Materials 2 Questions set 2, Comments and answers
Materials Properties

1. Define density and state its SI units.
Note: when you define properties of materials give the defining equation and state what the symbols mean.

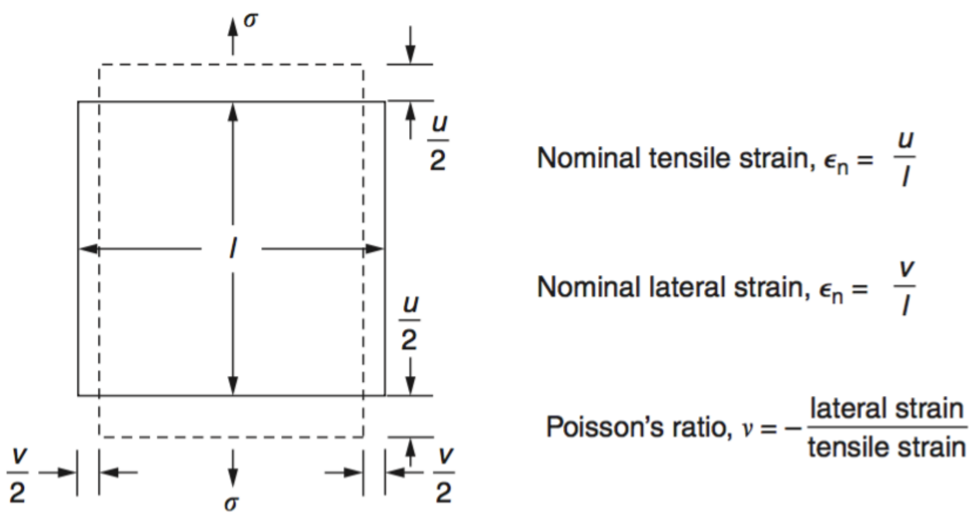
$\rho = m/v$
where ρ is density, m is mass, and v is volume
SI units: kgm^{-3}

2. Define stress, strain, Young's modulus, and Poisson's ratio and state the units where applicable.

stress = force / area
SI units: Pa (or N/m^2)

strain = change in length / original length
strain has no units

Young's modulus = stress / strain
SI units: Pa (or N/m^2)



(from p35 Engineering Materials 1)

3. Why do we use density, Young's modulus and stress when we define material properties rather than mass, stiffness and force?

Because they define the [intrinsic] properties of materials. Whereas mass, stiffness and force characterise the properties of an object, although the properties of an object depend on the properties of the material it is made from.

In engineering the properties of an object are important (rather than a material for its own sake). Part of the process in design is clearly defining the properties that an object requires and then choosing a material(s) that will fulfil these needs. This is the essence of **material selection**.

For example, a beam that requires a certain stiffness could be made from either steel or timber, but the dimensions would be different (the steel would be thinner).

4. Define thermal expansion and thermal conductivity and state the units where applicable.

$\alpha = \frac{1}{l}\frac{dl}{dT}$	α thermal expansivity l length T temperature Units K^{-1}

- Definition

$$J_q = -\lambda \frac{dT}{dx}$$

λ thermal conductivity
J_q heat flux density (heat flow per unit area)
dT/dx temperature gradient

Units [energy/(time x length x temperature)]
W/mK

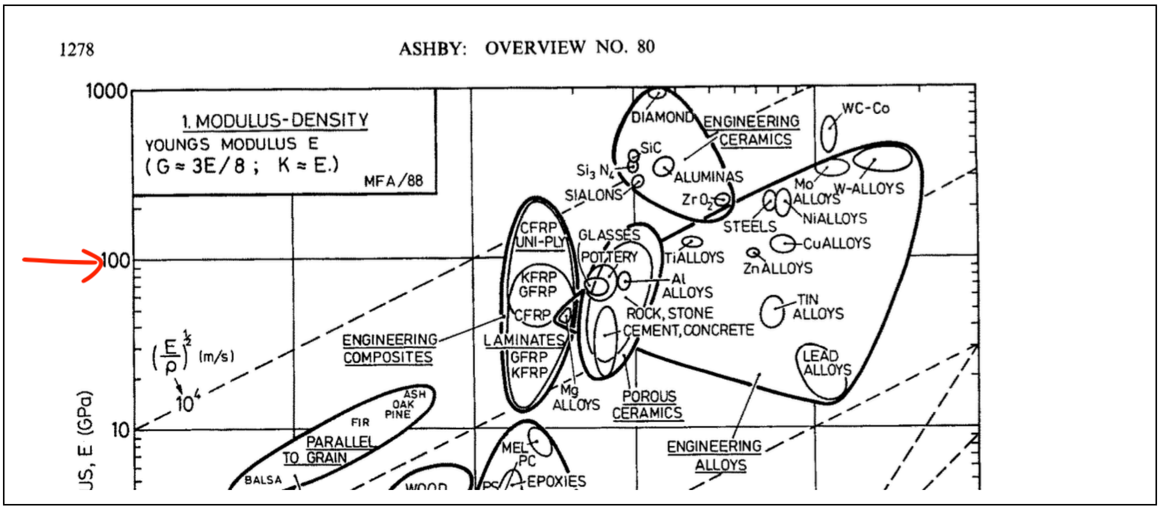
5. Consider the following materials:
aluminium, brick, iron, polyethylene, rubber, silicon carbide (SiC), steel
(a) State which classification each belongs to, choose from metals, ceramics, and polymers.
metal: aluminium, iron, steel
ceramic : brick, silicon carbide (SiC)
polymer : polyethylene, rubber

(b) For each material give approximate values, and state the reference source you use to find the data, for the following properties: density, Young's modulus, strength, Poisson's ratio, thermal expansion, thermal conductivity, approximate maximum temperature of use.

This data can be found in Ashby 1989, the videos on properties, and in the Granta software.

(c) For consideration and discussion in the seminars: what can you sense of feel kinaesthetically in a metal, ceramic, and polymers in relation to these properties?
The purpose of this question is to ‘bring materials into real life’ – as physical stuff that you can handle and interact with and get an actual ‘feel’ for the properties. Rather than properties being numbers that you read in a table, look up on an Ashby chart (from Ashby 1989 – on a screen or on paper), get from the Granta software, or from Google.

Within this there is a development of skills in terms of linking the qualitative, or semi quantitative, feel of a material that you get kinaesthetically from handling real stuff, with the quantitative (or semi quantitative) values of properties that you use in calculations. For example when you come across a Young’s modulus value of 100 GPa – what does that bring to mind?
For me it’s a material that’s less stiff than steel, but stiffer than aluminium; it’s likely to be a metal, possibly a ceramic, or an engineering composite e.g. a glass fibre epoxy composite. Then I’d go and look at Ashby 1989 to check my intuition, (which was reasonable).



Further commentary:
The stiffest ceramics are much stiffer
I find it interesting how a large a range of stiffness it is possible to ‘design’ into composite materials, we will cover more on composite material in the second half of the course in ‘Materials Stories’.

6. Imagine a pint glass that’s filled with soft, fluffy, fresh snow. If you took the snow and made it into a snowball (a) estimate what diameter the snowball would be. If the snowball then melts, (b) what volume of water do you estimate it will be.
State any assumptions you make in answering this question.

Estimate1:
(a) approx. 100 mm diameter
(b) approx. 1/7th of a pint

[JB] based on my knowledge of snow and making snowballs, and a simple experiment in 2021 – see images below. It’s striking how much more air than ice is in a full pint of snow (left image below). In terms of the behaviour of ice and snow – in some ways they are the same as they are both made of ice, but the amount of porosity in snow means it often behaves very differently. Snow that has settled on the ground is often considered as a *foam* of ice.

		
Fresh snow. The glass was originally full. Note it has already settled a little during the time it took to set up the camera.	Melting snow. The snow at the top is still 'snow' (ice particles surrounded by air; and perhaps some water because of the melting), while at the bottom of the glass it is snow, as ice particles, surrounded by water – this has much higher density than fresh snow.	Water from the melted snow.

Estimate 2, semi quantitative calculation (using values for snow and water density; and knowing the volume of the UK pint glass):
The density of fresh show is say 150 kgm^{-3} (typical ranges 50 to 200 kgm^{-3}), my estimate for the density of a snowball is 450 kgm^{-3} (this will vary, it will be higher if it is wetter, or lower if you don't compress it so much), the density of water is 1000 kgm^{-3}.

(a) approx. 70 mm diameter
Using starting density of 150 kgm^{-3}, at volume 1 UK pint (568 ml), compressed to sphere of density 450 kgm^{-3} (volume of sphere $v = 4/3\ \pi\ r^3$)
(b) approx. $1/7^{th}$ of a pint

7. Concrete comprises aggregate plus cement. Explain how the measurement of density is affected by the size of the concrete sample, and estimate approximately how large a sample you need, to get a reliable measurement. Explain your reasoning.

An estimate: a piece about the size of a tennis ball (larger is fine too; but not so large it is difficult to handle). Based on the following reasoning: estimating the largest aggregate particles to be about 10 mm in diameter it means we will have about 10 of them across the diameter of a 100 mm diameter sphere.

As a rule of thumb (i.e. an approximation) when you want to measure properties of a "composite" material it is good to have at least 10 "structural features" in a line across a cross-section. For example, if the largest aggregate is about 10 mm the **minimum** size for your test specimen would be about 100 mm diameter. But this is a rule of thumb – and you should think about what it is you are measuring and what it is you want to find out.

8. Ashby maps can be used for:
[See slide 19 in the properties video/slides; and p1292 of Ashby 1989].
A simple way to get approximate data, e.g. for 'back of envelop' calculations.
To check data from another source; to check it is of the right order of magnitude.
Materials selection. This will be covered later in the course.
To explore the nature of data, including 'new materials looking for applications'.

The following is important in terms of linking these maps i.e. **properties** to **small scale structure**, which is the next part of the course.
"The most striking feature of the charts is the way in which members of a material class cluster together… The position of the fields and their relationship can be understood in simple physical terms: the nature of the bonding, the packing density, … and so forth." [Ashby 1989, p1292]

9. What relationships, or patterns, can you find between density and other engineering material properties in Ashby's materials selection charts?
For this question use Ashby's materials selection charts you can find these in the video slides, in the Library Resources (including M.F. Ashby, On the engineering properties of materials (Overview No. 80)*,* Acta Metall, 37, 1273-1293, *1989).*

- as density increases Young's modulus tends to increase
- as density increases strength tends to increase
- as Young's modulus (or density) increases linear expansion coefficient tends to decrease

It's also useful to look for exceptions to the trends or patterns too. As a general trend as Young's modulus increases stress (e.g. yield stress) increases, however for steel Young's modulus has essentially a single value while yield stress exhibits a wide range of values.