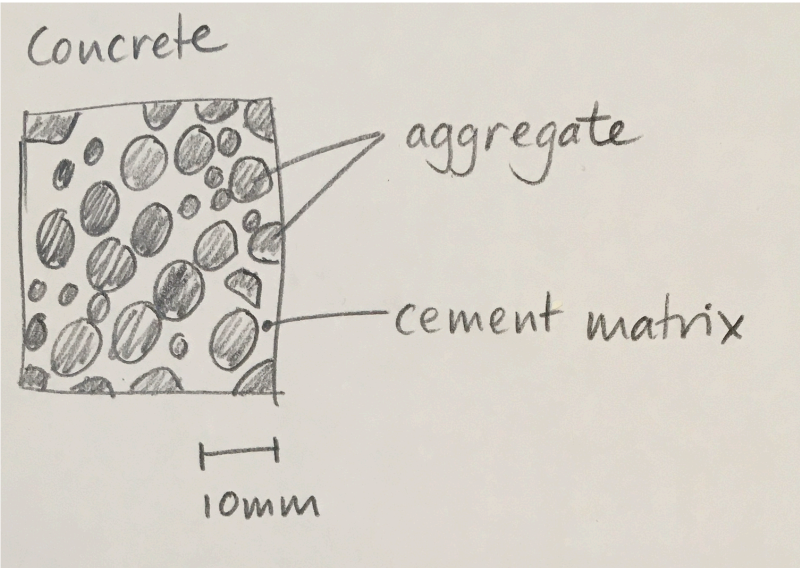
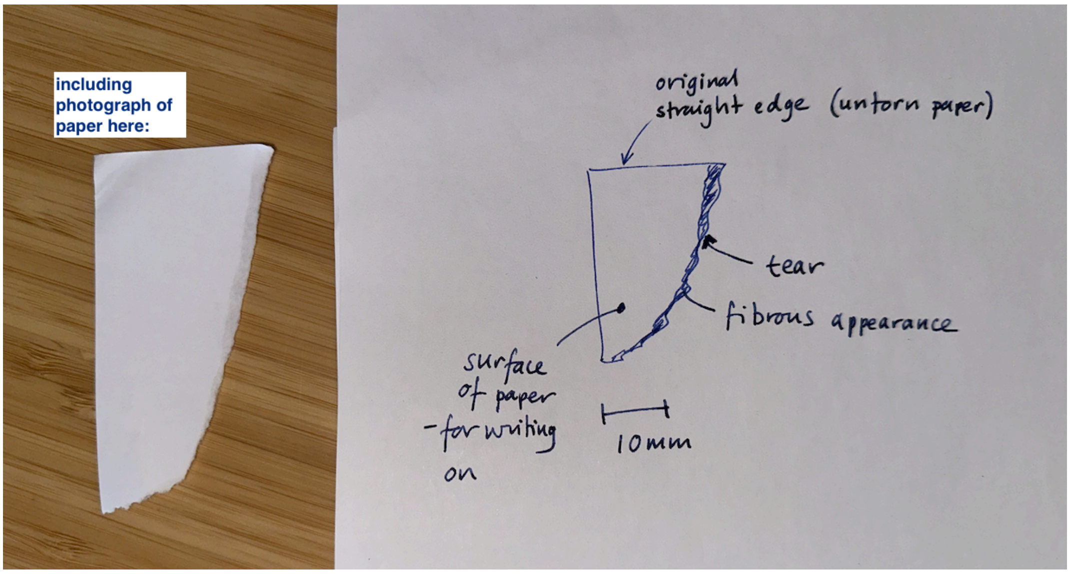
Materials 2 Questions set 3, Comments and answers
Small scale structure of Materials, and Sketching

1. When we look at a cut surface of wood, we can see the small scale structure of the material (you probably know this from ‘everyday knowledge’). Make an annotated sketch to describe another example of small scale structure that you can observe in materials (using your eyes), include a scale bar in your answer.

Examples: Concrete, and paper



Paper



The images above show what can be **seen by eye** when observing a piece of torn paper. Left: photograph. Right: sketch of the torn paper. The annotations on the sketch indicate key features.

Note that this is one example of a sketch. There are more possibilities of what could be observed, and hence sketched.

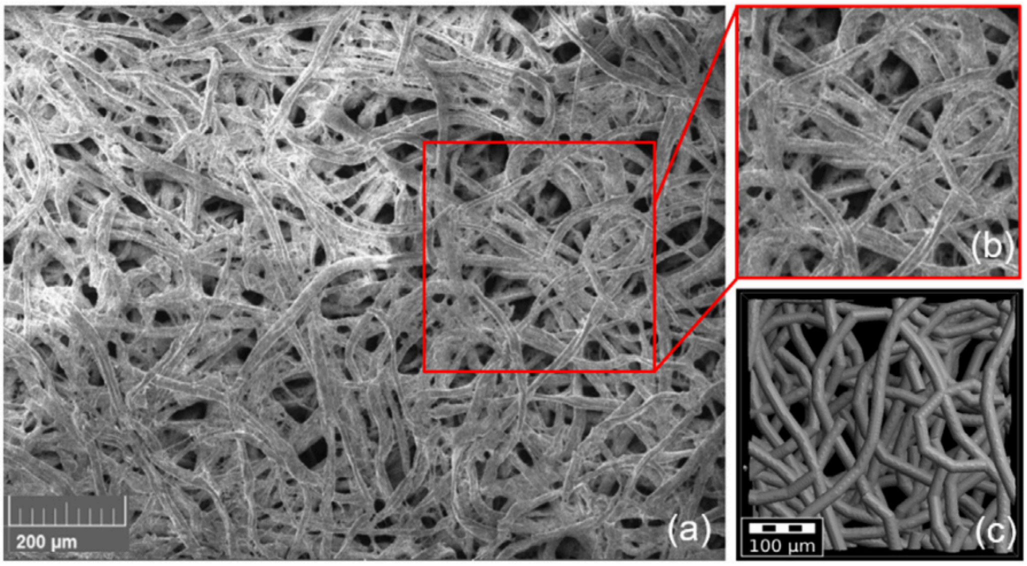
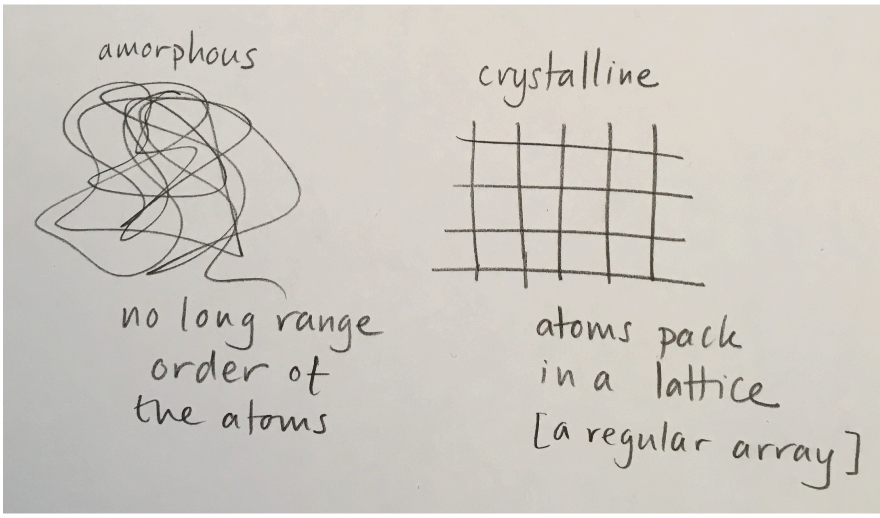


Fig. 1. a,b SEM image of Linters paper (Image courtesy by J. A.) vs. c Artificially generated fiber network sample.

The figure above shows the small scale structure, or microstructure, of paper.
Images (a and b) are of a real material, taken using a scanning electron microscope, which allows the 3D nature of the structure to be seen; image (c) is computer generated for use in modelling. Note that the width of the image in (a) is about 1mm across.

[Reference: Data-driven microstructure sensitivity study of fibrous paper materials Binbin Lin, Yang Bai, Bai-Xiang Xu, Materials and Design, 197 (2021) 109193]

2. Make simple annotated sketches to show the difference between amorphous and crystalline materials.



Give an example of a material that has an amorphous structure and of a material that has a crystalline structure.
Silica (SiO_2) as glass (amorphous).
Silica (SiO_2) as quartz (crystalline).

3. State approximate values for density, strength and Young's modulus for magnesium (Mg) alloys, state your reference source. Comment on the values, given that some small scale structures in materials are essentially fixed, while others we can modify.

[From Ashby, 1989 – **approx.** values taken from plots in the paper]
for magnesium (Mg) alloys
density 1.7 Mgm^{-3} (1700 kgm^{-3}, in SI units)
strength 90-300 MPa
Young's modulus 50 GPa

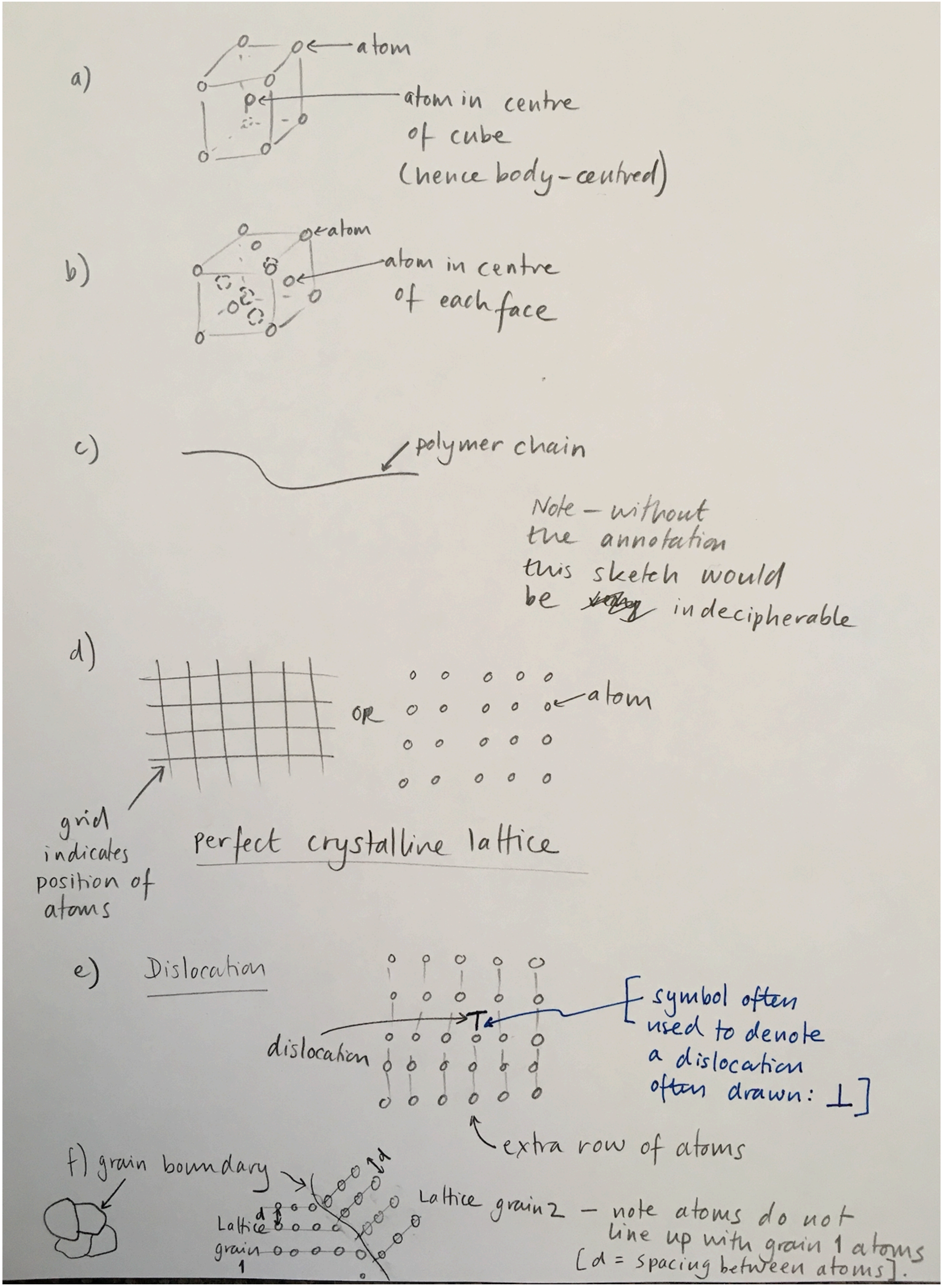
Young's modulus and density have narrow ranges – these properties depend mainly on the bonding which is essentially fixed.

Strength has a much larger range because it depends more on the microstructure which can be altered. This links to strengthening mechanisms in alloys – see videos/slide set: *Small scale structure-metals ceramics polymers-with links to practice-all slides-V2.pdf.*

4. Make annotated sketches of
(a) bcc unit cell, and give an example of a material that packs in this manner:
iron at room temperature
(b) fcc unit cell, and give an example of a material that packs in this manner:
iron above 910 ˚C
(c) a polymer chain

(d) a perfect crystalline lattice
(e) a dislocation in a crystalline material
(f) a grain boundary in a crystalline material

While all these structures are in the videos/slides, when you sketch them you engage with them differently and for many people it helps their learning and understanding.



5. Define the term phase.
From: Materials 2 small scale structure-slides from videos Parts 1 and 2.pdf (slide 57)

Definition of phase: regions of a material having a specific chemical composition and atomic arrangement.

Phases can be solid, liquid or vapour states. In Materials 2 we focus strongly on phases in the solid state. Over the years in teaching materials, I've found it's often not intuitive for students that one solid material can have multiple solid phases within it (this should become clearer when you learn about phase diagrams, and when you observe microstructures and can identify the different phases in them).

6. In engineering we often assume materials are isotropic and homogeneous. From your knowledge and understanding of materials so far (from the course and from everyday knowledge), what examples can you find of when these are good assumptions to make, and when they are not. Use annotated sketches to illustrate your answers.

From: Learning outcomes: small scale structure (video/slides)
deeper learning outcomes
In engineering, an assumption can be made that: materials are isotropic and homogeneous.
Begin to develop you decision making: when is this a good assumption, and when not?

Note the learning outcome is that you **begin** to develop you decision making. This question can be complex – and is often not a straightforward yes/no answer.

Homogeneous refers to the uniformity of the structure of a material; the opposite of homogeneous is inhomogeneous. Isotropic refers to the uniformity of physical properties; the opposite of isotropic is anisotropic.

Examples of homogeneous structures: Q7a, b.
Examples of inhomogeneous structures: Q7c, d.

Everyday example: sponge cake is homogeneous, fruit cake should be homogeneous (but if all the fruit sinks to the bottom of the cakes it's inhomogeneous).

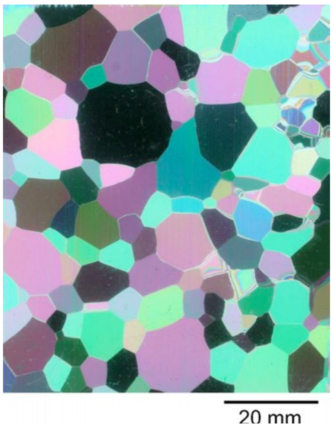
It is often a reasonable assumption that metallic alloys and many ceramics and many polymers are **isotropic**.

Anisotropic materials (that are also inhomogeneous): long-fibre reinforced composite materials, wood, and celery (stringy vegetable)! In addition [extra – as we do not cover this specifically in the course]: directionally solidified alloys such as nickel superalloy turbine blades.

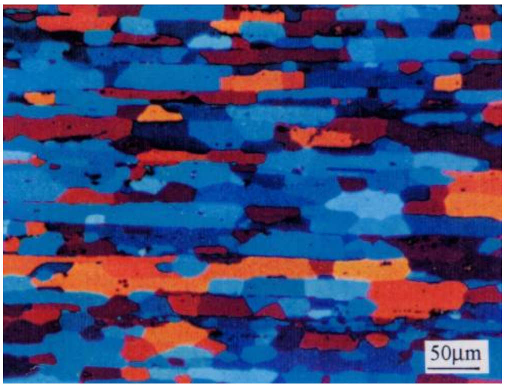
7. Make representative labelled sketches of the following images of microstructures.

A comment on the usefulness of sketching: when you sketch you tend to notice more features in an image than by looking at it quickly or taking a photograph. Sketches, with labels or annotations, are excellent ways to convey information in materials and engineering.

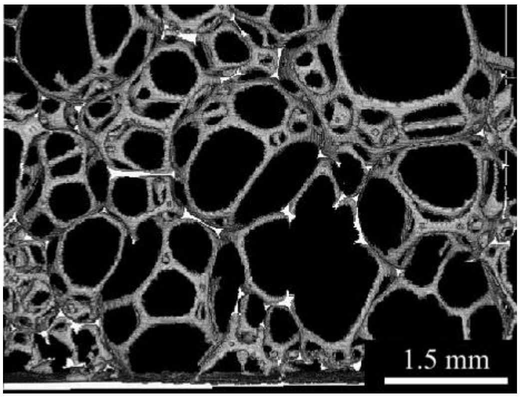
a



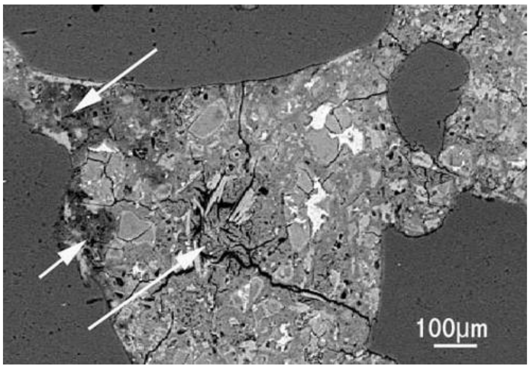
b



c



d



- This question is about observing and noticing.
- It is unusual as normally you would know something about the material you have an image of; the aim of this question is that you look carefully at what's there.

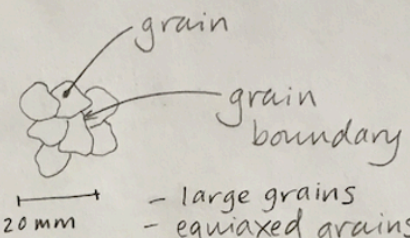
Sketching questions

Make representative labelled or annotated sketches of the following microstructures

- representitive ⇒ you do not need to sketch the whole image. But you need to sketch key features

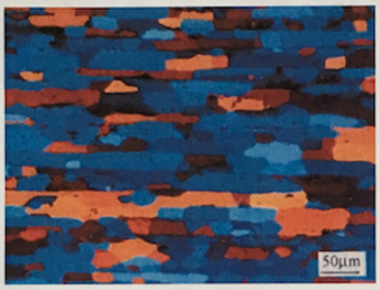
a

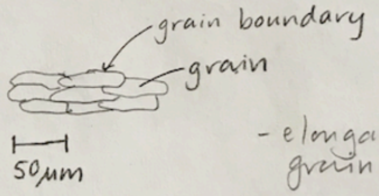
20 mm



- large grains
- equiaxed grains.
- grains different colours

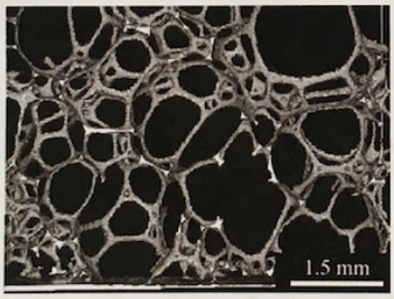
b

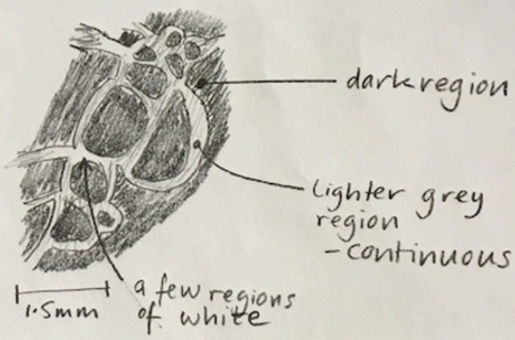




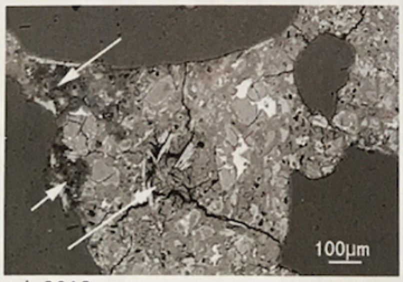
- elongated grains.
- grains different colours

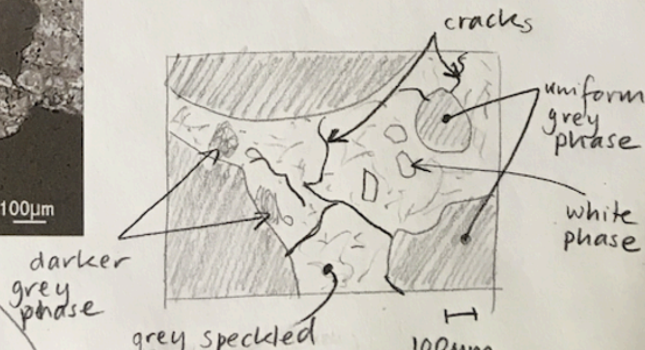
c





d





JRB March 2018

NB the arrows on the image point to (i) the darker grey phase (I saw these regions when I asked "what are the arrows showing?") and (ii) cracks.

3

The primary aim of question 7 is that you observe the microstructures – by making sketches you observe them more closely. The aim of the question was not to identify the materials – although you may have some ideas of what they are, and you may have noticed them in the videos/slides. However, in practice we generally want to know what the materials are, so: (a) is ice, (b) an aluminium alloy, (c) polymer foam, (d) concrete – this image is taken at a rather high magnification (cf. sketch in answer to Q1).

8. The microstructure movie has a series of images of the small scale structure in materials. A selection of images from the movie are shown below. In the movie we asked you to simply observe them – perhaps with a sense of curiosity. We want you to take this further and begin asking questions about the images below:

- What do you notice in the images?

This question is 'simply' about observing what you can see in the images. This is a powerful skill to develop in engineering, and extremely useful in materials science and engineering.

- How big are the images?

The images in the question had the scale bars removed – they have been added in the images below. It is important to indicate the scale on microstructure images to know how what the dimensions are. In 'everyday' photographs we know this because we're familiar with the dimensions of – for example – people, cars, trees or buildings, but this is not the case with microstructures – for example the microstructures in Q7 (a) and (b) are of rather similar polycrystalline materials – but the length scales are several orders of magnitude different (on an A4 sheet the image of ice in 7a is actually smaller in real-life than it is on the page – the grains are unusually large).

- What are the materials?

See details given on each image below.

- If you are not sure what a material is, how might you find out?

This question is open ended.

[see **Resource** given in solution to Q3 Question set 1, copied here]:
Techniques for identifying different material classes (it is useful to know about this information and how much detail you can go into; core+) https://www.doitpoms.ac.uk/tlplib/artefact/metals.php
https://www.doitpoms.ac.uk/tlplib/artefact/polymers.php
https://www.doitpoms.ac.uk/tlplib/artefact/ceramics.php

In answering this, the following approaches are useful, especially when used together:
• Characteristic appearances and
• Getting more information

Characteristic appearances: when you become familiar with microstructures in materials is often possible to identify them. For example, the microstructures of carbon steel in the virtual lab are typical of these steels, and with experience could be identified well with a good degree of certainty.

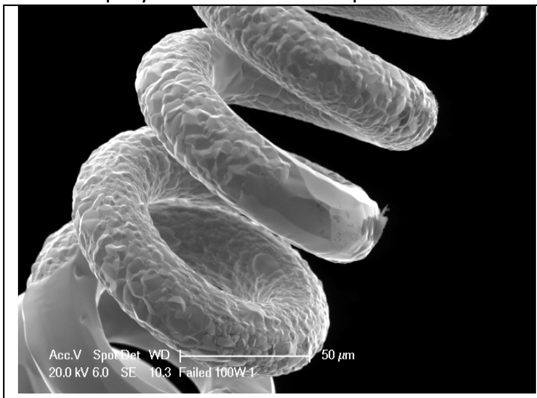
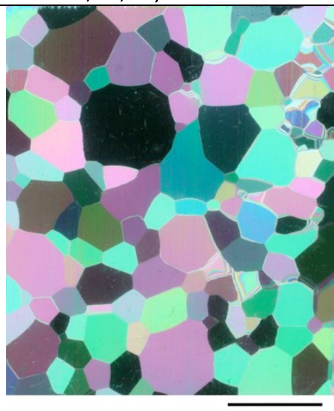
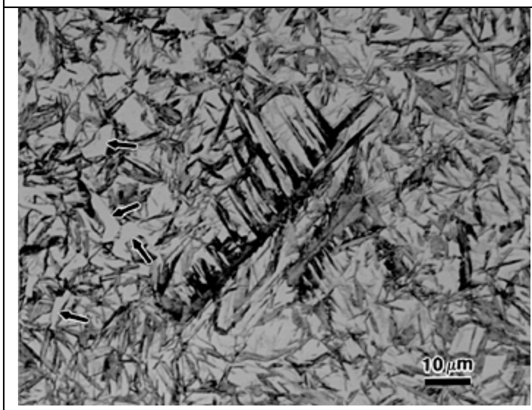
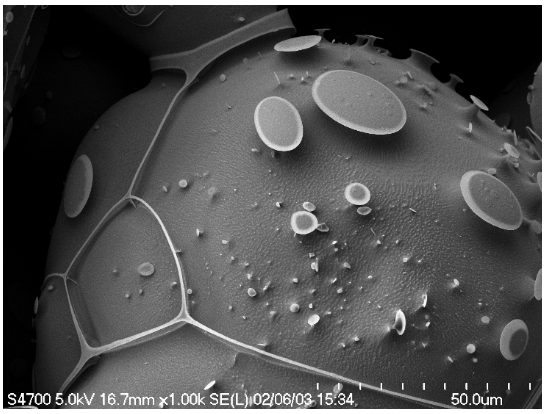
Getting more information: often when you have an image of microstructure you will have more information too, and the key is linking the information and perhaps doing more investigation to discover what a material is. More investigation can begin with asking questions – including questions about "what are useful investigations to do?"

[core+, extra – I would not expect you to know this] For example I took the image of the tungsten lightbulb filament and I knew I put a light bulb filament into the scanning electron microscope (common sense). I also knew lightbulb filaments are made from tungsten, but if I had not known this

(i) I could have used **Resources** (e.g. google) to investigate further, and (ii) in a scanning electron microscope it is possible to detect what elements are present in a material. This is because of the interaction from the electron beam, which scans over the sample and an imaged is created, and the material – the sample material emits a signal (characteristic x-rays) that is characteristic of the elements in the material.

• What other questions can you come up with? this depends on your curiosity and purpose

More details for three of the images below (*) are given in slide set (and videos) 'Small scale structure-metals ceramics polymers-with links to practice-all slides-V2.pdf' (slides 15,78,79).

 tungsten light bulb filament (SEM)	 ice (thin section, viewed in polarised light)
 martensite (steel rapidly cooled from above 900˚C, quite high carbon content – likely Fe-0.8C) *	 tempered martensite (tempering = heating to > 450 ˚C, and < 750˚C for enough time to allow the microstructure to spherodise; quite high carbon content – likely Fe-0.8C) *
 mm bone – cross section, ex-vivo (outside the mammal, and dried) *	 water droplet + NaCl, cooled in liquid nitrogen, then held at -20˚C. Grey parts = ice, white parts = frozen NaCl solution liquid; although not liquid in the image, as the sample is at about – 140˚C