate your findings and use sketches/images to illustrate key points (e.g. small scale structure) cf. the example of the superalloy turbine blade in the first lecture:

6. FASTBLADE will test many tidal turbine blades during its operation. This will help to accelerate the development of a very promising renewable energy technology. At the same time, however, most blades being developed are manufactured using thermoset polymers, which are not recyclable. How can we dispose of the thermoset blades at the end of their

life? How can we improve the sustainability of both tidal turbine blades and wind turbine blades? Write about three bullet points in response to each question.

CORE+: Huge open ended question.
This BBC's article is really nice and captures many of the existing ideas on this: https://www.bbc.co.uk/news/business-68225891#:~:text=Between%2085%20and%2095%25%20of,of%20hammering%20by%20the%20elements.

[[James Maguire] one of our former colleagues went to a conference on composites sustainability and saw a lot of nice ideas too.

First part
- A popular suggestion for existing blades is to grind them down and use them in cement manufacturing (resin as fuel for the kiln, glass to replace some of the raw ingredients – not sure which ones).
- There are pyrolysis and solvolysis techniques that aim to reclaim the fibres by burning off or
dissolving the matrix, respectively. I believe some of the raw chemical components of the resin can be recovered too, but both seem like they could be quite polluting processes.
- There is the suggestion that we should reuse blades as structures or structural materials first
(see Figures 4, 5, and 6 below). My feeling is that people will get sick of seeing structures made out of turbine blades (Fig 4), but I loved the idea TU Delft had to cut them into standard sections for construction (Fig 5 and 6)

Second part

- Reduce, reuse, recycle.
o Make more efficient structures (thanks FASTBLADE!)
o Make them out of recyclable composites (thermoplastics), or with a more easily degraded (biodegradable?) matrix. Some companies are developing recyclable epoxies with "cleavable" crosslinks i.e. crosslinks can be broken in acid. There's also quite a bit of advancement being made on aligning of recycled fibres, to improve properties (some collaboration being done on this with Ansys-GRANTA, see Fig 7 below).
o Find inventive ways to reuse the structures, or structural components, before breaking them down further to be recycled.
o Use recycled materials in the blades e.g. foam core made from recycled PET

Fig 4. Reusing blades for pedestrian/cycling bridges in Ireland; research from Georgia Institute of
Technology, University College Cork and Queen's University Belfast.

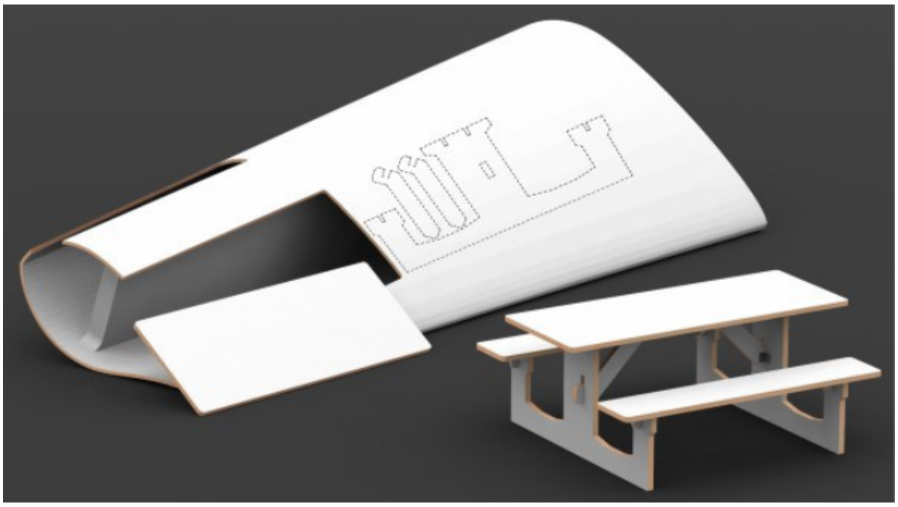

Fig 5. Concept for harvesting construction materials from wind turbine blades at the end of their life; research from TU Delft.

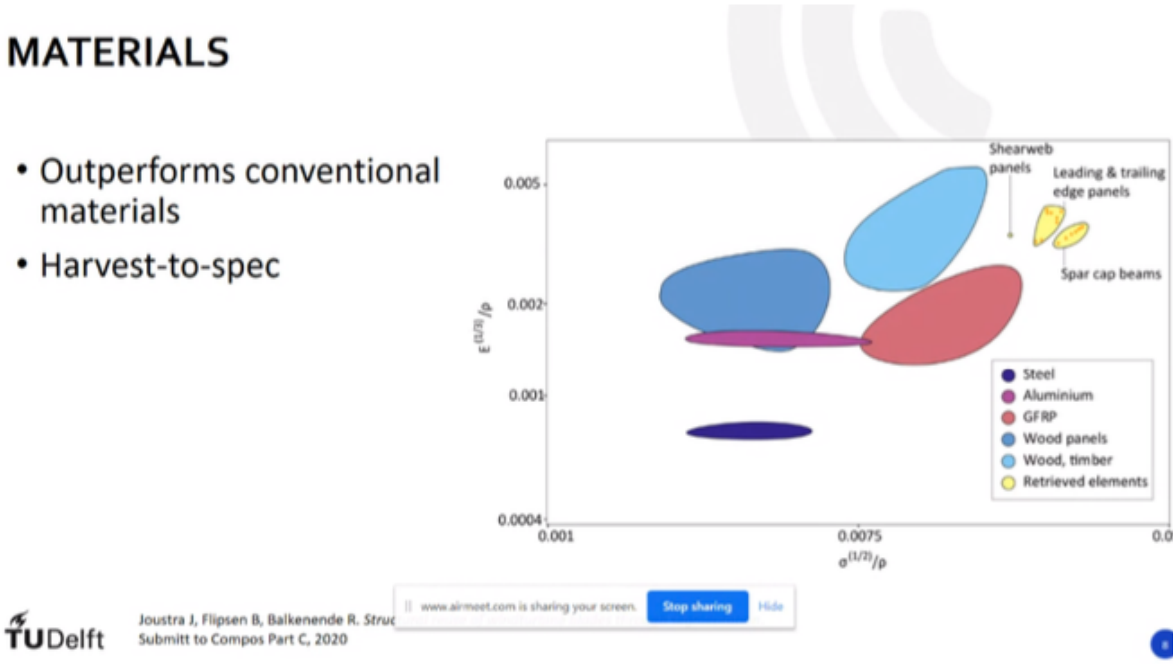

Fig 6. An Ashby map showing the mechanical properties of reused wind turbine sections; research from TU Delft.

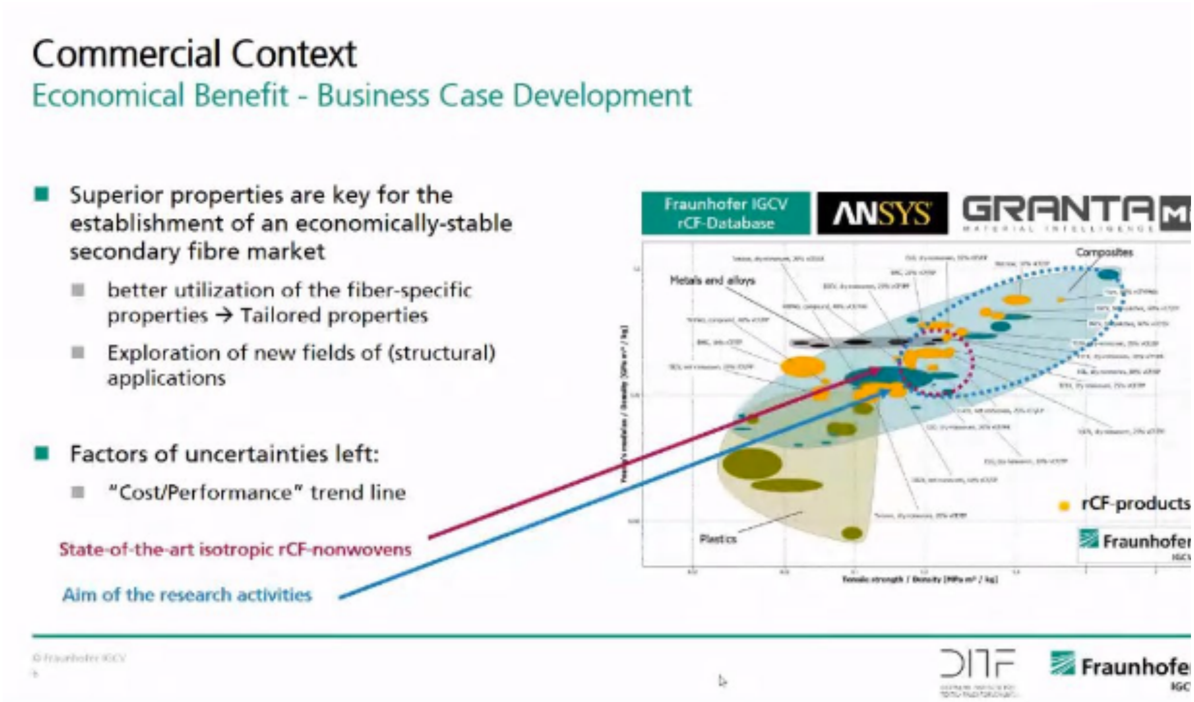

Fig 7. Ansys-GRANTA Ashby Map showing the mechanical properties of recycled carbon fibre materials relative to other materials; research by Fraunhofer IGCV.

Extra

This is a paper from colleagues in the Composites research group in Engineering in UoE, with some promising ideas around sustainability:

Repair of acrylic/glass composites by liquid resin injection and press moulding, Alp Bolluk, Machar Devine, James A. Quinn, Dipa Ray, Composites Part B 281 (2024) 111513

https://doi.org/10.1016/j.compositesb.2024.111513

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