Materials 2 Questions set 4, Comments and answers

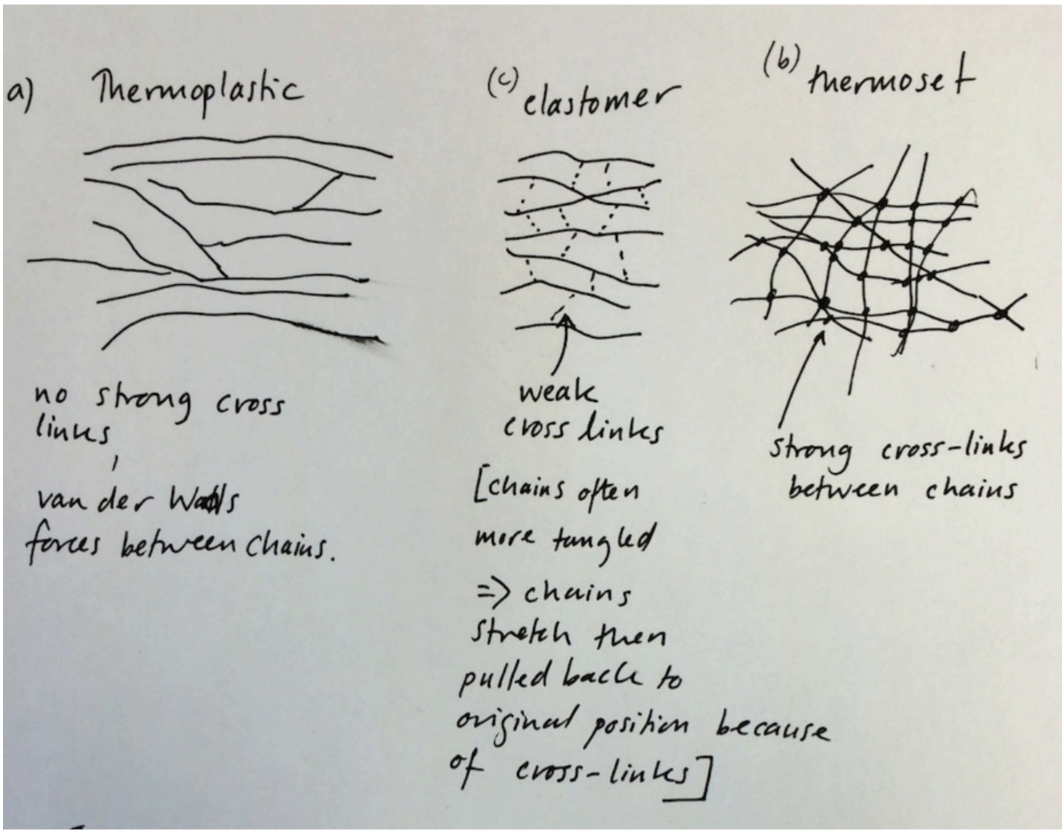
Small scale structure of metals, ceramics and polymers, and their behaviour

To give you context for these questions:
Questions (i) to (iii) are about basics you need to be clear on.

Questions 1-5 ask you to make, and give you practice in making, links between what we did in the section of the course about **properties**, and **small scale structure** (or **microstructure**). At first glance the materials we use may appear trivial, but they have been chosen carefully – as they illustrate important aspects of properties and microstructure and they will allow you to integrate your understanding of these, and to deepen your understanding by handling **real materials** and **observing – with curiosity and care –** and **bringing awareness to what you see and feel,** and linking back to what we covered in the videos and what you can read about in textbooks**.** A paper clip and a piece of polyethylene sheet are weak enough for you to be able to deform them easily by hand, but strong enough that you can feel the forces involved in the deformation, and to feel how these forces change as you move the materials. The concepts involved in these movement and deformation processes are important for many engineering materials, including the most sophisticated alloys, e.g. nickel superalloys, and advanced polymers.

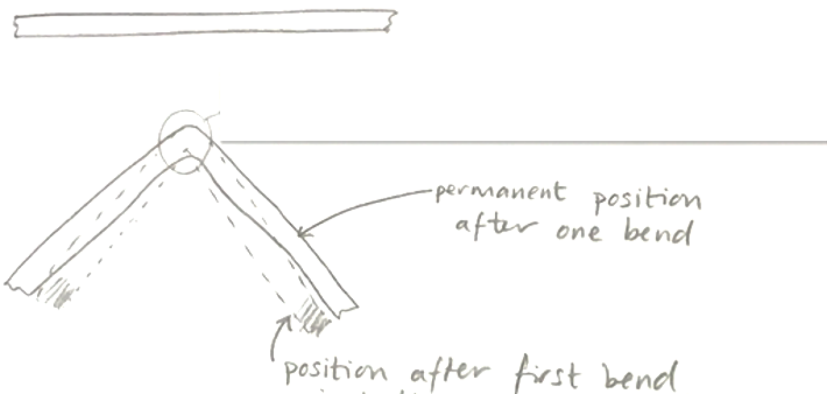
(i) In metals processing, drawing is an example of cold-processing. What is cold processing? What is drawing?
Cold processing, generally called cold working, is the term for processes that are performed at room temperature (or up to about 200°C for some metals). Cold working leads to anisotropy and increased stiffness and strength in a metal.
[https://www.doitpoms.ac.uk/tlplib/metal-forming-2/printall.php]
Drawing is a process to shape metal. In the case of steel rods or bars, the cold metal is pulled through a die, which reduces the diameter of the rod by plastically deforming the steel.
(ii) Annealing is another type of metals processing. What is annealing?
Annealing is a heat treatment carried out on metals generally after they have been cold worked. It alters the internal structure and tends to make the metal more ductile and lower the yield strength.

(iii)What are the three polymer subsets? Give an example of each type and sketch the structure.
The three polymer subsets are thermoplastics, elastomers and thermosets. Polystyrene is a thermoplastic, polyurethane is an elastomer and polyester is a thermoset.

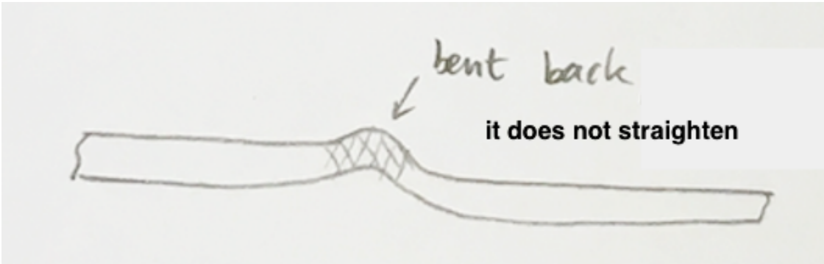


1. Consider a steel paperclip.
(a) Bend it. What happens?
Typically in sessions most people bend the clip rather a lot and it bends, as shown below. But if we slow down our approach and apply a force more gently, we notice it deforms slightly and if we remove the force it returns to its starting position.

An **extra** note, making links with structural mechanics. For those of you who have studied **structural mechanics**, in an introductory course and as an engineering approximation that often works well in practice, you make assumptions that the behaviour of the material is elastic. So what we cover in this question set that goes beyond the elastic behaviour is outside the behaviour that you've dealt with in structural mechanics. Although some of these questions, and some future questions deal with how we can alter the yield strength, and if we increase it we increase the region where a material can deform elastically.

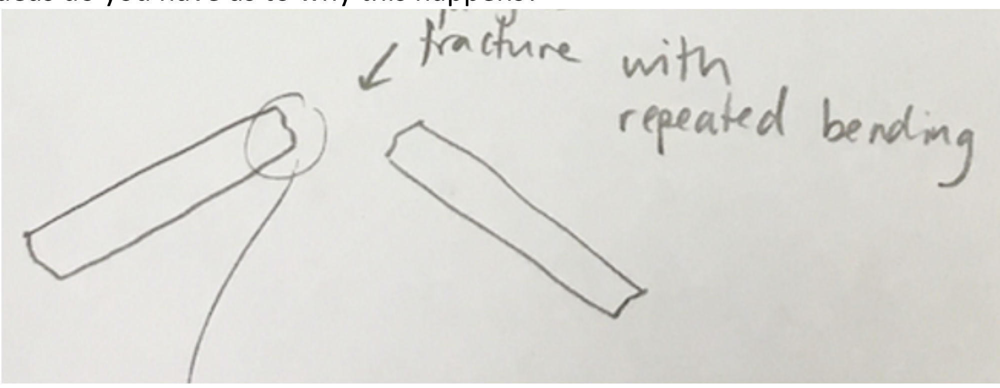


(b) Bend it back. What happens?



and it takes more force to bend it back than it took to bend it the first time

(c) Bend it repeatedly. What happens? We have not covered this in the course yet, but what ideas do you have as to why this happens?



You may also notice just before it breaks it get easier to bend/it feels weaker

The repeated bending is a fatigue process – we cover this later in the course.
It is important because components that are subject to repeated loading can break even though the load is less than the strength of the component. So, a component may have been designed to be strong enough for the maximum load but because of the repeated loading conditions it fails – disasters have occurred because engineers have not considered this.

(d) Why are these behaviours important in engineering?
Because mechanical properties are important in many engineering situations. This is relevant for <u>any</u> [metallic] component that has stresses, or cyclic stresses, applied to it.

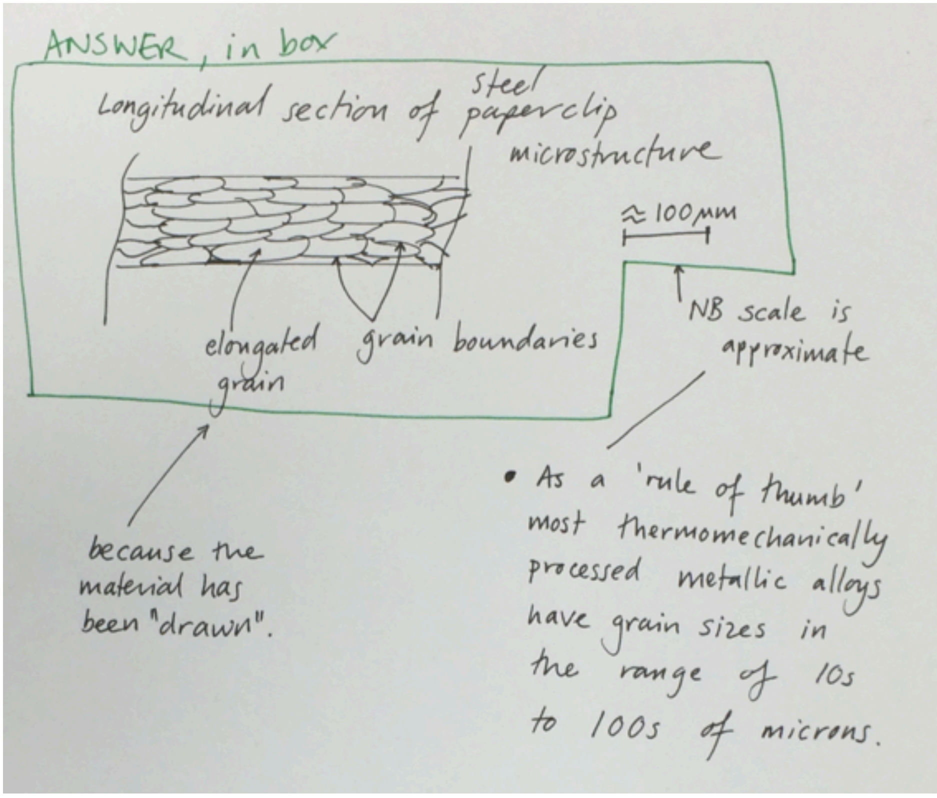
Further comments

These simple experiments allow you to see and kinaesthetically sense (feel) the behaviour (which corresponds to mechanical properties) of a metal when mechanical forces are applied to it.

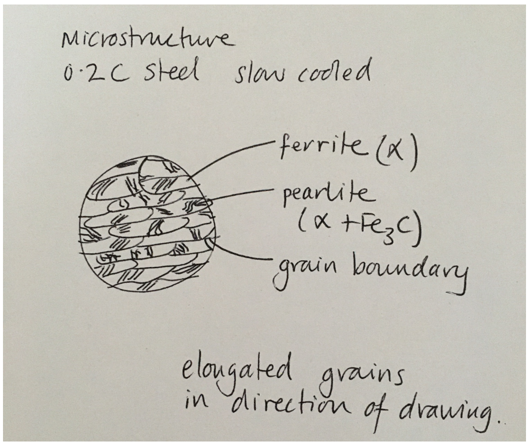
We asked Q1 before Q2 so that you observe the behaviour – learning by awareness – in Q1. In Q2 we go into **understanding why** this occurs by considering processes on small scales (microstructure).

2. Consider a steel paperclip:
(a) Sketch and label the microstructure, add a scale bar to you sketch. We have not covered this explicitly in the videos, however we have covered this subject sufficiently for to do make a simple sketch.

Simple sketch **in box** and further information



Below is a second more sophisticated sketch.

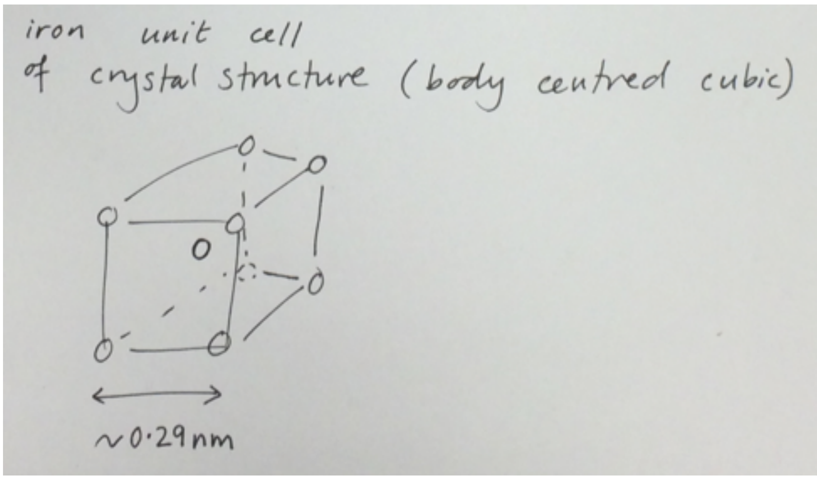


To make the sketch several assumptions have been made:
Assumptions:

- The steel has been **manufactured** by drawing (drawing is pulling the metal into a wire), a plastic deformation process, which leads to elongated grains in the microstructure.
- We assume the steel has been **slow cooled** not rapidly cooled. (Slowing cooling means we can use phase diagrams to predict the microstructure).
- **Composition**: we assume the **steel contains 0.2 % carbon**, and it has been slow cooled.

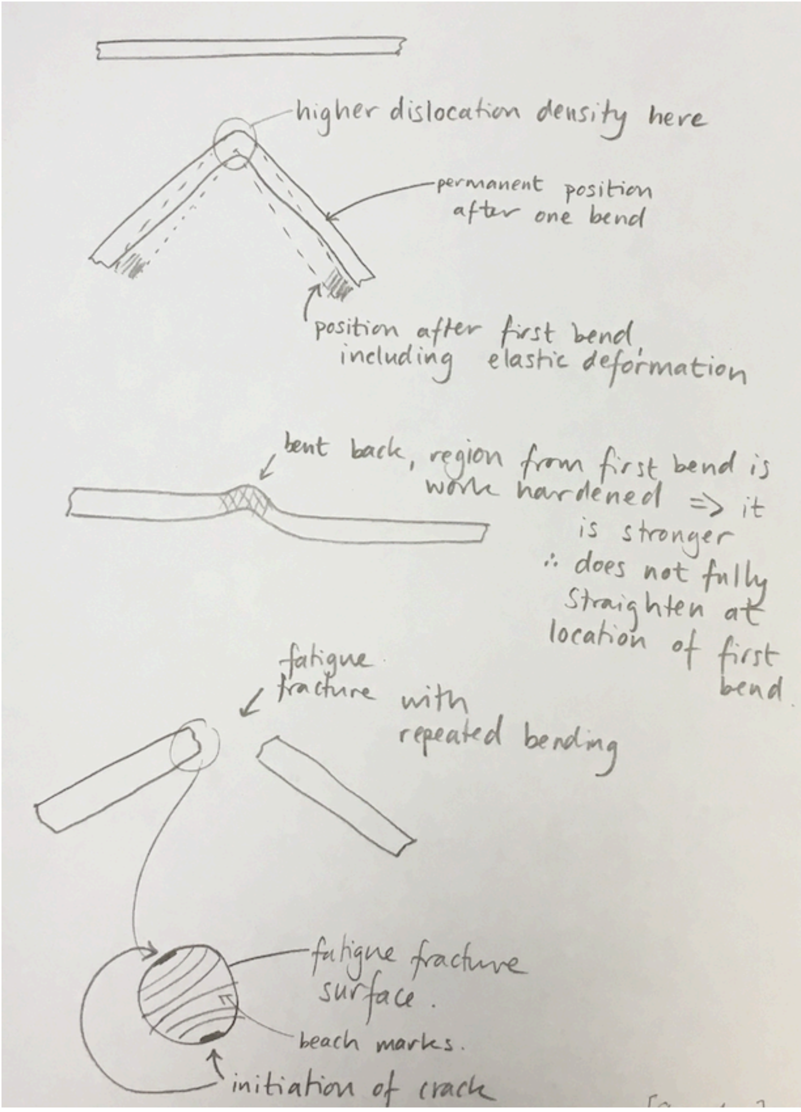
From using phase diagrams we can understand more about the microstructure. It exhibits equilibrium phases in specific proportions: ferrite and some pearlite (where, pearlite = ferrite + Fe_3C)

(b) Sketch and label the unit cell of the crystal structure, add approximate dimensions to your sketch.



(c) Explain the behaviour you observed in Q1 by considering the processes that occur at on small (microstructural) scales. Use annotated sketches to describe your answer.

This question integrates aspects from several weeks of the course, to understand the answers and comments that follows you will probably find it useful to go back to the course videos, or perhaps use other resources mentioned.

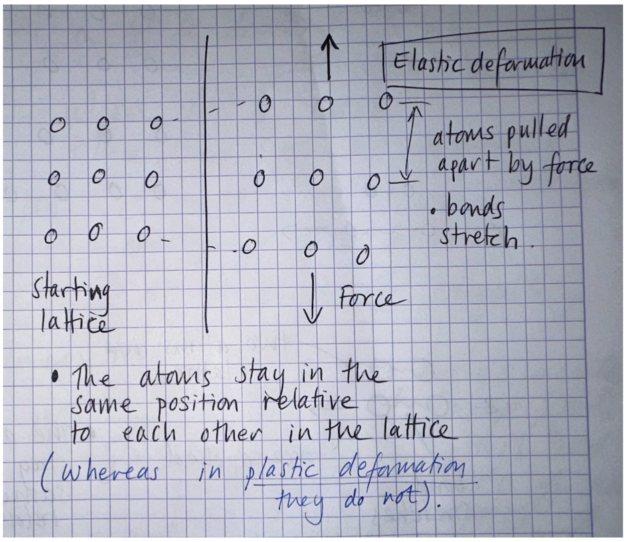


Concepts involved:

- elastic deformation
- plastic deformation
- dislocations
- strengthening mechanisms in alloys
- movement of dislocations
- work hardening
- fatigue (later in course)

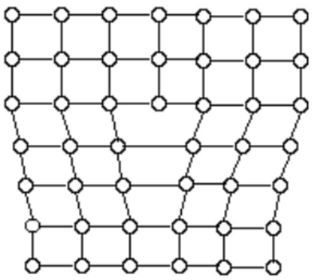
These are covered in the section on properties (including discussion of stress strain behaviour). The sections on small scale structure cover the underlying mechanisms and processes for the behaviour, or properties, of alloys.

Sketch of elastic deformation at level of atoms:

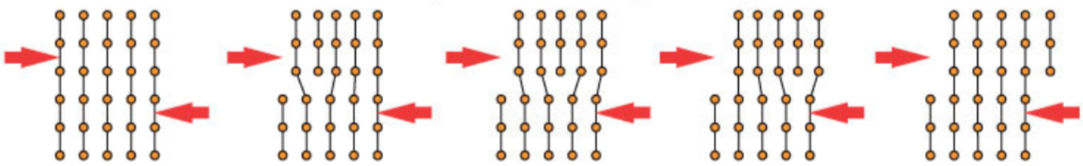


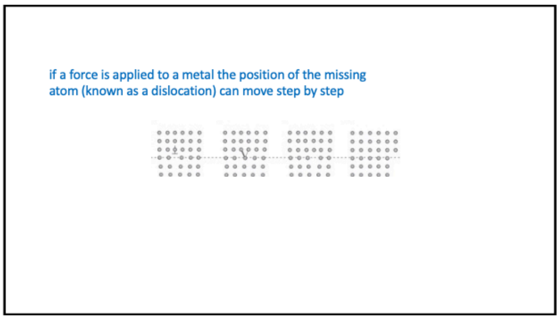
In Part 1 of the videos about small scale structure (Mat2 - small scale structure-V1-slides) slides 45, 46, 50-54 give you an introduction to dislocations. Note that the designation is all three of: core, core+ and extra. In Materials 2 we want you to know and understand the basics of these concepts, but there is a vast body of knowledge on these topics (many academics and industrial researchers have spent whole careers working this area, and there is still more to learn).

A simple sketch of a dislocation:



The image below shows what happens in plastic deformation at a small scale – how dislocations move through the material when a shear stress is applied (cf. fig 9.4 in Engineering Materials 1). Although the deformation of the paperclip will be more complex than simple shear, the principles of the behaviour are capture well by the image; and similarly in slides 52 & 53 in Small scale structure part 1 video (shown under the first image).





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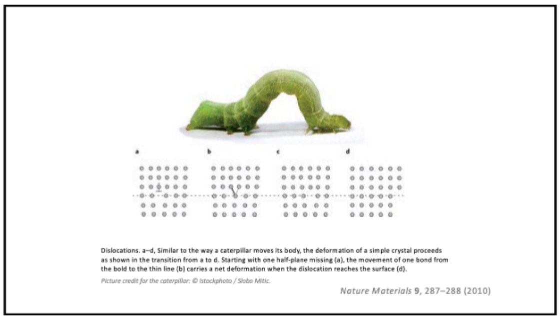

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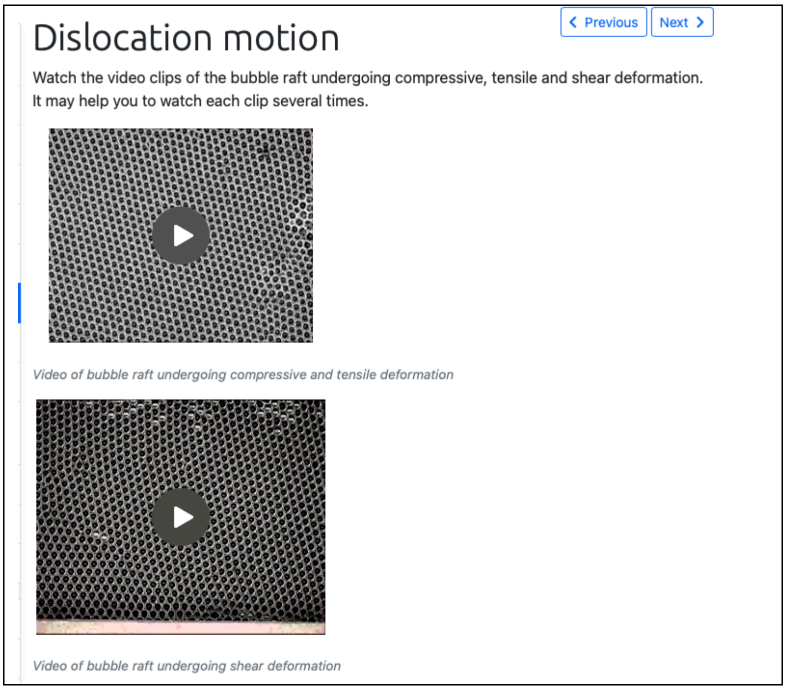
In Part 2 of the videos about small scale structure, slides 42-53 deal with dislocations some more (Note: slide 45 is similar to slide 52 from Part 1 above); slides 55, 56, 57 relate to linking properties and microstructure in metals; slide 57 has few words but it covers key concepts about elastic and plastic deformation - take time to understand this; slides 59-68 are about strengthening mechanisms in metallic alloys, as it says in the video what we're aiming to do is impede the movement of dislocations.

There are some links on the Doitpoms website that we find helpful in understanding and visualising dislocations:
https://www.doitpoms.ac.uk/tlplib/dislocations/dislocation_motion.php



And this link to a simulation of dislocations.
https://www.doitpoms.ac.uk/ldplib/work-hardening-polycrystals/video.php

For Materials 2 – the video itself is helpful in giving you an idea of the motion and build of dislocations in a block of material as it work hardens. But the terminology** used, especially at c. 160 seconds will likely be incomprehensible, and you do not need to understand it for Materials 2.

extra, a comment on use of language: such use of terminology** between people with expertise in dislocations is useful, as a few words can be used to describe something in a precise way, but for people outside the discipline it is jargon and is incomprehensible without further explanation.

Earlier in the video there is a nice practical example of work hardening copper (analogous to our paper clip experiment, although on a different scale and with a different material).

The movement of dislocations in real crystalline materials (metallic alloys, and also ice) is a huge topic, in Materials 2 we cover the basics (core and core+) these are captured in the videos. If you want to go deeper in the subject (core+ and extra), or read about the topic from an alternative source and different perspective, any materials science and engineering text book will have further information. The web (Google, chatGPT etc.) will have more information too – but be careful about which **Resources** you take your information from (JB note, this is a complex area and there are some resources that are poor quality / confusing / and sometimes just wrong). Note: the course texts are reliable Resources for further information, as it the Doitpoms website.

3. What are the attributes (properties, design and manufacturing criteria) for a paper clip? Discuss whether they are essential or desirable.

essential (+) or desirable (-).
+ low **cost**
+ possible to **manufacture**, **high volume** (mass) **production**

+ Appropriate **mechanical properties**:
elastic enough

So the clip can be opened elastically (low enough), and is stiff enough to clamp paper together (high enough)

strong enough

So it can be opened (low enough); so it doesn't deform plastically or break with the forces involved – the yield strength should not be reached under normal conditions of use (high enough).

Reasonable **fatigue strength** (note: we cover fatigue later in the course)

So the paper clip can be flexed multiple times without fracture
The fatigue strength does not have to be excellent as this is not a critical application – if a paper clip breaks the consequences are tiny, whereas if an aircraft component fails because of fatigue the consequences can be extremely high.

High enough **toughness** (e.g. characterised by fracture toughness. Note: we cover fracture toughness later in the course)

So the paper clip does not fracture too easily in normal use.

- ends radiused (smooth) enough so it doesn't rip paper
- corrosion resistance: so it doesn't degrade under normal conditions of use
- (recyclable – but this is not of primary importance, and paperclips can be used for years)

What are suitable materials for paper clips?
Metals – e.g. steel, brass, and polymers thermoplastics e.g. polyethylene.

Not ceramics – primarily because they have low fracture toughness.

Further comments about Trade-offs

Important: we want a **trade-off** (or **compromise**) values for these mechanical properties. While a paper clip is a simple, even trivial, example – the concept of trade-offs is important to consider in materials selection, design and use in engineering.

4. Get a strip of polyethylene (PE) (cut from a PE bag).
(a) Pull it in tension. What happens?
Explain why by considering the processes that occur at on small (microstructural) scales.

The polyethylene deforms irreversibly, or plastically. Note: irreversible deformation and plastic deformation are the same phenomenon. It extends and eventually fractures.
We can explain this by considering the small scale structure of the polymer, as intertwined polymer chains, when the bulk material is pulled in tension the chains are pulled relative to each, they slide over each other and align in the direction of the force.

In processing polymers by drawing, the same mechanism of plastic deformation is used, see Engineering Materials 2 p432 online.

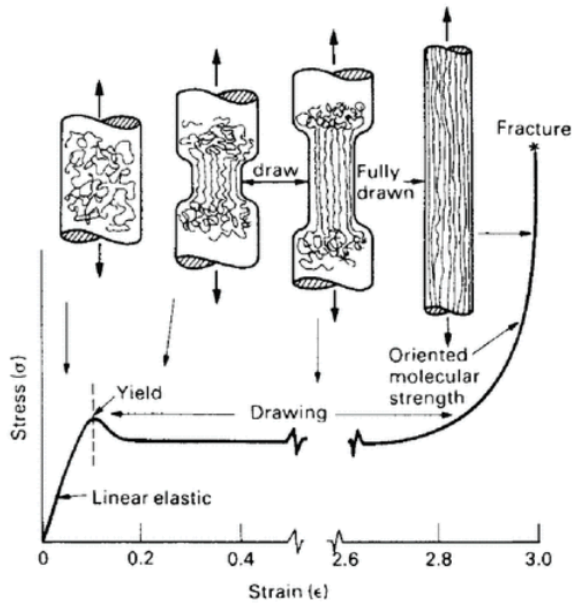


FIGURE 25.10

Cold drawing of a linear polymer: the molecules are drawn out and aligned giving, after a draw ratio of about 4, a material which is much stronger in the draw direction than it was before.

Engineering Materials 2 p432

(b) If you repeat the experiment, do you get the same results?
yes / no / maybe / it depends

How can you explain the behaviour?
Yes – because you are doing the tests in the same conditions and with the same specimens. Or, they may be slight variations, but your test methods are not subtle enough to detect them. The samples will vary – *because they are different samples* – but the material has the same properties that can be measured reproducibly and reliably with the technique(s) being used.

No / maybe / it depends
Because one, or a combination, of the following:
- you are doing the tests in the different conditions, e.g. do the test faster [i.e. increase **strain rate**] – it is likely the PE does not elongate as far as if you do the test more slowly.

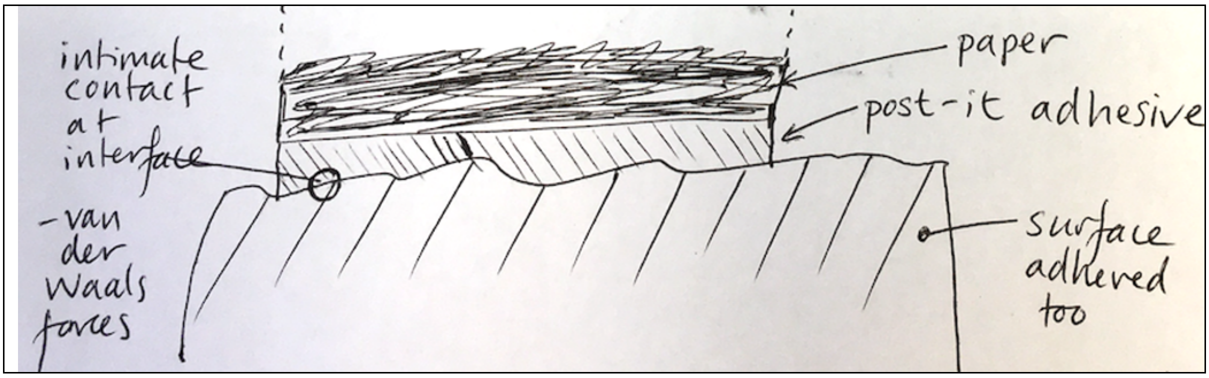
The results will depend on **how you grip the specimen**. How the specimen interacts with the grips/test machine is an important consideration when testing materials in practice.

The result will vary with **temperature** (we will cover this later on the course).

- the specimens are different – different enough that they give a different result e.g. there may be a **defect in the material** itself, the samples may be cut differently / have notches/cracks in it – **damage (defects, cracks) created by the sample manufacturing process** itself

The experiment can be expanded to investigate whether there is a difference depending on which direction you cut the sample from the bag (horizontally, vertically or at another angle). The short answer to this is that the behaviour does depend on direction, but the detail of this behaviour is complicated.

5. Post-it notes adhere well to many surfaces. Explain why this happens using annotated sketches.



What reduces, or prevents, them adhering?

This part of the question is open ended. **Dust** or **debris** that sticks to the adhesive which means that the adhesive on the post-it ceases to adhere to other surfaces, **degradation with age**, **moisture**, very uneven surfaces, very low temperature – this is unlikely to be an issue in conditions of normal use, but the compliance of the adhesive layer will decrease as temperature decreases.

Further comments

Adhesion, and lack of, is important in engineering – the concepts that are covered in this question can be applied to other – perhaps more sophisticated – applications in engineering.

To generalise further: a key learning concept to take from the questions in this set is how *understanding* behaviour of simple everyday materials/objects can be *transferred* to applications in engineering.